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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Technical Report 32-1550

Volume III

Mariner Mars 1971 Project Final Report

*Mission Operations System Implementation and
Standard Mission Flight Operations*

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**JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY
PASADENA, CALIFORNIA**

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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.

This five-volume document constitutes the Mariner Mars 1971 Project Final Report. Volume I consists of Project development through launch and trajectory correction maneuver. Volume II presents the preliminary science results derived from data evaluation to December 14, 1971. (The information contained in Volume II has appeared in *Science*, Vol. 175, January 1972.) Volume III describes the Mission Operations System and covers flight operations after trajectory correction maneuver through the standard orbital mission up to the onset of solar occultations in April 1972. Volume IV consists of the science results derived from the standard orbital mission and preliminary experimenters' interpretations of the data obtained from the extended mission. Volume V is an evaluation of mission success based upon comparison of science results to the stated science experiment objectives.

Detailed information on Project organization, Project policies and requirements, subsystem development, and other technical subjects has been excluded from the Project Final Report volumes. Where appropriate, reference is made to the JPL informal documentation containing this information. The development of most Mariner Mars 1971 subsystems is documented in JPL Technical Memorandums.

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Abstract

The Mariner Mars 1971 mission was another step in the continuing program of planetary exploration in search of evidence of exobiological activity, information on the origin and evolution of the solar system, and basic science data related to the study of planetary physics, geology, planetology, and cosmology. The mission plan was designed for two spacecraft, each performing a separate but complementary mission. However, a single mission plan was actually used for Mariner 9 because of failure of the launch vehicle for the first spacecraft.

This report, Volume III of the Mariner Mars 1971 Project Final Report, describes the implementation of the Mission Operations System, including organization, training, and data processing development and operations, and discusses Mariner 9 spacecraft cruise and orbital operations through completion of the standard mission from launch to solar occultation in April 1972.

Mariner Mars 1971 Project Final Report

Mission Operations System Implementation and Standard Mission Flight Operations

I. Introduction

Five days after launch of the Mariner 9 spacecraft, a trajectory correction maneuver was performed to precisely adjust the flight path so that the spacecraft would arrive at Mars five months later. This volume sequentially follows the account in Volume I and, like Volume I, deals with the engineering (i.e., nonscientific) aspects with emphasis on those areas that were new or unique to the Mariner Mars 1971 Project. Because of the orbital nature of the mission, with its long period of intensive operations and data acquisition, the mission operations organization and development are dealt with in some detail. The Mission Operations System (MOS) implementation, including the computer software development testing, was initiated well before launch, and in part could have been included in Volume I. However, to provide a comprehensive, unified picture of the MOS, the entire discussion was reserved for this volume.

Volume III covers cruise, orbital operations through completion of the standard mission objectives, and activities concluded at the onset of solar occultations on April 2, 1972. While this volume is not an exhaustive discussion of the flight operations, it adequately provides the necessary background for the science reports, Volumes II, IV and V.

Significant milestones and their completion dates are listed in the Appendix. A brief account of the extended mission flight operations will appear as an appendix to Volume IV, *Project Science Results, Twelve Month Report*.

Prior to the Mariner Mars 1971 Project, the United States of America had sent three spacecraft on successful flyby missions to Mars. In 1965, the Mariner 4 spacecraft acquired the first close look at Mars to be followed in 1969 by Mariners 6 and 7 performing more extensive and detailed planetary examinations. Flight operations, similar to the coverage in this volume, have been documented for Mariner 4 in Refs. 1 and 2, and for Mariners 6 and 7 in Ref. 3.

II. MOS Implementation

A. Organization and Operations

Conduct of the Mariner Mars 1971 mission was delegated to a mission operations organization consisting of eight teams headed by a Chief of Mission Operations (CMO) directly responsible to the Project Manager (Fig. 1).

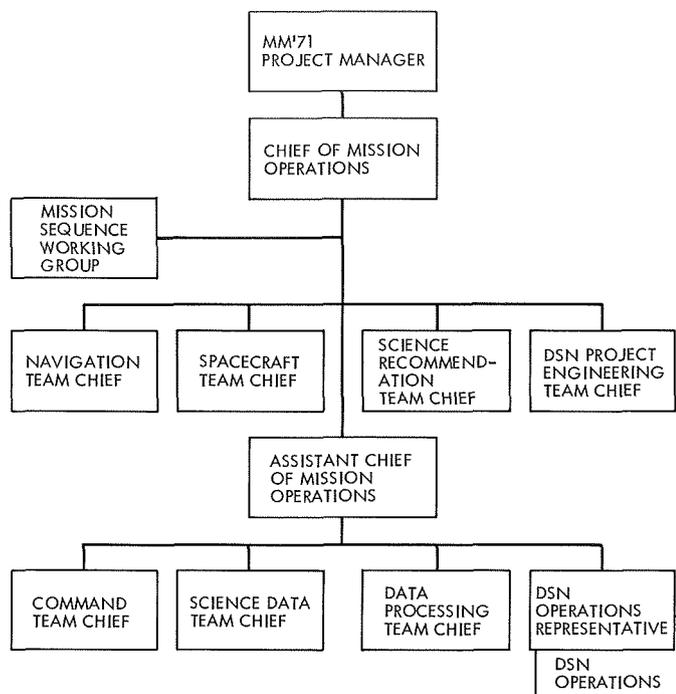


Fig. 1. Mission operations organization

The primary responsibility of this organization was to plan, coordinate, and execute operations from launch to end of mission, exclusive of preparing, testing, and launching the spacecraft. Specific activities to be performed included simulation tests for training purposes, countdown procedures to verify launch readiness, day-to-day commanding and monitoring of the spacecraft through cruise, maneuver, and orbital phases, and the recording and playback of science data from Mars and interplanetary space.

To accomplish the mission, a two-tier organization was developed, composed of specialists grouped into either planning and analysis teams or real-time operations teams. Coordination of activities among teams was the responsibility of the CMO and the five Assistant Chiefs of Mission Operations (ACMOs). Planning and analysis teams were responsible for science recommendations, navigation, spacecraft status, and the Deep Space Network (DSN) project engineering. Performance of their duties was satisfied by scheduled daily participation throughout the mission. Real-time operations teams consisted of personnel to handle commanding, Deep Space Network (DSN) operations, data processing, and science data logging. Staffing for such real-time operations was continuous.

The Mission Manager was responsible to the Project Manager for interpreting Project policy as related to mission operations. He was specifically responsible for mission planning decisions involving mission redirection and risk assessment, excepting those delegated to the CMO. In addition, he was the formal interface between the Project organization and the mission operations organization. The Mission Manager position was filled by the Project Manager or one of six appointed alternates on a rotating schedule.

1. Chief of Mission Operations. The CMO was responsible to the Project Manager and the Mission Operations System (MOS) Manager for conducting mission operations in accordance with mission plans, guidelines, and constraints as specified by the Project Manager; for coordinating and directing analysis and planning activities of the mission operations organization; and for specifying mission operations plans, policies, and instructions to the ACMOs for execution.

2. Assistant Chief of Mission Operations. The on-duty ACMO was responsible for executing mission operations in accordance with plans, policies, and instructions received from the CMO. He coordinated and directed the activities of mission operations, including the authorization to transmit commands to the spacecraft, maintained necessary interfaces with other agencies to assure proper implementation plans, directed the Mission Sequence Group in the preparation of a sequence of events, and provided a single point of contact for problem solving and conflict resolution.

3. Mission Sequence Working Group. The Mission Sequence Working Group was formed to develop detailed flight sequences for all the science phases, and to plan these sequences within operational system capabilities. This Group served as a centralized coordinating body for overseeing and controlling the entire process of sequence design and development. This complex process began with the interpretation of the mission plan and concluded with the specification of the detailed sequences, reflecting any adaptive sequence changes that might have occurred. One or more representatives from the four major planning and analysis teams provided the technical expertise for designing all facets of the mission. The Mission Sequence Working Group was a staff function of the CMO.

4. Planning and analysis. The four teams responsible for planning and analyzing various aspects of the mission were grouped into the Science Recommendation Team,

Navigation Team, Spacecraft Team, and DSN Project Engineering Team.

a. Science Recommendation Team. The purpose of the Science Recommendation Team was to determine science goals in cooperation with the various experimenters, select targets for data taking, recommend scientific preferences and priorities, and to analyze and report upon the received data. Four different science gathering experiments comprised the spacecraft payload. It was the goal of the team to optimize usage and performance of this payload. Experiments within the payload included two TV cameras (wide angle and telephoto), an ultraviolet spectrometer (UVS), an infrared interferometer spectrometer (IRIS), and an infrared radiometer (IRR). In addition, a celestial mechanics experiment and earth occultation radio frequency measurements were conducted. The Science Recommendation Team's responsibilities were to coordinate and support the activities of the science teams, and to integrate these activities with the other elements of the mission operations organization. Each science group was headed by a team leader (for TV and celestial mechanics experiments) or principal investigator (for IRIS, IRR, UVS, and earth occultation experiments) who organized his respective experiment team.

b. Navigation Team. The Navigation Team was responsible for all functions related to the spacecraft flight path including maneuver design, trajectory analysis, orbit determination, design and analysis of instrument scan sequences, and production of computer-generated documents needed to support the requirements of the Mission Sequence Working Group and other teams. The Navigation Team was functionally organized into three groups: Trajectory, Orbit Determination, and Maneuver Analysis.

During launch phase, the Trajectory Group generated nominal injection conditions and monitored mark events to assess the normality of the launch. During preinsertion and orbital phases of the mission, the Group designed the science instrument scan sequences in accordance with inputs from the Spacecraft Team, experiment representatives, and the Science Recommendation Team. They also generated best estimates of the coverage obtained based on data acquired from telemetry by the Spacecraft Team.

The Orbit Determination Group was responsible for estimating the spacecraft orbit using tracking data from the deep space stations (DSSs). Provided with each estimate were estimates of the uncertainties in the calculated parameters, such as spacecraft nongravitational forces and Mars gravitational harmonics. The Group also recom-

mended changes in the tracking pattern of the DSSs as required by real-time circumstances.

The Maneuver Analysis Group was responsible for computation of maneuver parameters necessary to achieve a proper spacecraft trajectory change. These data were supplied to the CMO for approval and to the Command Team for command generation.

A tracking data coordinator was assigned to assist the Navigation Team Chief in tracking data analysis. The Team Chief provided liaison between the DSN Mission Operations Team and the Navigation Team.

c. Spacecraft Team. Analysis of spacecraft performance, prediction of spacecraft performance characteristics, and formulation of spacecraft sequence options to best utilize spacecraft capabilities were the responsibilities of the Spacecraft Team. Comprising the largest group of analysts in the mission operations organization, this team was the principal source of knowledge of spacecraft design, test history, and status of all subsystem components throughout the mission.

The Spacecraft Team Chief and his assistants directed the efforts of the engineering and science subsystem analysts in the Space Flight Operations Facility (SFOF).

Specific duties of the Spacecraft Team Chief included overall coordination and direction of spacecraft-related planning, analysis of spacecraft emergencies, nonreal-time analysis of engineering telemetry and science house-keeping data, and coordination of team interfaces with other planning and analysis teams of the mission operations organization.

The Chief of the Spacecraft Team approved Spacecraft Team timelines detailing spacecraft command and response functions, sequence generation (the basic document of the team), and technical reports forwarded to the CMO.

The alternate team leaders coordinated and directed the subsystem analysts in the development of a daily schedule and the nonreal-time analysis of data from the spacecraft. The analysts provided spacecraft status, performance characteristics, and operational constraint information to the Spacecraft Team Chief on a periodic basis. The analysts assisted in evaluating the level of risk associated with proposed modes of spacecraft operation and reviewed all design operating tolerances and alarm limits. By collecting information from the engineering and science subsystem analysts, the alternate team leaders were

able to produce in minute detail the latest spacecraft status to aid the Spacecraft Team Chief in supervising overall activities.

Monitoring of the spacecraft subsystems by the engineering and science subsystem analysts was subdivided into groups: IRIS, UVS, and IRR instruments; TV cameras; radio frequency and flight command subsystems and S-band antenna; attitude control, scan platform, and power subsystems; structures subsystem, moving and fixed mechanical devices, and temperature transducers; central computer and sequencer, data automation, flight telemetry, and data storage subsystems; and pyrotechnic and propulsion subsystems.

Analysts also were responsible for software programs to create command files (COMGEN) and to monitor telecommunications performance, celestial references, scan calibration, power margins, and propulsion subsystem operations and performance.

d. DSN Project Engineering Team. The DSN Project Engineering Team was headed by the DSN Project Engineer and was supported by facility project engineers and assistants in charge of DSS operations engineering, DSS operations planning, DSS system data analysis, the Ground Communications Facility (GCF) operations, the SFOF data system, SFOF data processing, and SFOF support.

5. Real-time operations. Real-time operations were managed and directed by the ACMO. The operations were complex and continuous as evidenced by the average number of commands per day transmitted to the spacecraft (Table 1) and the total bits of data received from the spacecraft (Table 2).

The four teams responsible for continuous, real-time activities were the Command Team, DSN Mission Operations Team, Data Processing Team, and Science Data Team.

a. Command Team. The Command Team conducted real-time analysis of the spacecraft and monitored its performance via digital TV displays and printers located in the mission support area of the SFOF. The Team operated the Command Data System to command the spacecraft under the direction of the ACMO and to confirm proper system responses. Commands were either individual segments of daily operations sequences or were blocked in large updates loaded into the spacecraft. Commands for unscheduled spacecraft events, such as the fre-

Table 1. Spacecraft command history

Phase	Duration, days	Commands/day (average)
Launch	4	8
Cruise	147	12
Preorbit	17	96
Standard mission	140	247

Table 2. Bits acquired (launch to end of standard mission)

Source	Launch to start science	POS-1 through Apr. 1, 1972 ^a	Total
IRR	8.13×10^6	8.53×10^7	9.34×10^7
UVS	8.36×10^7	5.33×10^9	5.41×10^9
IRIS	6.64×10^7	4.09×10^9	4.16×10^9
TV	8.5×10^8	3.92×10^{10}	4.00×10^{10}
Science total	10.1×10^8	4.87×10^{10}	4.97×10^{10}
Engineering	4.0×10^8	2.23×10^8	6.23×10^8
Project total	14.1×10^8	4.89×10^{10}	5.03×10^{10}

^aPOS-1 = first preorbit science sequence.

quent detection of attitude control gas leaks in the roll jet valve, necessitated transmission of single direct commands to correct the problem.

Team members were divided into two categories: members who performed command duties, and analysts who evaluated the spacecraft in real time.

The Command Team Chief directed the Team members in real-time command and spacecraft data analysis operations. The Team Chief was responsible, with approval from the ACMO, for command transmissions; he directed the execution of the approved commands to the spacecraft and coordinated activities with the Spacecraft Team to satisfy the real-time and nonreal-time data analysis requirements. The Team Chief recommended approved contingency operating sequences for spacecraft emergency conditions to the ACMO. Further, he maintained proper spacecraft data tolerances, alarm limits, and calibration information in the real-time data systems based upon information generated by the Spacecraft Team.

The Spacecraft Data Analyst monitored spacecraft performance. His duties included tabulation of critical

spacecraft data from launch through end of mission, maintenance of a shift operations and status log, daily reports of spacecraft status and real-time performance, and coordination with division analysts to discuss real-time data analysis.

The Command Operator operated the command console in the mission operations area to format and initiate approved command sequences to the spacecraft. He verified proper entry of each command into the telemetry and command processor (TCP) at the receiving deep space station (DSS) and subsequently confirmed verbally and in a written record that the station had successfully transmitted each command.

The Division Analyst was the real-time performance analyst for various subsystems as needed. He provided the Command Team with real-time data analysis and performance evaluation of the subsystems and detailed knowledge of the operating modes and current status.

b. DSN Mission Operations Team. The DSN Mission Operations Team supported the Mariner Mars 1971 Project by coordinating the operation of the DSN around the world. This Team was a part of the DSN mission-independent operations organization, which also served other projects such as the Pioneer Project.

The Team's major responsibilities to the Mariner Mars 1971 Project were to provide tracking support of the spacecraft and initialization and monitoring of the Command Data System, and the acquisition of engineering and science data. The tracking requirement, telemetry acquisition, and command activities were met by the DSSs located in Australia, South Africa, Spain, and Goldstone, California.

c. Data Processing Team. The responsibilities of the Data Processing Team were to operate analysis programs in accordance with requests from project analysts, to monitor the operation of real-time programs in the IBM 360/75 and mission and test computer (MTC), and to respond to requests for modifications of real-time processing. The team coordinated the supply of video and spectral data products for the Science Data Team, and provided data product distribution to the Navigation Team, Spacecraft Team, Command Team, and to the Mission Sequence Working Group.

The Data Processing Team Chief was responsible to the ACMO for the execution of all team functions and for all activities in the data processing area. He determined data

processing requirements, ensured proper computer system support, scheduled the running of user programs and resolved any priority conflicts, coordinated Ground Data System configuration changes with the DSN, ensured that identical sets of data parameters were used in all applicable data processing software, coordinated changes in the Ground Data System, and maintained and scheduled an operations staff to meet Project requirements.

The Program Operations Group was responsible for running the navigation and analysis support programs in the IBM 360/75 and UNIVAC 1108 computer systems. Specific functions included collecting user requirements for the operation of computer programs, and assisting the Data Processing Team Chief in scheduling, coordinating, and executing program runs.

The Image Data Coordinator in the film recorder and photo processing area of the Mission and Test Video System (MTVS) served as interface between the Science Data Team and the MTVS. He coordinated availability of computers and film recorders with the Real-Time Data Coordinator. His area was responsible for converting science data into pictures and scan displays.

The Real-Time Data Coordinator controlled the mission-dependent processor functions of the real-time telemetry processors in the IBM 360/75 and MTC. He was responsible for the output format selection for display devices not locally controlled by analysts, and for the backup format selection capability for devices controlled by analysts. He monitored the performance of the real-time computer systems to keep the Project analysts informed of computer outages and changes in configuration.

The Data Distribution Coordinator was responsible for the internal flow of data products among data processing groups, the DSN reproduction facility, and Project users.

d. Science Data Team. The purpose of the Science Data Team was the assembling of a complete library of all science data accumulated during the mission. The team interfaced with the principal experimenters and personnel from the Science Recommendation Team, Data Processing Team, and instrument cognizant engineers from the Spacecraft Team. The Science Data Team provided (1) requirements to the Data Processing Team for real-time and nonreal-time data processing on behalf of the Science Recommendation Team and for instrument cognizant engineers on the Spacecraft Team, such as the Data Automation System (DAS) engineer; (2) acceptance tests for program checkout and validation of science programs; (3) real-time programs for processing science data;

(4) and an interface for nonreal-time data processing between the Data Processing Team and science data users.

The Science Data Team Chief coordinated the activities of four groups: Analysis Support, Library, Real-Time Operations, and Data Record. The Science Data Team functionally reported to the ACMO.

The Analysis Support Group coordinated preparation of card decks for programs to be run by the Data Processing Team. This Group supplied special processing support in the form of mathematics analysis and special-purpose programs and plotting. The Group worked with experiment representatives and provided analysis programs and experiment data records for the experiments.

The Library Group organized, labeled, stored, disseminated, and logged science data contained on magnetic tapes and in printed forms including photographs.

The Real-Time Operations Group served as interface between the Science Data Team and the DSN. The Group maintained various logs on real-time ground system operations to evaluate how such activities would affect incoming science data, and to determine when replays were necessary.

The Data Record Group interfaced with the DSN Master Data Record/Experiment Data Record Production Group, verifying and accepting their products, labeling and assembling data packages, and duplicating tapes and other material that comprised the experimenter data packages. The Group specified and validated a supplementary experiment data record, and defined and generated the master data record.

B. Data Processing System

1. Introduction. The Data Processing System for the Mariner Mars 1971 Project encompassed those facilities that were required to handle all data to and from the spacecraft, to handle the ground tracking data, and to simulate various data for training and testing purposes.

Some facilities operated in real time in conjunction with mission operations, and others performed data analysis functions in nonreal time. Initially, all data must pass through the real-time processors. All these data are then recorded for reference purposes and for nonreal-time processing.

Figure 2 portrays the physical distribution of the various components of the Data Processing System. The GCF

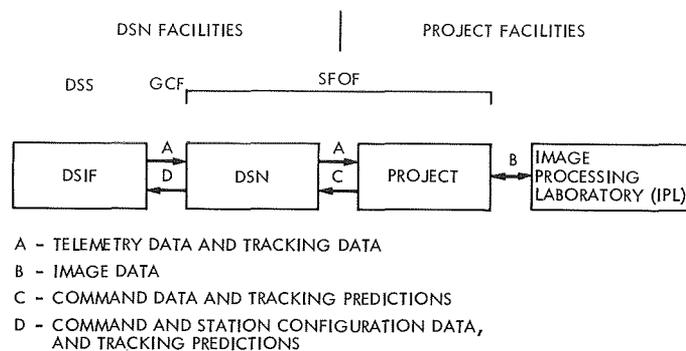


Fig. 2. Mariner Mars 1971 data processing system

is the connecting link of voice, high-speed data, teletype, and wideband lines between the SFOF and the DSN.

The general requirements for the Data Processing System were the processing of spacecraft and tracking data information, and the generation of commands during the conduct of the mission. The mission science data were processed and displayed in time to be useful in the decisions that affected those operations that had to be performed 24 hours after the data were received by the tracking and data acquisition facilities. Spacecraft information, tracking data, and the sending of commands to the spacecraft were processed simultaneously.

The data sampling rates of the tracking observables were:

- (1) Doppler data during all maneuvers: 1 sample/s.
- (2) Doppler data during occultation entry and exit periods: 10 samples/s.
- (3) Tracking data at all other times: 1 sample/min.

The telemetry data rates and modes characteristic of the Mariner Mars 1971 spacecraft are shown in Table 3. The spacecraft received command data at a rate of 1 bit/s.

Table 3. Telemetry characteristics

Mode	Engineering channel, bits/s	Uncoded science channel, bits/s	High-rate coded channel, kbits/s
Engineering	8½, 33½	Off	Off
Low-rate science	8½, 33½	50	Off
High-rate science	8½, 33½	Off	16.2, 8.1
Playback	8½, 33½	Off	16.2, 8.1, 4.05, 2.025, 1.0125

These data rates and modes were basic requirements placed upon the Data Processing System.

2. Data processing configuration

a. Overview. The Mariner Mars 1971 Data Processing System was composed of processing facilities provided by the DSN and by the Mariner Mars 1971 Project.

The DSN processing facilities are shown in Fig. 3. The following Project programs shown in this figure are operated at the SFOF: command generation (COMGEN), sequence events generator (SEG), scan platform operating program (SPOP), adaptive mode planning set (AMPS), and science subsystem events generator (SCISIM). Among the DSSs there are two TCPs, configured identically, so that one can serve as the primary processor and the other as a backup. Similarly, the SFOF contains two IBM 360/75 computers utilized in the same manner. The machines in the SFOF are host to Project nonreal-time operations control software, as well as the DSN real-time software.

The DSN software, described in Subsection II-B-5, provided the nonreal-time processing of tracking, command, and telemetry data as required for the conduct of mission operations.

The Project software, described in Subsection II-B-6, provided the real-time processing of tracking, command, and the science portion of telemetry data in support of mission operations. The Project processing facilities are shown in Fig. 4.

The MTC provided real-time processing and display of both engineering and science telemetry. The high-rate science processing was the primary function of the MTC, and the engineering processing served as a backup to the IBM 360/75 system. The MTVS accepted picture and spectral data from magnetic tape and generated hard copies. The MTVS also provided a real-time video display via scan converters.

The UNIVAC 1108 provided nonreal-time processing for various Project software, the largest category being navigation programs. Science processing and spacecraft subsystem analysis were also supported in the 1108. The IBM 360/75C provided nonreal-time processing for science programs, including the LIBSET function of SCISIM and SPOP. The IBM 360/44 provided special picture enhancement and picture analysis processing for the TV experimenters.

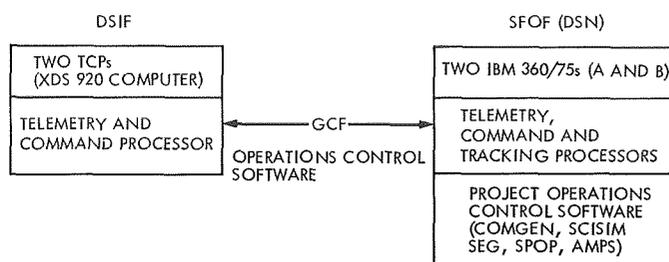


Fig. 3. DSN processing facilities

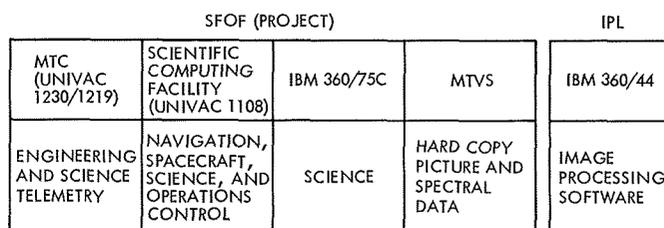


Fig. 4. Project processing facilities

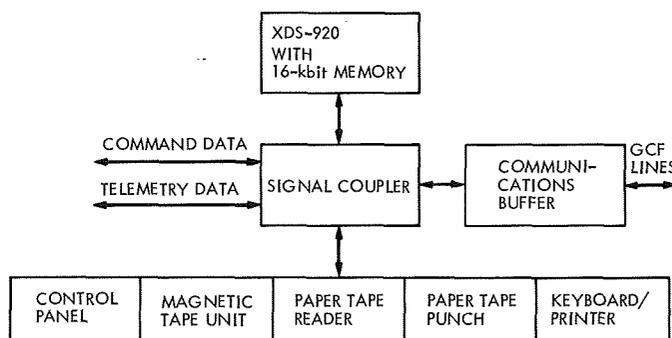


Fig. 5. DSS TCP hardware diagram

b. DSN computer facilities. The DSN provides computer facilities at both the DSSs and the SFOF.

DSSs. Figure 5 shows the hardware configuration of a TCP at the DSSs. The communications buffer is shared with two TCPs. Principal TCP hardware characteristics are:

- (1) 16-kword core memory.
- (2) 24-bit word.
- (3) 8- μ s memory cycle.
- (4) 16-channel external interrupt system.
- (5) 7-level paper tape photo reader.
- (6) 7-level paper tape punch.

- (7) Input/output typewriter.
- (8) 15-kbit/s magnetic tape drive (2).
- (9) Digital phase shifter/bit timing generator.
- (10) HSD/wide band communications buffer.
 - (a) Transmit and receive registers.
 - (b) Teletype transmit/receive channels (4).

SFOF. Figure 6 shows the hardware configuration of an IBM 360/75 at the SFOF.

The central processing unit (CPU) of the IBM 360/75 provides all functions required for the execution of instructions, including arithmetic, input/output, and executive control. Machine cycle time is 0.195 μ s.

Memory is provided by processor core storage, a large core storage add-on to the core, disk pack, and magnetic tape. The core consists of four processor storage units with four-way interleaving of data and a combined capacity of 1,048 kilobytes. Storage cycle time is 0.75 μ s with an 8-byte access width. Both store and fetch protection is provided.

Two high-speed printers, located in the IBM 360/75 central site input/output (I/O) area, perform with 132 characters/line at a maximum of 1400 lines/min. A card reader/punch, also located in the central site input/output area, reads at a maximum rate of 1000 cards/min and punches cards at a maximum rate of 300 cards/min.

The display station for the IBM 360/75 displays up to 12 lines of 40 characters on a cathode-ray tube. The machine uses a nondestructive cursor, line addressing, and an antireflective display screen. The data entry keyboard contains alphanumerics and control keys required to format and enter data.

The user area card reader has a 600-card/min maximum card-reading rate, a 1200-card hopper, and a 1300-card stacker.

The user area line printer employs a 63-character set and prints 144 characters/line at 200 lines/min.

c. Project Computer Facilities. The Project employs four computer facilities at the SFOF, namely, UNIVAC 1108, IBM 360/75, MTC, and MTSV.

UNIVAC 1108. Figure 7 shows the hardware configuration of the UNIVAC 1108 in the SFOF. A similar sys-

tem is available from the scientific computing facility as a backup. The 1108 consists of a central processing unit, three 65-kword main storage modules, an operator's control console, 16 available input/output channels (not all used), and a communications terminal module controller.

The central processing unit can perform all functions required for the execution of instructions, including arithmetic, input/output, and executive control. The unit has integrated circuit control registers, operating at 125 ns, which provide multiple accumulators, index registers, input/output access control registers, and special use registers. The central processing unit contains hardware storage protection to prevent reference to out-of-range storage addresses.

The three 65,536-word (36 bits/word) storage modules have a total capability of 191,608 words. The main storage read/restore cycle time is 750 ns.

The operator's control console is a free standing input/output device for directing and monitoring the central processing unit operation. The control console includes a keyboard, cathode-ray tube display, UNIVAC page-writer, day clock, and control and display panel.

The 16 input/output channels connect the central processing unit to peripheral subsystems (mass storage drums, flying head drums, tape units, disk pack units), to a high-resolution film recorder (model No. S-C 4020) and to communications terminals.

The communications terminal modular controller (CTMC) links five types of hardware to the UNIVAC 1108 central processing unit:

- (1) IBM 360/75.
- (2) EMR 6050 (simulation).
- (3) UNIVAC 9300, which provides computing and storage, card and keyboard input, and plotter, line printer, and card punch output.
- (4) Tektronix T4002, a remote interactive cathode-ray tube display device with keyboard input.
- (5) Data communications terminal 500, a remote interactive character printer with keyboard input.

IBM 360/75. Figure 8 shows the hardware configuration of the IBM 360/75 in the SFOF. The principal hardware elements of this system have been described in Subsection II-B-2-b.

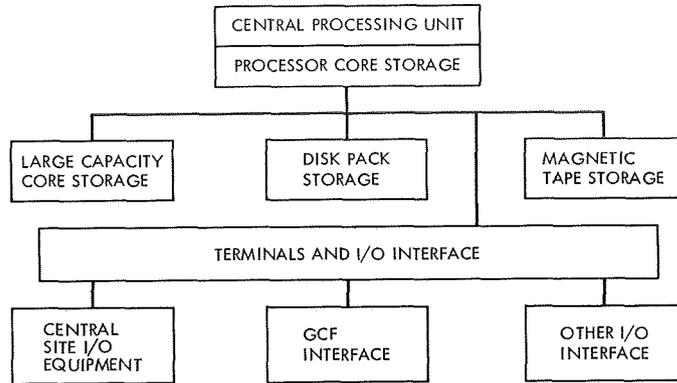


Fig. 6. DSN IBM 360/75 hardware configuration

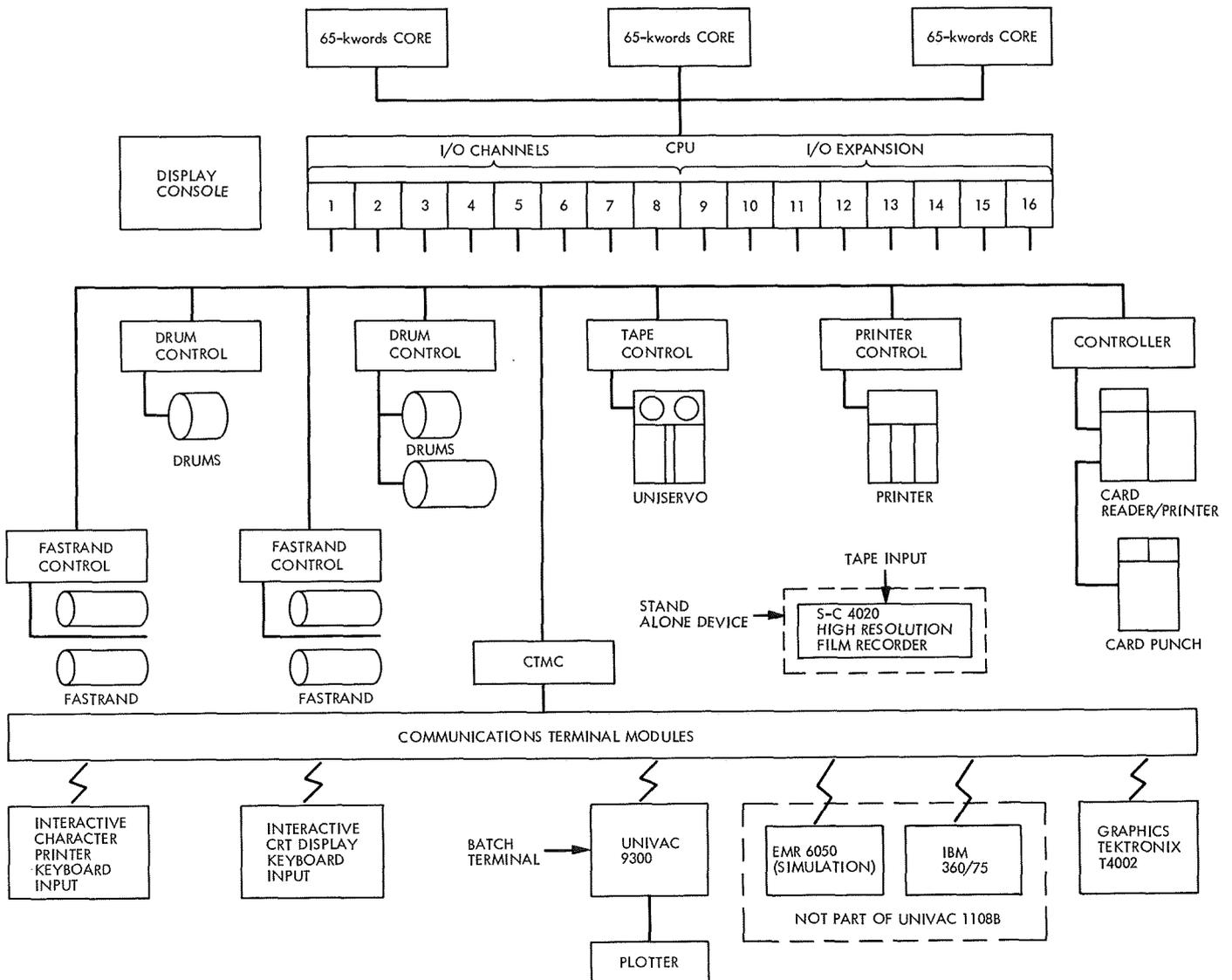


Fig. 7. UNIVAC 1108 hardware configuration

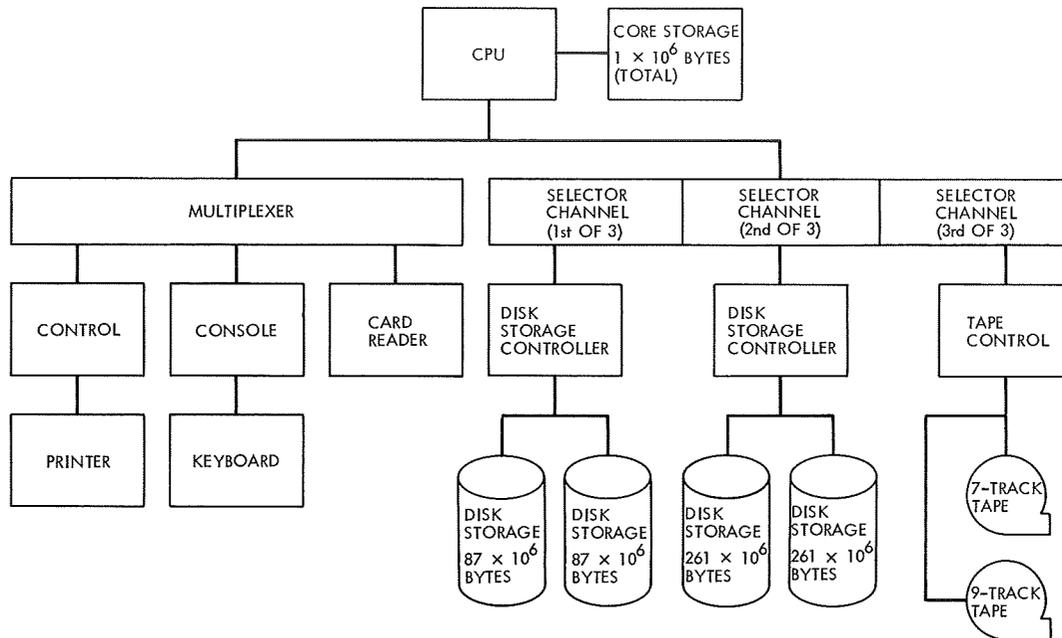


Fig. 8. Project IBM 360/75 hardware configuration

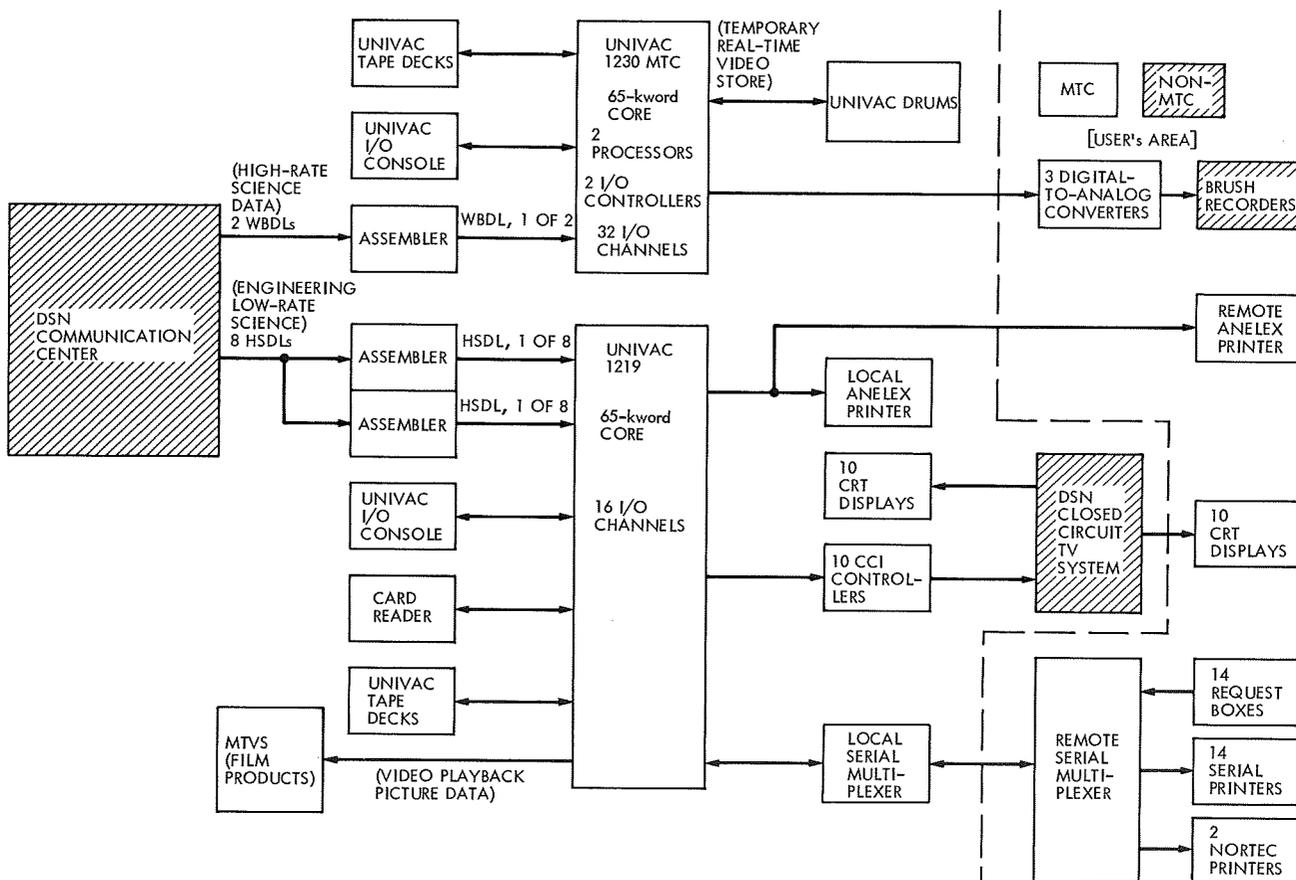


Fig. 9. MTC Goldstone configuration

Table 4. MTC hardware characteristics

Hardware	Characteristic	Hardware	Characteristic
UNIVAC 1230 main memory		Drum	
Capacity	65-kwords	Capacity	2 million words
Cycle time	1.8 μ s	Transfer rate	4 μ s/word
Word length	30 plus 2 parity bits	UNIVAC 1219 control memory	
Interface timing	Asynchronous	Cycle time	500 ns
Function	Program and data storage	Capacity	128 18-bit words
UNIVAC 1230 control memory		Function	Input/output buffer control
Capacity	48 words	UNIVAC 1219 main memory	
Word size	36 bits	Capacity	65-kwords
Function	Input/output buffer control	Cycle time	2 μ s
UNIVAC 1230 input/output Channels	16, each controller; 30-bit parallel	Word length	18 bits
Transfer rate	167,000 words/s/channel (500,000 maximum)	Function	Program and data storage
Input/output console facilities (2)		UNIVAC 1219 input/output Channels	16, 18-bit parallel
Paper tape perforator	110 characters/s	Transfer rate	166,000 word/s/channel (500,000 maximum)
Paper tape reader	300 characters/s	Card reader	500 cards/min
Alphanumeric keyboard	} 5, 6, 7, or 8 level	Analex line printer	600 lines/min
Page printer		Serial multiplexer	
Tape deck (2)		Output capacity	16 character printers and 2 low-speed line printers
Tape channels	7	Input capacity	16 display control boxes
Character rate	96,000/s	Nortec line printer	200 lines/min
		DCT-500 character printer	1560 characters/min

MTC. The configuration of the mission and test computer as it was established for handling both wide-band and high-speed data from the Goldstone tracking station is shown in Fig. 9. This computer system consists of two interactive machines, the UNIVAC 1230 and the UNIVAC 1219. Principal characteristics of the MTC system are given in Table 4.

The UNIVAC 1230 is a dual processor system that has an input/output controller associated with each processor. This system was specifically designed for real-time applications requiring rapid processing of continuous, high-rate data. The core memory is composed of four banks, each of which may be accessed by each processor and by each controller. Concurrent accesses are available to separate memory banks.

Each controller has access to both processors, and the processors have direct access to each other. Communications with associated peripheral equipment are handled by block transfer of data or by real-time events requesting one or more words. Once initiated, neither of these requires further processor attention unless intervention is demanded by some other event.

The UNIVAC 1219 is a single processor machine with 65-kword core memory and 16 input/output channels. The 1219 is designed for real-time applications.

The MTC overseas configuration utilizes a single UNIVAC 1219. This configuration is shown in Fig. 10.

MTVS. The MTVS facility configuration is shown in Fig. 11. The digital data control unit provides data flow control from the selected MTC processor to the desired film recorder. The DDP-24 computer serves as a data source for exercising the system to calibrate and adjust the processing characteristics of the various elements of the system. In operation, the system produces photographic negatives and positive transparency films, opaque positive prints and enlargements, and real-time closed-circuit TV display of standard and high-resolution video data.

3. Ground Data System functional description

a. Real-Time Data System

Tracking Data System. Doppler and range data were the metric data input to the tracking system at the DSS.

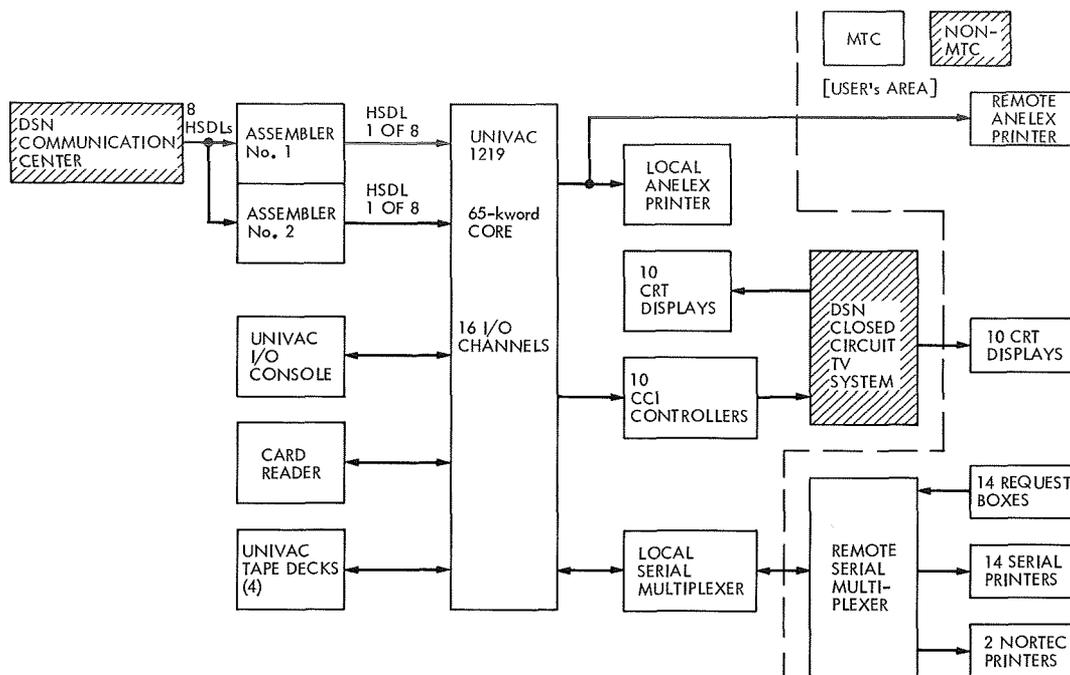


Fig. 10. MTC overseas configuration

Antenna pointing angles were also measured as required. These data (together with time tags, spacecraft identification, data condition codes, and ground transmitter frequency) were formatted, logged, and forwarded via 100-words/min teletype to the SFOF.

At the SFOF, tracking data entered the IBM 360/75 subsystem. These data were temporarily stored on magnetic tape and then input to the tracking data processor program for editing, validation, and storage on disk and on magnetic tape in the tracking data processor master file. This file served as the primary original data record for tracking data and was the interface to the Project-furnished navigation programs. The navigation programs (residing in the UNIVAC 1108 subsystem) accessed the original data record by calling a DSN-supplied 1108 program. The IBM 360/75 subsystem also generated pseudo-residuals for near-real-time evaluation of the tracking data.

From the navigation programs, a spacecraft ephemeris file was formed. A DSN software package manipulated and formatted these data to produce angle, doppler, and ranging predicts. This output was sent via the high-speed data lines (HSDL) or teletype to the DSS. The DSN also provided tracking system status information to the Project.

A program in the IBM 360/75 subsystem used the tracking data predictions to calculate open-loop receiver tuning requirements for each occultation exit occurrence. This information was forwarded to the DSS by HSDL or teletype. The open-loop receiver was tuned to the correct frequency, and data were acquired for each occultation. At DSS-14 (Goldstone, California) these data were digitized and recorded on magnetic tape. At the Woomera, Australia, Deep Space Station (DSS-41) and the Cebreros, Spain, Deep Space Station (DSS-62), the data were recorded in analog form on magnetic tape. The magnetic tapes from all stations were shipped to the SFOF. The analog data from DSS-41 and DSS-62 were digitized by the DSN in the media conversion center located in the SFOF. These data, together with digitized data from DSS-14, were input to the occultation support programs in the Nonreal-Time Data Processing System.

The Tracking Data System also produced correction factors for the tracking data observables to account for the effects of the troposphere, ionosphere, and timing errors. These correction factors were used to help achieve the tracking accuracies shown in the Support Instrumentation Requirements Document (SIRD). Tropospheric effects were modeled mathematically, while ionospheric and charged particle effects were obtained from the comparison of doppler and ranging data (DRVID). Timing

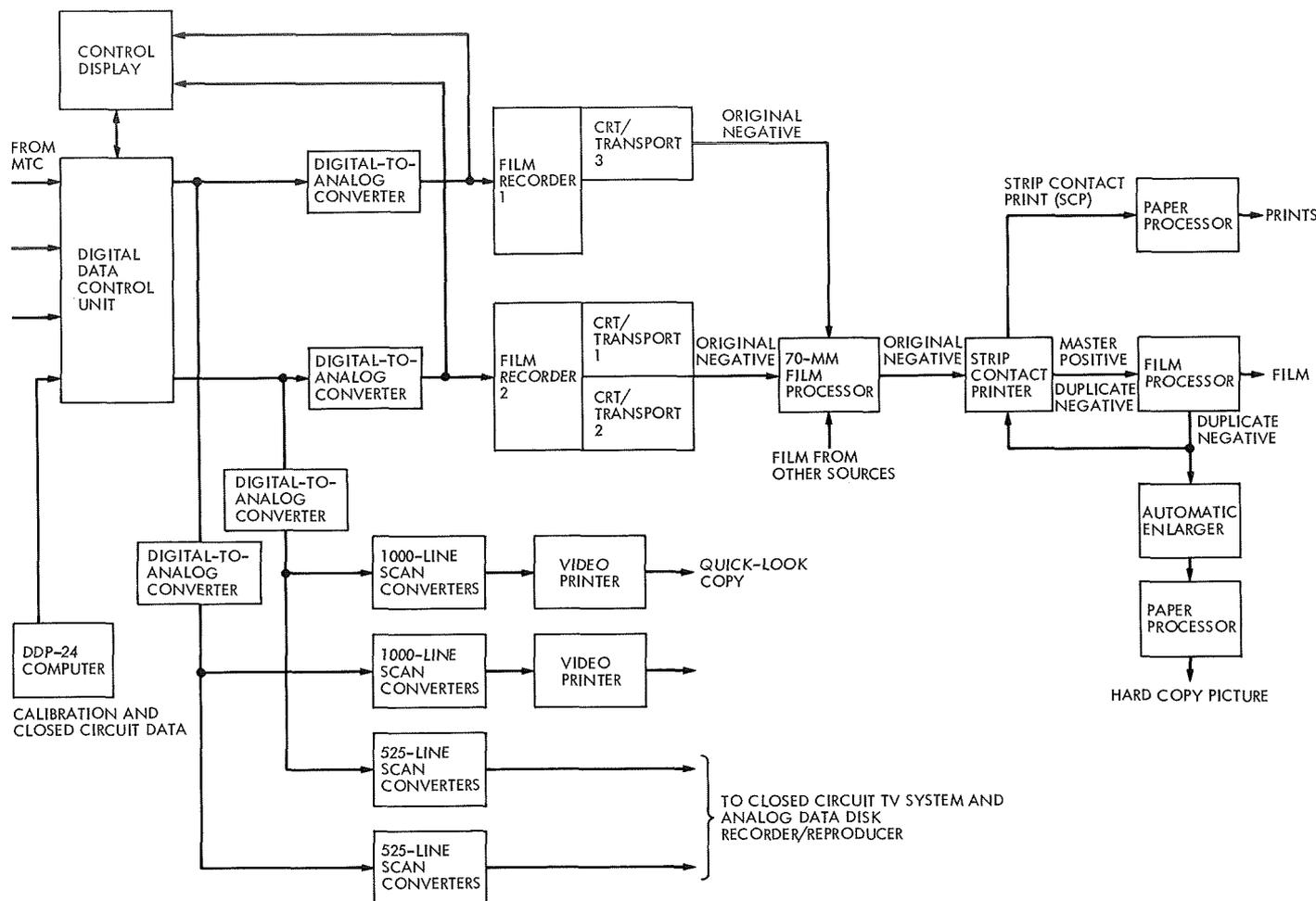


Fig. 11. MTVS film recording, processing, and display system

error correction factors were obtained from a variety of external sources including the U.S. Naval Observatory.

All correction factors were generated and handled by a set of software called the tracking system analytic calibration (TSAC) software assembly (Ref. 4). These programs were used to output data files on disk or magnetic tape for access by the navigation programs.

Command Data System. Command messages handled by the System conformed to the following requirements:

- (1) A command message contained the actual flight command subsystem bit pattern for each command in the message.
- (2) A command message consisted of a single command or a series of commands up to a maximum of 10.

- (3) A command message included a designation of the DSS that was to transmit the commands.
- (4) Provision was made for uniquely identifying each command message by a Project-assigned message number.
- (5) A command message included a Project-assigned priority level.
- (6) Timed command messages included time of initiation of each command.

Entry of command data into the System was made as simple and straightforward as possible. Entry was provided by two design features:

- (1) The man/machine interface for command entry employed state-of-the-art keyboard entry and display devices, consistent with requirements for reliability of operation and compatibility with the computers to be used.

- (2) A minimum number of keyboard operations were used in command entry. As many parameters as possible were predefined or were entered as initialization data.

At the SFOF and at a DSS it was possible to enter any command as a series of octal digits. In addition, at the SFOF the Command Data System generated properly formatted spacecraft commands when given a code indicating the command type and the required input parameters. The system was mechanized so that the CC-1/CC-2* pairs were transmitted together, i.e., a given CC-1/CC-2 pair was not interrupted by a higher priority command unless a DISABLE was sent. Required parity bits were entered by the Command Data System. For command entry at a DSS, this command generation capability was required for direct commands.

The Command Data System assigned a priority level to each command message:

- (1) Priority (P): a priority command message had precedence over all other command messages awaiting transmission from a given DSS. A priority message was transmitted immediately upon receipt of the required ENABLE message. If the contents of another command message were being transmitted to the spacecraft, the priority message was transmitted immediately upon completion of the command in progress.
- (2) Timed (T): A timed command message had the second highest priority. Transmission was initiated at a time specified in the command message. Each command in the message had a transmit time included.

Safeguards were provided against two types of possible command errors: system transmission errors and operator errors.

Commands stored at the DSS were verified prior to transmission to the spacecraft. In addition, the stored commands were compared on a bit-by-bit basis with commands actually transmitted from the station. A bit error indication resulted in the command message being aborted.

At both the SFOF and the DSSs, each command message entered was displayed to the operator prior to processing. When the operator was satisfied that the message was correct, he entered an instruction to process the message.

*CC = coded command.

The Command Data System checked the subaddress of each command entered into the System. If the command was a CC or QC*, it was transmitted. If the command was a DC†, the command address was checked against permissive and restricted lists. If the command was on the permissive list, it was transmitted routinely. If the command was on the restricted list, the System checked to see if it was followed by an interlock. Illegal command indications were returned to the operator and message processing was halted until the error was corrected.

For commands entered at the SFOF, these checks were made in the SFOF computer. For commands entered at a DSS, only the restricted list was checked, but the interlock feature was still required.

Telemetry Data System. The DSN Telemetry Data System, which comprised one element of the Mariner Mars 1971 Telemetry System, provided the following capabilities:

- (1) Decode block-coded data.
- (2) Time-tag and otherwise identify all received data.
- (3) Provide status of the Telemetry Data System.
- (4) Record data in its original form.
- (5) Transmit all detected data to the SFOF.
- (6) Provide an alternate data path for engineering data and low-rate science data as a backup to the HSDL and computers in the SFOF.
- (7) Convert data to engineering units on demand of users.
- (8) Display processed data in the user areas.
- (9) Recall data from the TCP, the IBM 360/75, or the communications processor.

Elements of the Mariner Mars 1971 Telemetry System provided by the project were the MTC and the MTVS.

The MTC had the capability to:

- (1) Receive from the GCF all telemetry data detected by the DSSs.
- (2) Accumulate GCF error statistics for the DSN on science telemetry data received via HSDL and wideband data line (WBDL).

*QC = quantitative command.

†DC = direct command.

- (3) Format television and spectral data for subsequent processing by the MTVS.
- (4) Convert data to engineering units on demand of users.
- (5) Accept TCP recall data.
- (6) Display processed data in the user areas.
- (7) Produce the telemetry master data record.

The MTVS provided the following capabilities:

- (1) Receive data preprocessed by the MTC.
- (2) Convert television and spectral data to an optical image and photo-record that image.
- (3) Produce quick-look prints and archival library negatives and prints of that image.
- (4) Drive the scan converter for real-time display of the image in the user areas by means of the SFOF closed-circuit TV.
- (5) Drive a device in the mission support area for near-real-time hardcopy of TV data images.
- (6) Produce enlargement prints on request.
- (7) Produce microfilm records of pictures produced by MTC and the IPL.

b. Nonreal-Time Data Processing System. Programming systems support for the hardware subsystems included executive systems, capability in several computer languages, mathematical functions, and assorted utility programs. In addition, the Nonreal-Time Data Processing System consisted of those computer programs required for nonreal-time support of mission operations. There were four categories of software:

- (1) Navigation programs.
- (2) Spacecraft programs.
- (3) Science programs.
- (4) Operations control programs.

The navigation programs performed the necessary computations to supply the Navigation Team with orbital and trajectory parameters, flight path change parameters (for maneuvers, orbit insertion, and trims), and scan platform pointing parameters.

The spacecraft programs performed the required computations to supply the Spacecraft Team with information for analysis of spacecraft subsystem performance.

The science programs provided nonreal-time support of science operations during the mission. The science programs supported the science data library, as well as the science experiments themselves.

The operations control programs performed the necessary computations to support mission operations by generating command sequences, simulating science subsystem events, producing a sequence of events, and providing scan platform information.

4. Simulation Data System functional description. To the degree possible, Simulation Data System functions were independent of the Ground Data System. Each data subsystem within the Simulation Data System was capable of independent operation so that training tests, which did not require all data types, could be conducted without scheduling the entire Simulation Data System.

Included in the Simulation Data System were the DSN simulation center and necessary elements of the DSSs. The GCF provided necessary communications capability to support data distribution requirements. The simulation operations organization controlled these facility elements during test support.

Specified data were injected into the Ground Data System either at each participating station or, when stations were not participating, at the SFOF. In the former case, data were injected as close as possible to the antenna; in the latter, the point of injection was located at the GCF/SFOF interface. DSSs, specified Air Force Eastern Test Range (AFETR), and MSFN functions were duplicated as required for the mission, when supporting tests with no station participation. This method was identified as the DSSs simulation mode.

Except for the science data, use of the Simulation Data System eliminated the requirement for pretest data tape preparation. During tests scheduled concurrently with mission operations, all data were identified as simulation data so that it would not be mixed or confused with live mission data.

The Simulation Data System provided realistic stimuli that duplicated an actual mission environment to the maximum degree possible. Dynamic command responsive telemetry data, which reflected accurately the various combinations of DSS support, were simulated during the test program. The following modes of DSS support were used:

- (1) Case 1: DSS-14 support only.

- (2) Case 2: single station support from any of the 26-m network DSSs.
- (3) Case 3: overlap between any two of the 26-m network DSSs.
- (4) Case 4: overlap between DSS-14 and any of the 26-m network DSSs.
- (5) Case 5: overlap between the Echo Deep Space Station, DSS-12, DSS-14, and either DSS-41 or -62.

5. DSN software

a. Introduction. The DSN software provides the processing of tracking, command, and telemetry data for the conduct of mission operations. Science telemetry is passed on to the Project facilities for further processing.

The DSN programs operate in the IBM 360/75 computer at the SFOF and in the XDS-920 computer at the DSSs in a real-time environment. These two computers are coupled by the GCF high-speed and wide-band data lines.

b. Tracking

DSS processing. Tracking data processing at the DSSs consists of forwarding the tracking data observables to the SFOF and of processing the tracking predicts received from the SFOF.

Tracking data observables (doppler, range data, antenna pointing angles, receiver/exciter frequency, and time) are formatted into teletype messages, which are then transmitted to the SFOF at 100 words/min. The formatting and buffering are performed by the tracking data handling subsystem, a hardware facility that processes these data in near-real time.

The DSS receives predicted tracking parameters from the SFOF via the HSDL in advance of the next tracking pass. These messages are processed by the monitor computer in the digital instrumentation subsystem. In this processing, the data are translated from the data link form to that of the computer in the antenna pointing system, and output to that computer.

SFOF processing. Tracking data processing is performed in the IBM 360/75 by three separate programs: tracking data processor, pseudoresiduals, and predicts.

The tracking data processor program receives tracking data, detects and displays outages in the real-time data stream, compiles accountability data by stream and pass

number in real time, stores the data on the tracking system data record in time sequence, processes transmitter and tracking operations group data, provides the capability to write the disk resident system data record onto tape and to restore that tape to disk, displays all data on the tracking system data record, passes data on the system data record to the flight projects via tape, and stores the data on archive tapes.

The pseudoresiduals program operates on all incoming tracking data observables with a maximum of 15 spacecraft/station combinations. A first difference (residual) between observed and predicted data for angles, range, and doppler is calculated and displayed. Also, calculations are performed to determine doppler residual noise, doppler residual sum, doppler residual mean, doppler residual expected noise, doppler blunder points, range residual noise, range residual mean, range blunder points, and angle tolerance. A doppler quality indicator is computed using the doppler residual noise as its primary input.

The raw residuals for all observables are displayable along with doppler residual noise, sum and mean, doppler quality indicator, and range residual noise. Alarms are displayed for blunder points, excessive noise, and for mean values that exceed specified tolerances.

The predicts program consists of five functional areas: computation of frequency independent station observables and view periods, interpolation and output of frequency-dependent station observables, computation of frequencies for tuning the open-loop occultation receivers (SYNLO predicts), the predicts file management, and display of predicts files contents.

c. Command

DSS command processor. The DSS command processor is a part of the TCP program. The basic function of the command processor is inputting command data to and controlling the operation of the command modulator assembly.

(i) Input. The overall control of the command program is possible through the typewriter, paper tape, and HSDL. The paper tape formats are completely identical to the typewriter input messages. The HSDL input consists of 50-word (24 bits each) blocks. The typewriter inputs are designed as a complete backup to the HSDL system. A manual/auto key provides capability to select input from the local typewriter or from the remote input of the HSDL. When the manual/auto key is in the manual mode,

the HSD messages are ignored. When the manual/auto key is in the auto mode, the majority of the typewriter messages are ignored.

It is possible to duplicate all the HSD command input functions by using one (or more) typewriter inputs. Because of the complete similarity between the typewriter and HSD inputs, all identifiable typewriter commands are formatted into HSD blocks whenever appropriate. The HSD blocks directed to the command section by the TCP executive and the blocks constructed as a result of typewriter inputs are checked for the following:

- (1) Error status bits.
- (2) Spacecraft identification.
- (3) Destination code.
- (4) Source code (SFOF).
- (5) Block format code.
- (6) Dependent data type code for one of the following types:
 - (a) Mission configuration table.
 - (b) Standards and limits table.
 - (c) Command.
 - (d) Enable/disable command processor.
 - (e) Recall request processor.

If any of these checks shows an error, (1) the block is retransmitted with an appropriate alarm code indicating the error in the block when the input source is the SFOF, or (2) a typewriter/teletype error message is typed when the input source is the typewriter. If the block is found to be error-free, a verification block is sent to the SFOF indicating acceptance of the block, and processing continues in a manner peculiar to the type of block.

(ii) *Command stack.* The command stack consists of two substacks representing the P and T priority levels. Each T command occupies $3 + \text{number of words/command}$, while each P command occupies $1 + \text{number of words/command}$. Each of the substacks has a priority hierarchy of its own based on relative times of execution (if a T-type command), or relative order of reception at the TCP (if a P-type command). P commands are transmitted on an as-soon-as-possible basis, and take precedence over T commands whenever there is a conflict. To change priorities, a command must first be disabled and then reentered with its new priority. After an abort, the command that failed must possess the capability of being

retransmitted without reentry of the command, which implies that the total command will reside in the command stack for the complete period of transmission. The maximum command that may be transmitted is 6 words in length.

(iii) *Tables.* The mission configuration tape input block is moved from the input area to an area allocated for processing the block. The mission configuration table contains constants used by the command program to configure the command modulator assembly.

Input data is routed to the standards and limits table. This table contains constants used in monitoring the system and associated parameters.

(iv) *Recall request.* The SFOF may recall the contents of the command stack, the mission configuration table, and the standards and limits table. In the case of the latter two requests, one block is sufficient to send the response. In the case of command stack recall, four blocks are used to respond to the recall request. In all cases, the data portion of the blocks is identical to that of the data in the command system. In other words, no reformatting is performed prior to transmission.

(v) *Mode control and command output.* The mode control and command output (MCCO) program controls the complete operation of the command modulation assembly and removes, as available, the top priority command from the command stack, and transfers the command to the register assembly of the command modulation assembly. Between transmission of commands, the MCCO transmits an idle word to the command modulation assembly for transmission to the spacecraft, when appropriate. The MCCO provides the information required by the configuration generator for activating or inhibiting information paths through relay control. At every midbit, the MCCO sends a reset signal to the watchdog circuit in the command modulation assembly. This function furnishes confirmation that the computer is operating and has sufficient time to process the command messages. When required, the MCCO transfers the appropriate control information to the subcarrier frequency generator. The MCCO also transfers the required information to the symbol rate generator for the purpose of external symbol rate and time synchronization control.

(vi) *Enable/disable commands.* The commands referenced in an enable/disable message are enabled or disabled according to the enable/disable code. Reference to the individual command is made by message number and subnumber. If the message subnumber is zero, all

messages with the indicated message number are enabled (disabled). A command is enabled by setting the enable flag, and disabled by removal from stack. If the command is being transmitted at the time it is disabled, the command will be aborted.

(vii) *Alarm/abort monitor.* The command system alarm/abort monitor accepts status messages from various portions of the software and hardware, and generates an appropriate alarm and status message. The command alarm monitor accepts the following inputs:

- (1) Mission configuration and limit alarm.
- (2) Configuration constants from configuration generator.
- (3) Bit-by-bit data comparison generated by comparing the phase-shift-keyed/frequency-shift-keyed (PSK/FSK) data against the command bit stream, and all inputs from the system check.

(viii) *System check.* The symbol and the 1-pulse/s interrupts initiate a series of hardware checks. Using limits contained in the standards and limits table, and information in the mission configuration table, the system check monitors the following:

- (1) Subcarrier frequencies.
- (2) Exciter, transmitter on/off status.
- (3) Exciter frequency.
- (4) Modulation level.
- (5) Data quality.
- (6) Configuration.
- (7) Bit check.

(ix) *Output formatter.* Command output consists of magnetic tape, HSD, teletype, typewriter, and output to the digital instrumentation subsystem. The function of the output formatter consists of manipulating all the outgoing messages into the appropriate formats. The messages include verification (or error messages) caused by inputs, confirmation or abort messages, recall response information, and log tape information. A digital tape recording is made of entered commands, verification messages, and confirm/abort messages.

SFOF command processor. The IBM 360 real-time command processor operates in the SFOF IBM 360/75 central processing system. At the SFOF, the command processor accepts input command data from a 2260 (cathode-ray

tube with keyboard), or COMGEN data tables, or card data tables. The commands entered via one of these devices are validity checked and reformatted for local display. Nominally, the commands are also formatted into standard HSDL blocks for subsequent transmission to a DSS.

To insure proper receipt of the command block at the DSS, each command block originated at the SFOF is routed back to the SFOF from the DSS. The SFOF then compares the returned block against the transmitted block. This process is called verification.

Once the commands are properly stored in the TCP computer, the commands may be enabled for transmission to the spacecraft or disabled and thereby removed from the processor stack.

At the time the TCP transmits a command to the spacecraft, a confirm message is routed to the SFOF over the HSDL. In the event of failure to successfully complete transmission of a given command, the processor returns an abort message to the SFOF. Confirm and abort messages are displayed at the SFOF and filed in a data set for later master data record processing.

In addition to the actual command handling functions (including command generation, validation, transmission to the DSS, verification, and confirmation), the software command processor provides various system specification and monitor capabilities that allow the user at the SFOF to vary the standards and limits, establish the TCP command configuration, and recall information stored in the processor.

The real-time command processor is able to support simultaneous command operations at 5 TCPs located at various DSSs. The minimum period between consecutive HSDL blocks transmitted to a selected TCP by the IBM 360 real-time command program is 5 s. This constraint is placed upon the IBM 360/75 real-time command processor by the TCP system.

(i) *User areas.* The real-time command processor is accessed and controlled from two areas: the Mariner Mars 1971 command mission support area and the DSN operations analysis area.

The IBM 360 software system in the Mariner Mars 1971 command mission support area has the capability to assign 2260 input devices (excluding all other 2260s) to the Project. This allows control messages to be entered and commands transmitted to the spacecraft from any assigned

2260 console. All other consoles are inhibited from commanding the spacecraft. This control is accomplished via assign messages enterable only from the data chief area. Nominally only one 2260 at a time is assigned as a command input device; the second 2260 is backup equipment. The real-time command processor software is not concerned with the number of 2260 input devices assigned to it. Essentially, all command 2260s are treated as a single source, each having equal software priority.

The IBM 360/75 real-time command processor in the command system operations analysis group area accepts DSN system command control messages input via a 2260 operated by the DSN Operations Group. This particular 2260 may be used to enter the following types of command messages: (1) standards and limits, (2) configuration table, (3) TCP recall requests, and (4) test commands. The IBM 360/75 real-time system has the capability to allow these command message types to be entered through a specific assignable 2260, excluding all others. Thus, these messages may not be entered via the command mission support area 2260, nor through any other 2260.

(ii) *Input devices.* Input devices accessed by the real-time command system consist of:

- (1) COMGEN data tables or card data tables.
- (2) 2260 cathode-ray tube with keyboard.
- (3) HSDL.

These input devices pass three types of data to the command processor:

- (1) Command messages (actual spacecraft commands and time).
- (2) System control data.
- (3) TCP response and recall data.

Command messages describing the actual 26-bit command to be transmitted to the spacecraft at a specific time may be input via a data table (generated by COMGEN or by card input) or manually by direct 2260 input.

System control data are entered via the 2260, exclusively. This type of input specifies such information as spacecraft number, DSS number, command priority, command message number, enable mode, and type of message being entered. Essentially, all information input at the SFOF and not specifically command data is categorized as system control data.

TCP response and recall data enter the command processor as an HSDL block. This information originates in the TCP at a DSS. It may be initiated by the TCP itself or it may be a response to a request initiated through the SFOF command processor.

(iii) *Command formats.* Command messages may be entered into the command system in three formats:

- (1) Alphanumeric.
- (2) Pseudo-octal.
- (3) Binary (26 bits).

Only the alphanumeric and pseudo-octal formats are entered for the purpose of command generation. The binary format is used exclusively for HSDL input to the SFOF from the TCP.

(iv) *2260 input software.* The 2260 is used to accept operator control messages. To facilitate entry of control and command messages, the command system displays to the operator the applicable entry variables after the operator has entered a key word. An exception to this occurs in the case of actual command entry. Commands are not enterable in free form. They must be entered in a fixed format in which fields are positional, and separated by one or more blanks.

The key word entry with option display has the additional feature of retaining selected fields and displaying these together with the field descriptors. In addition, selected fields have default values specified. Default values are either fixed or variable.

Although the real-time command system is capable of communicating with 5 TCPs at one time, the software retains only one set of 2260 message prompters (per message type). In other words, separate message variables will not be retained for different DSSs or different Mariner spacecraft. Normal operating procedure is to command a given spacecraft at a time; therefore, one set of message prompters is sufficient. An exception to this is the standards and limits and configuration table messages. Five configuration tables and five standard and limits tables are maintained in the real-time command processor for use as message prompters.

(v) *Command generation and validation.* This capability consists of accepting spacecraft command data in alphanumeric or pseudo-octal format from the 2260 or from a data set previously constructed directly from

cards or by a software program such as COMGEN. System control data must be entered through the 2260. Thus, header information (spacecraft identification, DSS, priority, source, mode) is required in the HSDL command block or required by the spacecraft command source.

The command priority level is specified in the header information. It is not possible to have more than one level of command priority per block of HSDL commands. All commands within a given HSDL command block have the same priority, and the priority is either (1) priority or (2) time, never both.

The real-time command system does not have the capability to construct and store command data in files nor to alter command data already contained in any file. Access to data tables through the real-time command processor is functionally in a "read-only" mode. Construction of large numbers of commands requiring mass storage must be accomplished external to the real-time command processor by using other major software processors such as COMGEN or, alternately, by using card input. Commands may be entered via the 2260 with keyboard, but these commands are not stored in a 360 file. The maximum number of commands that may be buffered (saved prior to transmission to any DSS) through the 2260s is eight, which can be contained in one HSDL block. The real-time command processor will never buffer more than one outbound HSDL block per DSS.

After each command is entered via the 2260, it is validity checked and time tagged (if it was entered without a transmit time). Assuming no errors are detected, the command is then displayed to the operator together with previous commands entered via the 2260 but not yet transmitted. Each time a command is entered it is appended to the previous commands for display and stored in the 2260 HSDL block being constructed. Message subnumbers are assigned to each command according to the position of the command in the block. The subnumber range is 1 to 8. The operator may initiate an HSDL block transmission to a DSS when that block contains from 1 to 8 commands. If the operator has not successfully transmitted the block to a DSS, he may not begin construction of a new 2260 HSDL block until the previous block is transmitted or cleared. An HSDL block becomes full when 8 commands have been placed in it.

To further facilitate command entry through the 2260, a repeat function allows a command to be generated up to 8 consecutive times without having to be repeatedly entered. As a precaution, certain predefined commands are

categorized as critical commands. Transmission of these commands to a DSS requires a further action, namely entry of an interlock key. This interlock is a 3-character code that must match the prestored code assembled into the real-time command processor. If a match does not occur, the critical command is not transmitted.

(vi) *Command transmission and verification.* After the desired commands are validity checked and formatted into a HSDL block, the block is transmitted to a selected DSS. An interval timer is set to 5 s. When the SFOF receives a correct, corresponding command verification message from the TCP, the interval timer is reset. If the interval timer expires, it is reset to 5 s and the same HSDL command block is retransmitted to the TCP. This procedure is repeated as required until at most 8 unsuccessful attempts have been made to transmit the same block to a given processor. Further attempts to transmit to this TCP are abandoned until the 2260 operator initiates a transmission request. If the sequence of commands to be transmitted exists in data tables and exceeds the transmission capacity of one HSDL block, additional HSDL blocks are automatically constructed and transmitted as required at a rate controlled by the TCP. This capability is mechanized using the HSDL alarm message originating in the TCP.

Whenever the TCP receives and accepts an HSDL command block, but cannot accept another HSDL block of commands, the TCP sends an alarm message back to the SFOF indicating a command stack warning. If the TCP receives an HSDL block of commands, but does not have sufficient available room in its stack, it transmits a different alarm message indicating that the block was rejected because the TCP command stack is full.

When the TCP stack becomes sufficiently empty such that it can hold one or more HSDL blocks, an HSDL message is sent to the IBM 360 indicating "command stack normal," that is, the TCP can accept another HSDL command block. Upon receiving the "command stack normal" message from the TCP, the IBM 360 real-time command processor determines if more commands are queued for transmission to that TCP. If so, the IBM 360 accesses the commands, constructs an HSDL command block, and transmits that block to the selected DSS.

(vii) *Command enable/disable.* Enabling is required before a command may be transmitted to a spacecraft. Commands may be considered to be in the "not enabled" mode. These commands are stored in the TCP for later transmission, but until the commands are actually en-

abled they are not transmitted to the spacecraft, even if the transmission time associated with the command is reached and passed.

The process of enabling may be accomplished in one of three modes:

- (1) Immediate: a bit is contained in the command block indicating that the commands therein are all right for transmission, that is, they are enabled.
- (2) Automatic: the real-time SFOF command system transmits a separate enable HSDL message to a DSS after the preceding command message has been transmitted and successfully verified.
- (3) Manual: the operator requests that a given block of commands or a specific subset of that block of commands is enabled. This is accomplished manually via the 2260. A HSDL message referencing the command is generated and transmitted. Until this manual enable message is entered, the preceding nonenabled commands may not be transmitted from a DSS.

Once a command has been enabled, it is ready for transmission. However, it is possible to inhibit an enabled command from transmission to a spacecraft by disabling the command in the TCP command stack. The command to be disabled is specified by command number and sub-number or by command number and zero subnumber. In the latter case, all commands having that number are disabled.

(viii) *Confirm/abort messages.* When a command in the TCP command stack is transmitted to the spacecraft, the processor sends a message to the SFOF. If, for some reason, the command is aborted prior to or during transmission, the TCP sends an abort message to the SFOF via the HSDL. The IBM 360/75 real-time command processor displays the confirm/abort messages on digital TV. Confirm/abort messages are also logged on the system data record.

Confirm/abort HSDL blocks for Mariner Mars 1971 contain the actual command bits to be used for local display. This display is in pseudo-octal.

(ix) *Configuration table, standards, and limits.* The command systems operation group controls the TCP command configuration and establishes standards and limits through the corresponding HSDL messages. The configuration table and standards and limits values are entered through the DSN Operations Control 2260 cathode-ray tube with

keyboard. Input of these messages is limited to this 2260; all other 2260s are inhibited from entering the messages.

(x) *Alarm messages.* Occasionally, a command alarm message is sent by the TCP. This message is received by the IBM 360/75 real-time command processor, displayed on digital TV, and logged on the system data record.

The alarms are divided into two categories: discrete and continuous. A discrete alarm corresponds to an event that occurs at a point in time, whereas a continuous alarm corresponds to an event that persists over an interval of time.

An alarm message is displayed for a discrete alarm every time that alarm signal is present in an HSDL block.

For a continuous alarm, an alarm message is displayed whenever the alarm is newly turned on (that is, whenever the alarm signal is present in an HSDL block but was not present in the preceding block). An alarm-clear message is displayed whenever the alarm is turned off (that is, whenever the alarm signal is not present in an HSDL block but was present in the preceding block). In between the setting and clearing of a continuous alarm, an alarm message is displayed at 1-min intervals as a reminder that the alarm is still on. Provision is made to suppress these once a minute displays, and to cancel the suppression.

(xi) *Recall.* Commands recalled from a TCP stack are displayed at the SFOF in mnemonic form and in accompanying pseudo-octal form on digital TV. Because the stack recall is accomplished with four HSDL messages they are displayed in four separate display formats.

(xii) *System-data-record logging.* Logging of outbound HSDL blocks normally occurs upon verification by the command system. If an outbound block is not verified after eight attempts at 5-s intervals, the block is logged and marked "not verified." Inbound HSDL blocks are logged as they are accepted by the command system.

(xiii) *System-data-record validation.* Validation of the command system data record is accomplished by a message number and subnumber match. All command message numbers and subnumbers are stored in a table in the order received. When an enable/disable or confirm/abort message is encountered, the table is scanned from the top and entry is made in the first applicable slot. Thus, for enable messages, the first matching nonenabled command is marked "enabled." For disable messages, the first matching enabled command is marked "disabled."

For confirm/abort messages, the first matching enabled command is marked "confirmed" or "aborted." If no match is found, the enable/disable or confirm/abort message is stored as an anomaly without a matching command.

(xiv) *Confirm/abort system data record merge.* During normal operations of the command system, command data is logged chronologically into the command system data record file. However, data record gaps, which are caused by computer hardware/software failures and line outages, occasionally appear in this file. The confirm/abort merge task provides the capability of merging into the command system data record file both command confirmed or aborted high-speed data blocks replayed from DSS stations and simulated high-speed data blocks generated from user prepared card input.

(xv) *Master data record generation.* Confirm/abort data are extracted from the command system data record file, assembled into a master data record file, and output to magnetic tape for library use. This function is performed in response to a manual request. The normal procedure is to accomplish system data record validation and, if necessary, confirm/abort system data record merge prior to master data record generation.

(xvi) *Displays.* All command messages generated within the SFOF and all those received at the SFOF are converted into displays for the operators. Command files, configuration, standards, and limits tables may be displayed in the "display only" mode. All of these outputs may be assigned to digital TV, line printer, or teletype printer. In addition, the system data record validation results are output on a line printer only.

d. Telemetry

DSS telemetry processor. The DSS telemetry processor is a part of the TCP program. This program processes the engineering telemetry data stream and the science telemetry data stream, and monitors functions such as the ground receiver automatic gain control voltage, signal-to-noise ratio, and hardware lock indicators. Each telemetry data channel packs the nonframe synchronized data into HSDL formats and outputs on the HSDL to the SFOF telemetry processor. The ground receiver automatic gain control is sampled and merged with the telemetry data in the HSDL format. The lock indicators of the various hardware components required to detect the telemetry data are also monitored and merged into the HSDL format along with a signal-to-noise ratio estimate for each data stream. The operation of the TCP program is in turn monitored by an internal monitor routine and

formatted for transfer to the digital instrumentation subsystem. All HSDL messages are recorded on the original data record magnetic tape, and backup teletype capability is available for monitoring both engineering and science telemetry.

(i) *Engineering data Channel 1.* The engineering telemetry is processed by Channel 1. This consists of the TCP internal bit tracking loop, data detector, and engineering HSDL formatter. The channel processes uncoded data at $8\frac{1}{2}$ and $33\frac{1}{3}$ bits/s.

The tracking loop consists of the hardware and software elements that automatically respond to the signal transitions of the received telemetry data. This constitutes the digital phase shifter, the analog-to-digital converter, the software routines that integrate and dump the input signal, and the algorithm that determines the correction to the digital phase shifter.

The spacecraft telemetry data with subcarrier are processed by the subcarrier demodulation assembly (any one of six), and an integrated analog data signal is output to the analog to digital converter. The analog signal is then converted to digital data, which are received by the TCP. The TCP calculates a frequency bit period to provide bit synchronization control for the tracking loop.

The logical value of the received data bit is obtained from the integrate and dump output of the data interrupt. A logic one is detected when the processed data interrupt level is more negative than the previous level and a logic zero is detected if this level is more positive than the previous level. The actual algorithm subtracts the i value from the $i - 1$ value of the data interrupt and produces a bit one if the value is negative, and a bit zero if the value is positive.

The TCP operational program outputs processed data in HSDL blocks generated by the HSDL formatter routine. The HSDL block consists of a header, data body, and trailer. The header is essentially fixed information that identifies the data type, station, and spacecraft identification. The body consists of 168 bits of data packed into seven words of 24 bits each, a number of ground receiver automatic gain control samples, a filler, the telemetry configuration, telemetry lock status, and the estimated signal-to-noise ratio. The trailer consists of diagnostic messages for communications facility usage.

The Channel 1 acquisition procedure makes an estimate of the bit transition period, takes a fixed number of sam-

ples, and forces the bit loop into phase with the incoming telemetry bit stream.

(ii) *Science telemetry Channel 2.* Science telemetry is processed by TCP Channel 2. Science telemetry consists of 50-bit/s uncoded science data, 16.2-kbit/s, 4.05-kbit/s, 2.025-kbit/s, and 1.0125-kbit/s block coded data. The TCP Channel 2 consists of the symbol synchronizer assembly for uncoded data together with the block decoder assembly for coded data. Uncoded data bits are accumulated in the symbol synchronizer assembly. When 24 bits have been accumulated, the assembly interrupts the processor, and the program then transfers the 24-bit data word and time tags the data referenced to bit 24 of the data word. Similarly, coded data are accumulated in the block decoder assembly and decoded. When the block decoder assembly has accumulated 24 bits, it will interrupt the TCP and transfer the data word with the appropriate time tag. The TCP then formats the received data into HSDL blocks for transmission to the SFOF and concurrently records the HSDL message on log tape.

The data obtained from the symbol synchronizer assembly or block decoder assembly is packed into the HSD format in 24-bit words as received. 50-bit uncoded data are packed into the HSD block at 7 words per block (168 bits). The high-rate data (1.0125-kbit/s to 16.2-kbit/s data) are packed into the HSDL block in 34 words of 24 bits each for a total of 936 bits.

One automatic-gain-control sample is included in each HSDL block. The station configuration lock status bits are also included, with the latest signal-to-noise ratio calculation.

The initialization parameters for the symbol synchronizer and block decoder assemblies are provided by the TCP program. There are no manual operating controls for these units. The initialization procedure takes the form of sending the initialization parameters into the unit, receiving back a verification word, running for a specified number of bits, then confirming the lock status.

(iii) *Signal-to-noise ratio estimate.* The signal-to-noise ratio estimate is an important parameter in measuring the performance of the telemetry system. The estimate is calculated from measurements made at the input to the bit loop or symbol synchronizer assembly and has units of decibel. The signal-to-noise ratio estimate is included in the HSDL format for transmission to the SFOF, is recorded on the original data record log tape, and is transferred to the digital instrumentation monitor system. An

input/output typewriter output signal-to-noise ratio is also provided.

(iv) *Lock indicators.* The TCP operational program monitors the lock status of the receiver, subcarrier demodulation assembly (SDA), bit loop, symbol synchronizer, and block decoder assemblies, which are part of the received telemetry system. This lock status is formatted and distributed for partial status information. Lock status data are output to the HSDL, input/output typewriter, teletype, and the digital instrumentation subsystem monitor.

(v) *Ground-receiver automatic gain control.* The ground receiver automatic gain control voltage is sampled each second, converted to dBm (decibels referenced to a milliwatt) by means of a straight line approximation calibration curve, and merged into the HSDL format. The engineering HSDL formats contain the 1-s samples. The science telemetry HSDL format contains only one automatic gain control sample (the latest taken).

(vi) *Monitor.* The monitor routines gather data concerning the operations of the TCP program and format this data for transfer to the monitor system. Three message formats are generated: the initialization message, the events message, and the status message.

The initialization message, which is generated during TCP initialization, selects real-time events that contain the telemetry initialization parameters and configurations for Channel 1 and Channel 2, the telemetry bit rates, magnetic tape, and HSDL enable/disable messages.

The events message primarily contains the telemetry system lock indicators and is output every 30 s or whenever one of these indicators changes.

The telemetry status message contains various performance measurements such as the number of times the log tape was written, the tape write errors experienced, and the signal-to-noise ratios for the various data channels. This message is transferred to the monitor system once for every HSDL block, for the data rates 50 bits and below. It is transferred to the monitor system at selected rates for the high-rate HSDL/wideband data block.

(vii) *Frame synchronizer and decommutator.* Engineering data at 8 $\frac{1}{2}$ and 33 $\frac{1}{2}$ bits/s are frame-synchronized, and the data in the 140-bit subframe are decommutated and formatted for teletype output and monitor system transfer output. The subcommutation identification is determined

and output as a part of the teletype format. The subcommutation identification that identifies the central computer and sequencer (CC&S) dump is checked and, when received, forces the teletype output to a nonframe, synchronized CC&S dump format.

Science data at 50 bits/s are also frame-synchronized and the science data decommutation routine extracts selected parameters for teletype output and output to the monitor system.

(viii) *Teletype output.* The teletype output is a backup capability and therefore is not automatically enabled at initialization. If the teletype output is desired as part of the nominal configuration, the operator can enable the output with a statement specifying the output line. Two teletype data streams can be output using separate teletype lines.

SFOF telemetry processor

(i) *Data input processing (HSDL).* The actual input processing is performed by the real-time operating system routine function. However, each uniquely identifiable set of telemetry streams that are being processed in real-time or simulated real-time is identified by its own identification number and has HSDL blocks routed by a unique routing control block to a unique independent task via a unique queue. The exception is that if two or three streams from the same spacecraft, but different DSSs, are being validated, then each stream has its own identification but uses the same independent task and queue.

The time tags of the HSDL blocks on each stream are tested for linearity and compared to the expected values for the known data rates. Mission blocks are noted and the frame synchronization routines are terminated at the end of the last sequential block and, reinitialized at the next received block.

The data is displayed as it appears in the HSDL block. In case of engineering telemetry, this may be done with or without the "10" modulo 2 pattern.

(ii) Frame-synchronized algorithms

(a) *Engineering (E140) data stream.* Initially, 154 bits of the data stream are scanned for a valid pseudonoise (PN) code. A valid PN is any sequence of 15 bits that matches the engineering telemetry PN with less than a specified number of bit mismatch errors. A PN code is called the "leading" PN of the following (included) sub-

frame and is also called the "trailing" PN of the previous subframe. If a PN is found within the 154 bits, the first partial frame with trailing PN only is output. When at least 140 or more bits are available, the 15 bits that start 140 bits from the beginning of the known PN are scanned for a valid PN. If the PN is found where expected, full high-rate synchronization is found and the subframe is extracted from the data for further processing. This process is repeated until either a valid PN is not found where expected or until an HSDL block is lost.

If an expected PN is not found, high-rate synchronization is either lost or has not been found or CC&S readout has started. In either case, the subcommutation index is extracted from the data following the leading PN. If the subcommutation index matches that for the CC&S readout, processing is performed. If it does not match, the data stream is scanned starting with the next bit following the last PN up to and including one bit before the next expected PN. A partial subframe with leading PN only is output to the processed data file. If a PN has been found, the look-ahead for full synchronization is resumed.

If an HSDL block is lost, the previous partial subframe is output and the look-ahead for full synchronization is resumed. In all cases, the appropriately formatted messages are output.

The allowable operational variables to the frame synchronization algorithm are the 15-bit PN code and the number of allowable bit errors. The operator can also "discard the first data bit" to unlatch a false synchronization.

When the "PN mode" flag has been set by a control input message, processing differs from that described above only in that trailing PN is ignored and the 140-bit subframe is extracted whenever a leading PN is found.

When an operationally variable number of data bits have been processed, a special data channel is calculated. The special channel reflects the percentage of bit errors detected in the PN codes accepted as valid. This processing requires that the allowable bit errors in a PN be greater than zero. The channel is computed and placed in the latest available data (LAD) table along with the validation parameters extracted from the HSDL blocks.

Two modes of the Mariner 9 CC&S readout are possible. Mode 1 has a quasi-fixed number of zeros between CC&S memory words, and Mode 2 has an indeterminable number of zeros between CC&S memory words. In both

modes, however, the synchronization pattern is the same: a zero-one pattern. Therefore, the CC&S word synchronization algorithm will be the same in either mode. Zero bits will be discarded until the zero-one pattern is encountered. The following 22 bits will be assumed to be the CC&S word. If less than 8 zero bits (at 33½ bits/s) or 1 zero bit (at 8½ bits/s) are found between successive CC&S data words, an out-of-synchronization condition is assumed and the telemetry PN scan mode is resumed.

(b) *Orbital science (o 420) data stream.* The orbital science telemetry frame extraction algorithm is almost identical to that described above for the engineering telemetry frame mode. The major difference is that there is no element comparable to the CC&S readout. Otherwise, the basic program flow is the same.

(iii) *Data validation algorithm.* For the special case where the spacecraft telemetry data are being received by two or more DSSs, a provision is included to perform real-time "validation" on that set of streams.

Two of the streams are ranked 1 and 2. When a full subframe has been extracted from stream 1, certain parameters describing the condition of the data and the transmission link are extracted from the HSDL block and are compared to a standard set of values. If the parameters are above these values, the subframe is passed on for recording and further processing. If the parameters are below these values or if a full subframe could not be extracted from that stream, the corresponding subframe from stream 2 is examined. The parameters extracted from the HSDL data block describing stream 2 are compared to those of stream 1 or the standard. In this manner, the "best" subframe is used for processing in real-time and recording as the system data record.

Whenever the prime data source fails data stream validation and the secondary stream passes, the priorities are reassigned to prevent the data source from toggling indiscriminately.

In this discussion, it is assumed that all data streams are essentially simultaneous. However, provision is made for the prime source to be as many as four subframes behind the secondary. If the prime source is behind more than that, the prime source is assumed lost, the priorities are reversed, and processing is resumed.

The HSDL block variables used for validation include the lock status of the ground receiver, demodulator, bit synchronization loop, symbol synchronizer, and block

decoder as well as a threshold value of the signal-to-noise ratio of the spacecraft/ground link.

(iv) *Decommutation*

(a) *Engineering data stream.* After each subframe of telemetry data is extracted from the data stream and the superimposed "10" modulo 2 pattern is removed, the subframe is recorded for possible playback and further decommutation. First, the subcommutation index is verified for correct sequence. If it is out of sequence, a message is displayed. The expected sequential index is used only if the data-extracted index is invalid. If two valid successive subcommutation indexes are found in the data, subcommutation index synchronization is said to be established and the appropriate message is displayed via the display interface. If any index is found out of sequence, subcommutation index synchronization is lost.

The subcommutation index is used as a key to obtain a set of decommutation tables that describe the format of the subframe and the location of each channel in the LAD table, and identifies any special processing keyed from this subframe. The decommutation module updates the LAD table with the raw value for those channels found in each subframe. As each explicit channel is extracted from the subframe, all specified standard and special processing is applied and the LAD is again updated with those channels that are generated by the special processing.

When the subframe processing is completed, the LAD for this data stream is passed to the data display function for formatting and output to display devices via the display interface.

In the normal decommutation mode, CC&S memory words are extracted from the data stream one at a time and formatted into mnemonic simulation language and displayed via a fixed format. This continues until normal engineering telemetry data resumes or until synchronization is lost. (Synchronization is lost if insufficient zero bits are found between CC&S data words.) The raw data are recorded in the engineering telemetry system data record file with the telemetry data. The extracted CC&S data are also stored in a file for nonreal-time access by COMGEN.

In the compare decommutation mode, a CC&S memory mask is available in a data table file from COMGEN. CC&S memory words are extracted from the data stream one at a time and are compared to the corresponding word extracted from the COMGEN mask. If a match occurs,

only the mnemonic simulation format of the word is displayed. If a mismatch occurs, both the extracted data word and the expected memory word is displayed in mnemonic simulation language. At every 140-bit interval from the last valid PN, the data are scanned for a PN. If it is found, engineering telemetry processing is resumed and full synchronization is maintained.

CC&S compare decommutation continues until the engineering telemetry resumes, until the COMGEN mask is exhausted, or until an invalid CC&S data condition occurs. In the latter case, out of synchronization is assumed and the normal telemetry processing resumes in out-of-synchronization mode.

(b) *Orbital science data stream.* The decommutation process applied to each subframe of orbital science telemetry is identical to that described above for engineering telemetry. The orbital science telemetry does not have the "10" pattern superimposed. Only the frame mode synchronization algorithm is applied to the orbital science telemetry.

Discrete orbital science telemetry data channels are all 1-bit quantities. Standard processing of these channels consists of suppression tolerance testing with a fixed tolerance of 1 for each channel. The result is a flag update in the LAD table. The time of the event and the new state are indicated in the table.

(v) *Special processing.* This processing consists of the transformation of certain telemetry channel contents into other channels not explicitly part of the telemetry stream. The transformations are arbitrary and are defined by independent algorithms. The new data channels created by these independent programs are subjected to all standard processing and then placed in the LAD table.

(vi) *Nonreal-time processing.* Each display recall request is initialized and processed in a manner similar to all real-time processing. Each recall runs at a lower priority than a corresponding real-time mission but runs at the speed of the selected display device if it is a hard copy device. The data may be input from either tape or disc. The recalled stream is processed and displayed exactly as a real-time stream except that the data are not validated or recorded. The recall control input message contains all the parameters that a process control message contains plus a start and stop time. This processing also includes summary and histogram processing.

Special user recall requests must be initialized by the user program making the request. After initialization, the

data are located on the master or system data record input by the recall processor module and then processed by the decommutation module frame by frame. As each frame is decommutated, the LAD table is returned to the user program. This continues until the user's request is satisfied or the data are exhausted.

Telemetry data playback from a DSS is performed when data have been lost at the SFOF IBM 360/75 because of a ground communications failure. Playback sequences are initialized and processed exactly as though the data were being received in real time from a spacecraft. When playback is completed, a special merge program is required to insert the missing data into the original history file for the spacecraft.

6. Project software

a. *Introduction.* The Mariner Mars 1971 Project mission-dependent software operated in three different data processing systems: the MTC system, a UNIVAC 1108 general-purpose computing facility, and two separate IBM 360/75 systems.* The DSN mission-independent real-time system* consisted of two IBM 360/75s, which were supplemented by a separate IBM 360/75 system provided by the Project for operating Science Data Team software for general data processing support of the UVS, IRR, and IRIS instruments, for some LIBSET operations, and for occultation science and Image Processing Laboratory (IPL) support.

Most of these data processing systems were new because neither the UNIVAC 1108 systems nor the IBM 360/75 systems were available for Mariner Mars 1969 support. Also, the UNIVAC 1230 dual processor and a UNIVAC 9300 terminal were added to the Mariner Mars 1969 MTC system configuration, which consisted of two UNIVAC 1219s and a UNIVAC 1218.

The nonreal-time MOS software, which operates in the UNIVAC 1108 and IBM 360/75, was divided into categories of operational control programs, navigation programs, and science programs. A small mission-dependent command translator program, required as an adjunct to the DSN mission-independent command software, operated in the real-time system.

The programs considered mandatory for accomplishment of the mission (Category 1) were developed under the management of a Project software system engineer,

*Described in Subsection II-B-2.

who was responsible for program design, schedule accomplishment, and incorporation of approved changes. A large number of other programs (Category 2) were used for navigation support, spacecraft subsystem analysis, and science data processing. There were 122 navigation support programs in the UNIVAC 1108 mission build, including optical-navigation programs, plus 28 spacecraft subsystem programs, and 10 utility programs. The software system engineer maintained a schedule for the spacecraft support programs and, in some cases, provided programming support for Category 2 programs, although he was not responsible for their development.

The statement of program requirements documented in Software Functional Requirements and Software Requirements Documents (SRDs), and the documentation of program design in design specifications [Division Engineer Planning Documents (DEPDs)] paralleled that of Mariner Mars 1969. Detailed software functional requirements were published in Ref. 5, and the SRDs and DEPDS were published in Ref. 6. Formal specification of the primary MOS software was contained in 40 functional requirement documents (which included the requirements for 21 Category 2 programs), 20 SRDs and 32 design documents, exclusive of telemetry processors, mission-independent programs in the areas of tracking and command, and the DSN sequence of events program.

The Mariner Mars 1969 practice of assignment of a program cognizant engineer for each program developed under the authority of the software system engineer was continued. Each cognizant engineer was responsible for stating the program requirements in the SRD and for providing acceptance test plans consisting of requirements, procedures, and data sufficient to permit program acceptance. The development of the software for which the software system engineer was responsible was coordinated by a software design team, as was done in the Mariner Mars 1969 Project. The software system engineer published 51 detailed status reports in the period of December 22, 1969 through October 25, 1971 and provided software schedule updates approximately biweekly throughout the period of January 1970 through March 1972 in accordance with the standard Project scheduling system. The process of requirements generation, design, the review of requirements and design, implementation, acceptance testing, program integration, and configuration control closely paralleled that of Mariner Mars 1969.

Table 5 lists the MOS programs by type, the data system in which they operated, the program size (number of instructions), and a brief functional description.

The real-time DSN software providing tracking, command, and telemetry support was described in Subsection II-B-5. The tracking and command software had the highest development priority in the IBM 360/75 system. In April 1970, the MOS and DSN managers stated the following policy on computer utilization for telemetry:

System	Engineering telemetry		Science telemetry	
	Real-time display	MDR	Real-time display	MDR/EDR
Prime	IBM 360/75	IBM 360/75	MTC	IBM 360/75
Backup	MTC	MTC	IBM 360/75	None

This plan was subsequently modified because of schedule problems encountered in IBM 360/75 development. The IBM 360/75 science telemetry data processing requirement was limited to only orbital science data (O 420 format, 50 bits/s) and the responsibility for the engineering telemetry master data record (MDR) and the master data record for all science telemetry was transferred to the MTC system, including preparation of the TV experiment data record (EDR). The additional function of driving UVS instrument data to the University of Colorado via HSDL was also transferred to the MTC system.

The initial IBM 360/75 computer system became operational in October 1969, using either of two operating systems, the IBM operating system multivariable tasking (OS-MVT) or the Real-Time Operating System (RTOS), obtained from the Manned Spacecraft Center, Houston. The second computer system was operational in April 1970. The third system, which provided Project science support, was first installed and operated in September 1971. In January 1970, all MOS software was still assigned to the dual-processor UNIVAC 1108 system, and a proposal was made to move nine (nonimplemented) programs to the IBM 360/75: COMGEN, SCISIM, SEG, SPOP, SCILIB, UVS/IRR, PRDX (DSN tracking prediction program), TPAP, and CELREF. Since there was inadequate time for DPODP conversion, all navigation programs were left on the UNIVAC 1108. The recommendation to transfer programs was partly based on problems in obtaining adequate UNIVAC 1108 code-check turnaround. By this transfer it was hoped to reduce UNIVAC 1108 loading, thereby improving the development of navigation programs, and also to expedite implementation of the

Table 5. MOS software programs

Type, acronym, and name	Computer system	Size, kwords	Functional description
<i>Navigation programs</i>			
ICG: injection conditions generator	UNIVAC 1108	1.8	Computes injection time, velocity, radius; coordinates flight path angle and launch azimuth, using launch time and a polynomial approximation equation
DPTRAJ: double precision trajectory program	UNIVAC 1108	380	Integrates equations of spacecraft motion from epoch to desired point using input from ODE, ICG, or nominal data; provides listings and SAVE tape of position, velocity, look angles, and DSS view periods
TMOPS: transit maneuver operations program system	UNIVAC 1108	96	Calculates maneuver capabilities, maneuver values, and commands required for midcourse maneuver
OMOPS: orbit maneuver operations program system	UNIVAC 1108	72	Calculates maneuver capabilities, maneuver values, and commands required for orbit insertion and orbit trim
POGASIS: planetary observation geometry and science instrument scan program	UNIVAC 1108	40	Determines the orbital science strategy that optimizes science data return and computes for the spacecraft the required scan platform angles and instrument viewing times; conversely, computes actual coverage and observation conditions based on data received from SPOP (platform orientation and time)
ODE: orbit data editor	UNIVAC 1108	19	Prepares double precision orbit data file from the real-time tracking data master file by selection, compression, correction, or calibration
DPODP: double precision orbit determination program	UNIVAC 1108	—	Predecessor of SATODP
SATODP: satellite orbit determination program	UNIVAC 1108	760	Calculates best orbit from ODE file data using weighted least-squares trajectory fit; maps statistical errors to encounter; also may solve for physical constants, DSS locations, and perturbing forces
<i>Operational control programs</i>			
COMGEN: command generation program	IBM 360/75	147	Assembles and checks CC&S programs, simulates the CC&S action of the program, and forms spacecraft command messages for loading CC&S memory from this assembly or other sequences provided by SCISM and SPOP
SCISIM: science subsystem event simulator program	IBM 360/75	102	Generates flight command subsystem and CC&S commands and timing for COMGEN to accomplish specified Data Automation Subsystem (DAS) sequences; simulates DAS sequencing, and predicts time of occurrences of actual science events in any specified time base
SPOP: scan platform operations program	IBM 360/75	38 53 ^a	Provides commands to COMGEN based on data received from SCALP or POGASIS; determines best estimate of platform positioning angles from data received from SCALP
AMPS: adaptive mode planning system	IBM 360/75 and UNIVAC 1108 (POGASIS)	405	Automates the operation of a set of programs, i.e., POGASIS, SPOP, SCISIM, COMGEN, SEG, required for the adaptive planning of orbital operations
SEG: sequence of events generator	IBM 360/75	60	Generates and displays a time-ordered sequence of events from file or card input, with capability to display or output by mission and tracking station number
<i>Science programs</i>			
IRIS: infrared interferometer spectrometer program	IBM 360/75	77	Accepts experiment data record tape of engineering and interferogram data, processes data and parity information to provide spectral plots and listings, instrument coverage, and performance
SCILIB: science library program	IBM 360/75	19	Provides an index of science measurements for all instruments, including coordinates of planetary "footprints," slant ranges, and illumination angles

^aLIBSET version.

Table 5 (contd)

Type, acronym, and name	Computer system	Size, kwords	Functional description
UVS/IRR: ultraviolet spectrometer/infrared radiometer program	IBM 360/75	46	Provides calibration and formatting of ultraviolet spectrometer and infrared radiometer science telemetry data for display purposes
OCCULTATION: occultation science program	UNIVAC 1108 and IBM 360/75	89	Accepts received doppler tracking data; calculates residuals from SATODP or predicted values, and analyzes the data in relation to the spacecraft trajectory derived from DPTRAJ to compute planetary atmospheric parameters
LIBSET: science library index system	IBM 360/75 and UNIVAC 1108 (POGASIS)	162	Automates the operation of a set of programs, i.e., POGASIS, SPOP, SCISIM, required for producing the science library index
<i>Important Category 2 programs</i> TPAP: telecommunications prediction and performance program	UNIVAC 1108	65	Computes predicted channel performance from antenna pattern data, spacecraft and ground system characteristics, and trajectory data; computes actual performance from real-time telemetry data and ground system, and compares with predicted data
CELREF: celestial reference program	UNIVAC 1108	—	Computes sensor performance vs clock angle; lists acquirable objects using sensor characteristics and trajectory data; calculates spacecraft attitude relative to Sun, planets, or selected stars; and outputs cone and clock angles of celestial objects
PSOP: propulsion subsystem operations and performance program	UNIVAC 1108	36	Predicts subsystem performance based on propellant/pressurant subsystem analysis, spacecraft mass distribution, and thrust vector orientation based on gimbal actuator preaim data
SCALP: scan calibration program	UNIVAC 1108	—	Provides corrections to SPOP for improving accuracy of scan platform pointing, based on calibration data derived from television pictures of stars, and actual scan platform angles

operational support and spacecraft programs by using the IBM 360/75 system being developed. Movement of these programs also was expected to simplify interfaces between the data files produced by the real-time system and the MOS programs, e.g., engineering telemetry, science telemetry, command, and operations control.

The decision to transfer COMGEN, SCISIM, and SEG to the IBM 360/75 was made in February 1970. SPOP, SCILIB, and UVS/IRR plot were transferred in April 1970. Not fully recognized at the time of the program transfers were the difficult technical and schedule problems that would be encountered while attempting to develop simultaneously the IBM 360/75 operating system (JPLOS), the DSN real-time programs (command, tracking, engineering telemetry, science telemetry, and monitor and operations control processors), and the eight Mariner Mars 1971 MOS programs and systems (COMGEN, SCISIM, SEG, SPOP, IRIS, SCILIB, UVS/IRR, and AMPS/LIBSET). Similar difficulties occurred during the UNIVAC 1108 system development because of serious problems with its EXEC 8 operating system, lasting into mid-1970, and the reconfiguration of the dual processor

into two single processors to separate general-purpose computing from DSN mission operations support. This effort was completed in May 1970.

The following paragraphs provide additional information on developments or programs that were new for Mariner Mars 1971, or significantly different from Mariner Mars 1969.

b. MTC software for spacecraft system test and mission operations. The MTC software requirements for spacecraft system test were generated by a Data Processing Review Board (DPRB) that reviewed all requests, established priorities for requirements, and maintained close liaison with the MTC software and hardware system development personnel to keep requirements and the developing computer system capabilities in reasonable balance. The chairman of the DRPB was head of the Data System Group in the Systems Test and Launch Operations Section. The MTC engineering telemetry capability for mission operations was an extension of the spacecraft test capability, and there were no formal requirements published for MOS engineering telemetry processing. The

orbital science telemetry processing was also a carryover except for IRR instrument data processing, which was developed according to requests of the coinvestigator/experiment representative. Similarly, for spectral science format data, the requirements for MOS processing were derived principally from information provided by the IRIS and UVS experiment representatives. The MOS video data processing capability for orbital operations was developed with close collaboration between representatives of the TV team and the MTC programmers. Only a capability for handling raw video data was available during system test.

Spacecraft system test. The history of development of the MTC system for spacecraft system testing is summarized in Refs. 7 and 8. Reference 6 also includes an MTC configuration drawing for spacecraft test. User handbooks that describe in detail the capabilities of this system for both the spacecraft system test and mission operations phases of the Mariner Mars 1971 mission were also published (Refs. 9 and 10).

The higher data rates of Mariner Mars 1971 compared to Mariner Mars 1969, and the need to handle and process as much as possible of the data in real-time to increase testing efficiency and avoid saturating the system with nonreal-time processing requests required additional computing capability to supplement that of the existing two UNIVAC 1219 systems. The combined worst-case input data rate for two Mariner Mars 1971 spacecraft undergoing test simultaneously was estimated to reach 300 kbits/s. Because of these requirements, a dual high-rate data preprocessor was procured in December 1969, consisting of a UNIVAC 1230 computer and peripheral equipment, to receive, frame synchronize, decommutate, and perform all input processing functions on all high-rate data streams.

The data system capability for supporting spacecraft test was developed in three phases, with the first phase providing single UNIVAC 1219 support of the proof test model (PTM) testing, which began March 18, 1970 with initial turn-on of the spacecraft power subsystem. This capability consisted of logging all data acquired including low-rate orbital-science-format data, decommutation of engineering telemetry, the acquisition of events and status-change signals, commands, and spacecraft CC&S memory dump functions, and the display of an appropriate extract of these data on a line printer on the system test complex. During this test phase, the second UNIVAC 1219 computer was used for software development and driving video data to the MTVS to produce TV pictures.

The system was also enlarged to provide for the simultaneous testing of the two flight spacecraft. Dual test support, with a UNIVAC 1219 computer assigned to each spacecraft began in late September 1970. This system provided the additional capability to process the 132-kbit/s science data automation system hardline data, handle the autopilot test data, or decommutate and process the recorded science telemetry data at the maximum rate of 16.2 kbits/s. This system was limited in processing capability, which required these capabilities to be separately provided as overlays.

The total processing requirements on the UNIVAC 1219 used for PTM spacecraft test support required increasing its core memory size from 49-kwords to 65-kwords by reducing the second UNIVAC 1219 to a 32-kword machine. An additional 32-kword memory bank was obtained in late September 1970, thus removing the limitations on dual-spacecraft test support capability and the operational inconvenience of supporting two different program configurations in the UNIVAC 1219 computers. By mid-October, sufficient programming development was completed to begin testing the UNIVAC 1230 MTC computer and a UNIVAC 1219 computer in the dual computer system configuration. In this configuration, the UNIVAC 1230 frame synchronized and decommutated the high-rate data streams (1 – 16.2 kbit/s telemetry and hardline data) and forwarded the data to the UNIVAC 1219 computer for tape recording, processing, and formatting for display. The UNIVAC 1230 decommutation programs were developed in a sequence that provided critical science instrument data handling capability as early as possible in the flight spacecraft test program.

Such processing was limited during the PTM spacecraft tests because of lack of a spectral science format decommutation program. The development sequence was:

- (1) Spectral science format (486 bits/frame) data decommutator.
- (2) IRIS science format (4725 9-bit words/frame) decommutator, for extracting IRIS interferogram data from the spectral science format or the recorded science format.
- (3) UVS science format (5400 bits/frame) decommutator, for extracting UVS instrument data from the spectral science format.
- (4) UVS science format (4800 bits/frame) decommutator, for extracting UVS instrument data from the recorded science format.

- (5) Video science format (972 bits/frame) decommutator.
- (6) Recorded science format (7938 bits/frame) data decommutator.
- (7) Orbital science format (420 bits/frame) embedded-data decommutators, for extracting the intermingled bits of the 420-bit frame from the recorded science, video science, and the spectral science data formats, simultaneously if necessary.

The engineering and orbital science telemetry data continued to be decommuted by the UNIVAC 1219 computers. The additional memory, which became available in the 65-kword UNIVAC 1219 by transfer of the recorded science format decommutator to the UNIVAC 1230, was utilized to accommodate the programs for cathode-ray-tube system data display, the real-time plot processor, and other special processors. Magnetic tape records of all the above listed decommuted formats were recorded in real time, along with additional records of the decommuted channels of engineering telemetry, orbital science data, spacecraft event and status occurrences, and CC&S commands. These records were later sorted selectively and rerecorded on tape to save only the data required permanently. The IRIS- and UVS-formatted records provided data for offline processing, such as Fourier transformation of IRIS interferogram data by the IBM 360/75 computers. The decommuted engineering and science data records were used for producing nonreal-time data channel tabulations and plots without requiring decommutation, which was not available as a nonreal-time MTC system capability.

MOS software. Much of the MTC system and utility capability developed for spacecraft test was carried over for MOS use. It was necessary to add a processor to accept the 4.8-kbit/s data from the GCF in HSDL block format, extract the data, and route them for engineering and science frame synchronization and decommutation. An analogous processor was added that accepted 50-kbit/s wideband data line blocks from the GCF, extracted the data, and passed them to the appropriate frame synchronization and decommutation processors for either the spectral science format, video science format (never used in operations), or recorded science format.

A processor was also developed to handle the spacecraft command/abort message blocks received for each command transmission. Significant data in the form of DSN automatic gain control signal-to-noise ratio, bit error rate, and ground data system status are either contained

in or derivable from the GCF data blocks, including filler blocks. The MTC block processors extracted these data for use by the project (and, to some extent, the DSN) to monitor the performance of the ground data system, including the GCF.

Changes were made to all five telemetry frame synchronizers to improve their capability to maintain synchronization in the presence of bit errors introduced by the spacecraft-Earth link and the GCF. The data system configurations used to support orbital operations are shown in Figs. 9 and 10. The overseas configuration, which utilizes a single UNIVAC 1219, is used when no high-rate science is available, regardless of the tracking station. The processing is limited to low-rate science and engineering data. It is possible to process two HSDL sources, but only one engineering and one low-rate science stream can be extracted. This configuration is essentially that which was used during cruise. All display, nonreal-time processing, and request message capabilities were retained. The additions to this configuration included the ability to record the 1- and 2-kbit/s spacecraft playback data for subsequent processing, and to provide background programs with the capability to drive UVS data to the University of Colorado via HSDL, and to provide nonreal-time UVS plots via MTVS film recording.

The Goldstone configuration consists of both the UNIVAC 1230 and UNIVAC 1219 computer systems. Data processing is limited to spectral science or recorded science data received via WBDL, and low-rate science data received via HSDL. The engineering telemetry is processed only through the decommutation stage for master data record purposes, with an engineering full frame printout available on a line printer. No display of engineering data on digital TV and no nonreal-time processing of engineering data (data channel tabulations and plots) were provided in this mode. The science processing included real-time video and analog plots of UVS and IRIS data in addition to the capability of providing pages, tabs, and time-based plots. An additional digital TV capability was added to display plots of the UVS pedestal and IRIS peaks and to tabulate UVS pedestal and IRIS interferogram data number (DN) values.

The frame-synchronized instrument data record formats developed for system test later became the basis for the telemetry master data record. As a result of management decisions to reduce the load on the DSN real-time IBM 360/75 system to provide higher confidence in meeting its development schedule milestones, the MTC became the prime system for producing both the engineering

and science telemetry master data records in addition to continuing as the prime system for processing science telemetry data for real-time display. A block diagram of the master data record/experiment data record processors and related data record functions is shown in Fig. 12, where ISE is the infrared interferometer spectrometer extract, IRE the infrared radiometer extract, UVE the ultraviolet spectrometer extract, and CT the channel tabulation tape for channel tab or plot; the CT requires a separate run of the master tape (MT) and the EDR processor. The master tape records described previously provide the input data for the near-real-time experiment data record processor and the nonreal-time master data record processor. The experiment data record processor produces the preliminary TV tape for the Imaging Processing Laboratory, the quick-look tape for IRIS and UVS/IRR analysis (which is the source of data for driving UVS data to the University of Colorado), and the preliminary LIBSET tape for the science library working records. The master data record processor receives input from the master tape or the original data record from a DSS station (to fill data gaps) and produces a master tape record of the best merged science data. The master tape data then are used to drive the experiment data record processor to produce the TV experiment data record, a science extract tape for production of the other instrument EDRs on the IBM 360/75, and the output for the final version of LIBSET.

Real-time MOS video data processing. Significant effort was expended in development of the real-time video processing capability. Because large amounts of data were manipulated in this effort, a UNIVAC FH-1782 drum mass-storage system with a capacity of 2×10^6 30-bit words was added to the UNIVAC 1230 computer system in August 1971. Figure 13 shows the video software options provided by the UNIVAC 1230 and 1219 computers. At the 16.2-kbit/s maximum spacecraft data rate, a TV picture is received every 5 min 42 s. Raw data pictures were always displayed and exposed on film by MTVS, but they were generally of little use because of their extremely low contrast.

Contrast stretching provides a dramatic improvement in picture usefulness by systematically increasing all data values representing the brighter gray shades towards the white region and correspondingly decreasing all values representing darker gray shades towards black. This function is performed without wiping out parts of the picture (creating all-black or all-white areas) by correcting the shading introduced by the spacecraft vidicon, using the preflight calibration data. Noise elements in the picture, resulting from significant bit errors produced by random

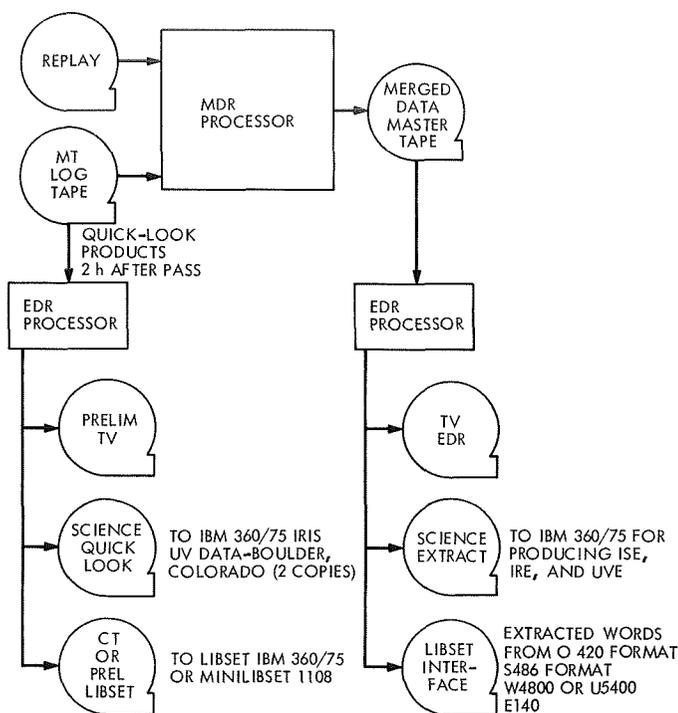


Fig. 12. MTC MDR/EDR system

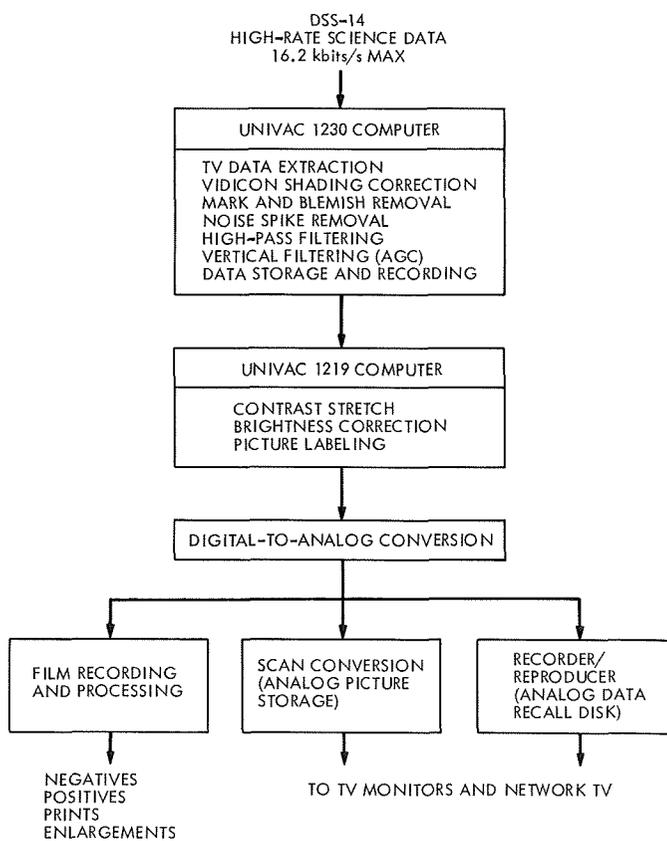


Fig. 13. MTC video data processing functions

noise inherent in the spacecraft-Earth communication link, also are removed. Because the human eye does not perceive variations in brightness equally at different levels of illumination, the MTC removes such "deficiencies" by applying a brightness correction function to the value of each data word. Brightness correction greatly improves the ability to distinguish differences in brightness in the high-brightness areas of the final picture.

The variation in average brightness between large areas in TV scenes of Mars represents significant information but limits the maximum stretch allowable without encountering a washout of high-brightness and low-brightness areas. Consequently, a digital high-pass filter was developed to reduce the variations in average brightness level along each TV line, thus enabling the use of extreme contrast stretch to display maximum Martian surface detail. The filtering is accomplished by subtracting the average value of the 125-line elements on both sides of each picture element from the value of the element.

A vertical filter was introduced after orbital insertion to reduce the visibility of the nearly vertical bars of noise that appeared in the highly contrast-stretched Martian dust-storm pictures. While improving picture contrast, the large stretch had made the electronic noise in the TV subsystem noticeable. The vertical filter (automatic gain control) is also a high-pass filter but it operates on vertical sets of picture elements instead of on the TV-line elements. The filtering correction for each element is performed by subtraction of a smoothed value analogous to the running average value used in the high-pass filter. The processing flexibility provided by the combination of the two types of filtering and the subsequent stretching resulted in pictures with much improved contrast and minimum spikes, blemishes, and marks. The variation in average brightness from print-to-print was also decreased, which significantly reduced the "jigsaw puzzle" appearance of the mosaics made from contact prints. A more complete semitechnical description of the real-time video data processing capability is contained in Ref. 11. The MTVS film recording and processing system used to produce negatives, positives, prints, and enlargements is described in Ref. 12.

c. Navigation software. The navigation programs listed in Table 5 were operated in UNIVAC 1108, in the computer system configuration shown in Fig. 7. The tracking data were received via magnetic tape by the orbit data editor (ODE) from the DSN tracking data processor (TDP) in the IBM 360/75 after translation from 9-track to

7-track format in an IBM 360/75 utility program. In the reverse direction, the UNIVAC 1108 DPTRAJ program generates a probe ephemeris tape that is carried to the IBM 360/75 for translation and then entered into the DSN tracking prediction generation program (PRDX). The IBM 360/75 to UNIVAC 1108 electrical interface was not used in Mariner Mars 1971 operations.

Because Mariner Mars 1971 was an orbital mission, whereas Mariner Mars 1969 was a fly-by, extensive modifications were made to the trajectory program (DPTRAJ) and the planetary observation geometry and science instrument scan platform program (POGASIS). The maneuver operations programming system (MOPS) was an entirely new and extremely large effort, and much of the double precision orbit determination program (DPODP) had to be rewritten to create a satellite orbit determination program (SATODP) capable of calculating orbits for a spacecraft in planetary orbit. Because of the advances in navigation technology represented by programs such as SATODP, development continued over an extended period and was divided into phases to provide adequate support of each mission phase. Two years elapsed between publication of the SATODP Phase A SRD and the delivery of SATODP Phase D in January 1972.

Orbit data editor. ODE was completely rewritten for the Mariner Mars 1971 mission. The ODE accepts tracking data from the TDP master file and prepares a file of data observables acceptable for processing by SATODP. The data on the TDP master file may consist of the following types: S-band doppler cycle counts, angle pairs, Mark IA range units, and planetary range units. The ODE performs double precision calculations on the master file data to prepare a data file acceptable for orbit determination work.

Satellite Orbit Determination Program. SATODP is a modification of DPODP that specializes it for determining the spacecraft orbit while the spacecraft is in orbit about Mars. It accepts tracking data observables on a DPODP file written by the ODE Program. The SATODP uses a modified least square routine to define a trajectory such that the sum of the squares of the data residuals is a minimum. The statistical errors associated with the trajectory are determined and may be mapped along the trajectory. The guidance dispersion ellipse is combined with the orbit determination uncertainty to determine the a priori navigational accuracy for the mission. The conversion of DPODP, developed for the Mariner Mars 1969 fly-by, from operation on the IBM 7094 system to the UNIVAC 1108, was completed in January 1971. Meanwhile, devel-

opment of SATODP Phase A had begun early in 1970, with delivery in March 1971. Many changes to significantly decrease DPODP running time were made after conversion, which carried over into the SATODP versions. DPODP was replaced by four successive versions of SATODP with the following characteristics:

- (1) Phase A (delivered March 1971): this version provided adequate capability for launch and early cruise. A restructured nonlinear estimation capability was the only one intended primarily for orbital phase.
- (2) Phase B (delivered August 1971): the capability was added to handle DSN Tracking System Analytic Calibration (TSAC) data to correct for local perturbations to the tracking data introduced by the ionosphere and troposphere.
- (3) Phase C (delivered October 1971): this version supported orbital insertion and trim phases of the mission. The sequential estimation capability was included and the capability to handle expanded gravitational harmonics.
- (4) Phase D (delivered January 1972): Phase D provided all capabilities required for the celestial mechanics investigation. These included differenced-range doppler and relativity parameters, plus MASCON accelerations, atmospheric lift and drag, a solar corona transmission model, and a backwards sequential estimator.

Double Precision Trajectory Program. DPTRAJ is a double precision trajectory integration program consisting of four major links. Link ODINA reads, organizes, and edits input data. Link TRIC performs the required coordinate transformations. Link PATH computes the probe ephemeris based on input initial conditions by numerically integrating the equations of motion. Any or all of several detailed force models may be included in the equations of motion. Link POST produces the requested output, including a save tape and plot tape, if desired.

Maneuver Operations Programming System (MOPS – TMOPS and OMOPS). The Mariner Mars 1971 spacecraft was scheduled to perform one midcourse (M/C) maneuver early in the flight and one about two-thirds of the way from Earth to Mars. A long burn near Mars was required to slow the spacecraft into orbit about Mars, and one or two subsequent trim maneuvers were scheduled to trim the orbit to the required shape. This is a more complex sequence of maneuvers than any JPL spacecraft has

made before. The large set of guidance programs required to design the maneuvers and analyze the statistics is shown in Fig. 14, where the transit program is designated TMOPS, and the orbital program designated OMOPS.

The upper links are design and analysis links used to determine the target parameters for the next maneuver based on a statistical analysis of the remainder of the flight. For example, in preparation for the first midcourse maneuver, first and second midcourse epochs and aim points are input to design-and-analysis midcourse, and the desired post-insertion orbit is input to design and analysis TRIM. MOPS then computes the first midcourse and statistically defines all the subsequent maneuvers and the target parameter statistics resulting from each.

The middle links are called command (CMD) links because they determine the ΔV and execution time required to achieve the input target parameters (encounter or orbital). The ΔV magnitude computed is that to be sensed by the spacecraft accelerometer and includes compensation for accelerometer misalignment and command quantization. The PATH link of DPTRAJ is used in all command links to map the best estimate of the trajectory to the execution epoch.

The lower post processing links process information from a CMD link. TURNS computes the spacecraft

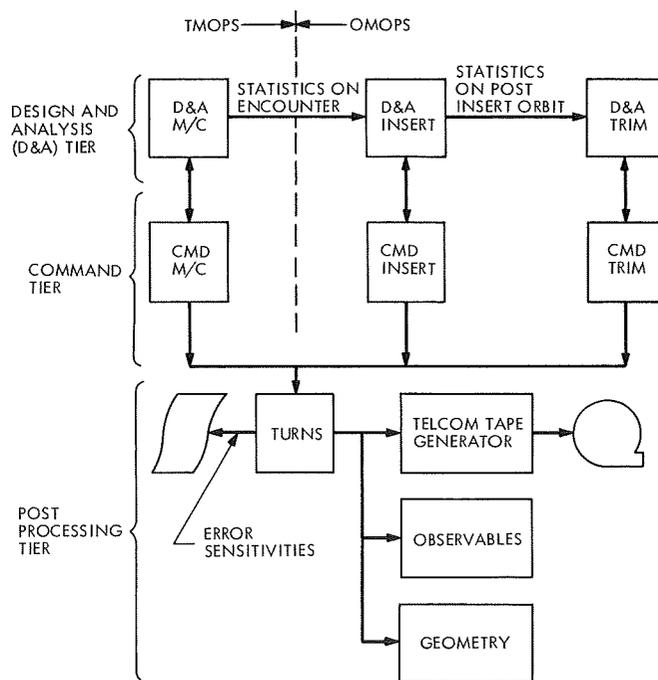


Fig. 14. Maneuver operations programming system

rotations required to achieve the correct thrusting attitude and also computes the sensitivities of target parameters to turn errors. The TELCOM TAPE GENERATOR, OBSERVABLES, and GEOMETRY links generate data needed for telecommunications analysis, real-time maneuver monitoring, and spacecraft-celestial object geometry analysis, respectively.

Planetary Orbit Geometry and Science Instrument Scan Program. POGASIS determines the sequences required to obtain desired observations that will be specified by input in terms of surface area and/or object coverage, and observation conditions. After the sequence is actually executed, POGASIS also determines the best estimate of the coverage and observation conditions actually achieved based on input of the best estimate of the actual scan platform orientation (cone, clock, and twist angle) and observation times derived from spacecraft telemetry. A sequence is defined to be a series of observations times and the scan platform orientation for each observation.

The input typically includes the latitude and longitude of surface targets and the observation criteria for each. Alternatively, the latitude of the initial observation, the timing interval between observations, and maximum incidence and illumination angle limits may be input. The observation times and platform positions are output in a file that is input to the scan platform operations program (SPOP). For postsequence analysis, the inertial scan platform orientation and observation times are input via a file generated by the SPOP.

d. Operational Control Programs. The Operational Control Programs consisted of COMGEN, SCISIM, SEG, and SPOP. COMGEN and SEG were modifications of Mariner Mars 1969 programs but SCISIM and SPOP were entirely new for Mariner Mars 1971. All these programs operated both individually and as a part of the adaptive mode planning sequence (AMPS). SCISIM, SPOP, and COMGEN may be operated to satisfy the planning mode requirements, in which the spacecraft command sequences for future operations are planned and executed, or in the library mode in which actual spacecraft operations are analyzed to provide the best information on pointing angles, observation times, and instrument operational conditions.

Science Simulation Program. SCISIM provides for predicting the time of occurrence of events at the spacecraft in either or both Earth time frame or spacecraft time frame. It simulates data-automation-system activities and provides a means for testing command sequences involv-

ing the data automation system to verify those sequences prior to initiation. SCISIM also provides a table of the times associated with the start of each measurement, which may be input to POGASIS to obtain the parameters associated with each measurement for the data record.

Scan Platform Operations Program. In the planning sequence, SPOP substitutes the closest achievable cone and clock angles of the scan platform for the angles needed to satisfy the science requirements. The program also computes the ground commands for platform cone and clock stepping or CC&S update (quantitative and coded command formats) and the expected scan fine and coarse telemetry values for the commanded steps. When used in the library mode to provide data records, the program uses the scan and attitude control telemetry data to determine the true platform cone and clock pointing directions.

Adaptive Mode Planning System. Figure 15 shows the AMPS programs and interfaces where CC is the coded command, DC the direct command, QC the quantitative command, and SCE the spacecraft event. The function of this system is to accept the requirements of the Science Recommendation Team for the acquisition of science measurements and to turn these requirements into: (1) plots of the Martian surface showing the footprints of the instrument coverage, (2) the sequence of commands to be sent to the spacecraft, and (3) a listing of all significant events for use by SFOF and DSIF operational personnel.

POGASIS receives the inputs of the Science Recommendation Team and produces plots of the resulting instrument footprints as well as a list of the scan platform clock and cone angles vs time required to achieve these plots. POGASIS operates in an interactive mode through an 1108 Tektronix graphics terminal.

SCISIM provides POGASIS with pairs of numbers that describe the exact achievable picture times and the time increment between frames calculated in advance of the execution of the planning sequence. The initial scan platform angles are determined from the low-rate telemetry and provided to POGASIS on punched cards. POGASIS also generates the number of data automation system pauses required and the timing of those pauses, considering the constraints of the camera shuttering interval and the availability of 1.2-s data-automation-system pause commands.

POGASIS output provides the achievable instrument operational times and desired (but not exactly achievable)

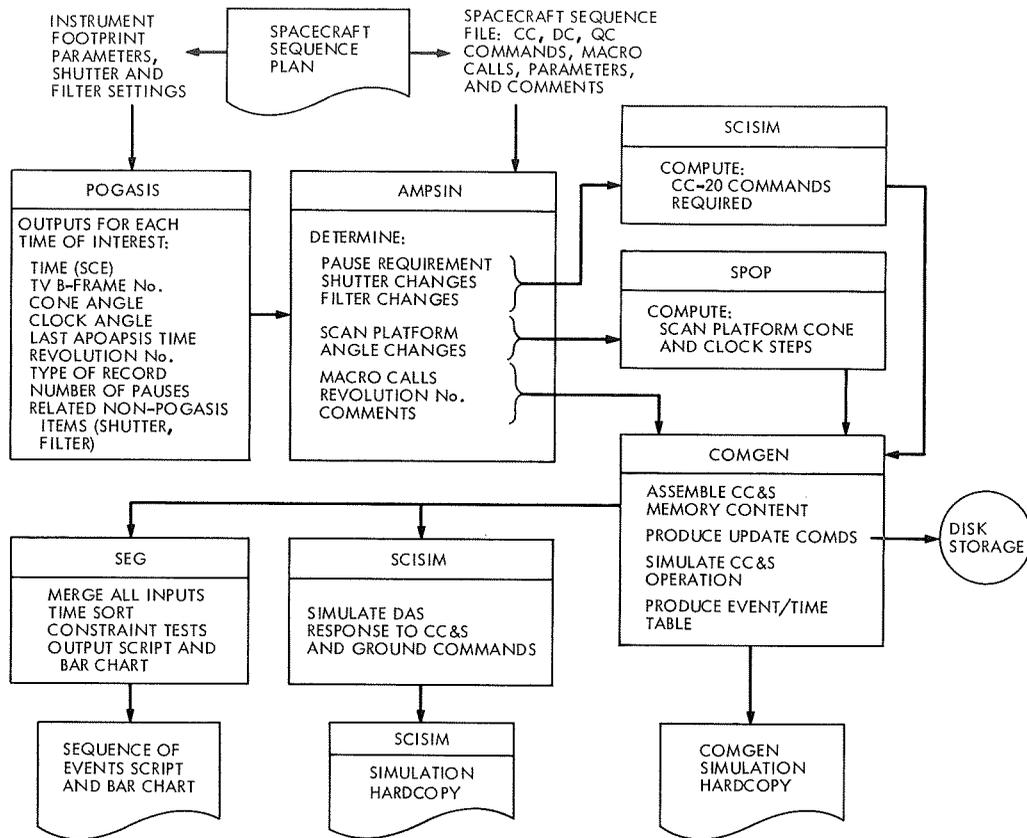


Fig. 15. AMPS data flow

scan platform angles at these times. POGASIS also outputs the times during which the platform is to slew.

SPOP then converts the required changes in scan platform cone and clock angles into scan platform slew commands using calibration coefficients passed to it by SCALP, and checks the slew times from POGASIS to make sure sufficient slewing time is allowed. These commands will slew the platform as close as possible to the desired angles.

To simplify the operation of the planning sequence, items such as shutter speed, filter settings, and the initial angles are input to POGASIS and are passed along the sequence until used by the appropriate program. SCISIM generates and time tags the CC-20 commands required to effect the pauses, using light-time files to calculate their correct arrival time at the spacecraft.

SCISIM models the data-automation-system clock performance with respect to time, including temperature effects, which enables the conversion of GMT-related

observation-time pairs to TV B-frame start number, and elapsed time thereafter.

The spacecraft's CC&S contains a generalized slew routine that controls scan platform slewing. This slew routine is controlled by a table containing two words for each platform movement in cone or clock angle. COMGEN formulates the set of table entries necessary to position the platform and generates the CC-1/2 commands necessary to load the CC&S memory with the table entries. COMGEN can output its entire memory mask to the real-time data processing system for comparison with spacecraft memory dumps. COMGEN also returns to SCISIM a file of both ground and CC&S commands affecting the data automation subsystem. SCISIM then uses this input to simulate the data automation subsystem performance to determine possible time conflicts within the subsystem. Finally, COMGEN simulates the operation of the Mariner 9 CC&S and sends to SEG a file of all CC&S related events.

e. Science programs. The science programs, IRIS, UVS/IRR Plot, the Occultation Programs, and LIBSET,

were all new for Mariner Mars 1971. LIBSET, like AMPS, is a system that joins together several programs. SCILIB is a set of programs appearing only in LIBSET and is included in the LIBSET description.

Infrared Interferometer Spectrometer Program. The IRIS Fourier Transform Program provides IRIS data edited and plotted in such a way as to allow effective analysis of the instrument engineering performance and the acquired science data. The program output display equipment permits the IRIS data to be used in adaptive mission. The program receives magnetic tape data from the MTC in instrument frame-synchronized form, tagged with both time of receipt of the data at Earth, and data automation subsystem time. Other relevant data from the orbital science and engineering telemetry frames are also provided.

The final outputs of IRIS processing are:

- (1) Plots of noise-equivalent radiance, temperature, standard deviation of temperature from engineering values, and atmosphere spectra for each averaging period. These plots are produced from a Calcomp plotter drive tape.
- (2) Printout of each interferogram time, location in latitude and longitude, instrument temperatures at various points, and parity correction statistics.
- (3) Magnetic tape record of the housekeeping data and spectra.

Infrared Radiometer and Ultraviolet Spectrometer Plot Program. The UVS/IRR Plot Program provides for evaluating large volumes of data during mission operations. Several UVS spectra and IRR data points are plotted on a three-dimensional grid representing a limited portion of the Martian surface. This permits association of spectra with TV pictures of the selected area.

IRR and UVS inputs are obtained from punched cards, magnetic tape, or remote terminal. The following outputs may be generated:

- (1) SC 4020-plotter formatted magnetic tape to produce separate IRR and UVS data plots on a three-dimensional grid of a limited portion of the planet surface.
- (2) SC 4020-plotter formatted magnetic tape, to produce a plot of IRR-measured temperatures and ΔT vs time.
- (3) List of plotted data values for diagnostic purposes.

Occultation programs. A set of occultation support and data handling programs (DECIM, SPECTR, LLR, and SPLINE)* runs on the IBM 360/75 and extracts frequency information from the noisy digital data samples taken near occultation times. The occultation analysis programs (RPP, DIP, ATMOS, CDAT, and HIDOP)* run on the UNIVAC 1108 and extract information about the structure of the Martian atmosphere from the frequency data derived from the first set.

LIBSET. Each day of the standard mission, some 5,000 science measurements were taken. A measurement is considered to be a TV picture, an IRIS spectrum, a UV spectrum, or a frame of IRR points. These data, stored on thousands of magnetic tapes, would be useless without an index that lists each measurement, its description, the circumstances under which it was taken, and its location in the tape library. The purpose of the science library sequence is to compile such an index. The science library sequence does not deal with science data itself but only with the index.

The descriptors for the science measurements consist of items such as slant range from the spacecraft to the center of the measured area on the planet's surface, the surface lighting angle, the GMT and data automation subsystem times of the measurements, the Mars latitudes and longitudes of the corner points of the area, and TV filter and shutter speeds. To produce these descriptors, the library sequence must be supplied with the best estimate of the spacecraft trajectory, the time of each measurement, and the scan platform position and spacecraft attitude at the times of measurement.

In the library sequence, SCISIM determines the actual measurement times using both the file of commands sent to the data automation subsystem from the ground and from the spacecraft's CC&S and the orbital science telemetry data. Using the command master data record and telemetry data, SCISIM determines whether or not the planned measurements actually were taken. The output from SCISIM to SPOP is a list of the instrument measurements and measurement times.

SPOP uses the command files and the light time files to calculate scan platform position as a function of time. This data is verified (or corrected) using engineering telemetry data. SPOP also interpolates attitude control measurements in the low-rate telemetry to determine the instantaneous angular orientation of the spacecraft.

*See Ref. 5 for the functional requirements of these programs.

Knowledge of the orientation of the spacecraft and of the scan platform relative to the spacecraft allows determination of the boresight of the scientific instruments on the scan platform. The output passed to POGASIS includes the best estimate of the platform cone, clock, and twist angles.*

POGASIS uses the measurement times from SCISIM, the cone, clock, and twist angles from SPOP, and the spacecraft trajectory and planetary position from the tape ephemerides to determine the footprints of the measurements. POGASIS also provides geometric quantities such as slant range to the center of the measurement area, and the lighting angle.

The orbital science telemetry contains data automation subsystem status bits representing filter settings and exposure times, IRR mirror position, and other quantities relevant to the scientific data. SCILIB extracts this data, adds it to the file output by POGASIS, and thus prepares the science catalog file for each instrument.

f. AMPS and LIBSET development. The development of MOS analysis programs for Mariner Mars 1971 did not differ much from the corresponding development in Mariner Mars 1969, except for AMPS and LIBSET. AMPS, which was necessitated by the use of the adaptive mode in Mariner Mars 1971, automated the generation of the next day's orbital plan. LIBSET, which was necessary because of the large number of science measurements received from the Mariner Mars 1971 spacecraft, automated the generation of the instrument data index for daily operations.

The need for these two sequences was not recognized until May 1970. By that time, most of the programs comprising the AMPS and LIBSET systems were already designed. These programs (COMGEN, SCISIM, POGASIS, SCILIB, SEG and SPOP) were specified by cognizant engineers in several different divisions, who viewed their programs only as planning and analysis tools and not as a part of some overall system. The design of AMPS and LIBSET was therefore complicated by the necessity to build them out of pieces that were already designed and in many cases implemented.

The end of program development was signaled by completion of the acceptance tests. The acceptance test completion for AMPS, originally scheduled for June 1,

1971, was not achieved until September 15, 1971. Even then, many of the same system, interface, and operational difficulties, which had delayed completion of the acceptance tests, continued to plague the usability of AMPS to such an extent that, by January 1972, it was still not able to support flight operations. By that time, flight operations were being conducted successfully without AMPS, and the Project no longer considered AMPS to be a requirement. A successful operational demonstration was finally conducted in March 1972.

LIBSET acceptance was originally scheduled for April 1, 1971. Delays in obtaining a cognizant engineer slowed the development of requirements and accordingly postponed implementation to August 15, 1971.

However, the same kinds of system, interface, and operational difficulties experienced with AMPS also impaired LIBSET acceptance testing, and it was not completed until November 15, 1971. In late October 1971, a small FORTRAN program was written on the UNIVAC 1108 that replaced SCISIM and SPOP in LIBSET. The resulting "mini-LIBSET," was used during the early months of the flight operation to produce the instrument data index for daily operations, although the data produced were less accurate than that produced by the full LIBSET. The use of LIBSET to produce the archival science data record began in March 1972.

C. Training

The Mariner Mars 1971 mission operations training and test plan developed a "building block" training method covering the various mission phases in four major areas:

- (1) Orientation lectures.
- (2) Intrateam training.
- (3) Interteam training.
- (4) Operational tests.

1. Orientation lectures. Starting in the last quarter of 1970, a series of orientation lectures were presented at JPL and recorded on video tape for dissemination to participating NASA and contractor agencies, personnel at overseas DSN stations, and personnel returning from Cape Kennedy. These lectures described the various organizational functions, responsibilities, and relationships existing within the MOS and DSN as well as the hardware, software, and operational aspects involved. In all, a total of ten lectures was given.

*Twist angle is the small rotation about the TV line of sight due to misalignment and offsets.

2. **Mission operations intrateam training.** The general intent of mission operations intrateam training was to exercise and refine procedures and interfaces while teams operated independently within their assigned sections of the mission support area within the SFOF.

The Navigation Team ran intrateam exercises covering the launch and first trajectory correction phases of the mission. Each exercise ran about four hours and was repeated several times. Simulation was provided by data tape packages played from the simulation center. Of particular value was the experience gained in the determination of flight parameters, the analysis of data, and the familiarity with the computer support systems.

The Data Processing Team did not have independent exercises but supported the other teams in the execution of computer programs, the coordination of data flow, and the operation of display devices.

The Command Team participated extensively in the DSN operational verification testing for team training as well as working closely with the test operations of the live spacecraft in the spacecraft assembly facility. Two MOS command and telemetry preliminary test sequences, lasting about four hours each, were conducted on January 26 and 30, 1971. Simulation provided engineering data and commanding capability while the command team gained further experience as a prelude to more complex training exercises.

The Spacecraft Team utilized a special area in the mission support area called the "Mini Ops," which was equipped with character printers and digital TV display devices for training the analysts. Live data were routed to the printers from the spacecraft assembly facility or Cape Kennedy. The analysts monitored the composite readiness tests and precount launch operations. In addition, the Spacecraft Team conducted one exercise on launch operations, and another on a trajectory correction maneuver that utilized simulated data from the UNIVAC 1108 computer mathematics model.

During the cruise of Mariner 9, the Science Data Team conducted three data flow tests to train personnel in the required data handling procedures and evaluated the adequacy of the software/hardware to support orbital operations. The exercises were designed to represent the data generated and distributed during a typical 24-hour period in Mars orbit.

The Science Recommendation Team conducted one functional exercise in early November 1971 to demon-

strate its ability to meet time lines and to interface with other MOS elements during orbital operations.

3. **Mission operations interteam training.** Although some interteam training resulted from earlier exercises, integration of the mission operations teams and support systems officially began with two mission operations/SFOF exercises.

One exercise, conducted on February 3, 1971, covered cruise operations and a trajectory correction sequence. Spacecraft simulation was provided by the simulation center's mathematics model in the UNIVAC 1108 computer, and the data-flow closed-loop within the SFOF. A sequence of events document was generated by the sequence group to integrate the various events and team efforts. The mission phase started with the command for maneuver execution and ended with the spacecraft acquisition of the star, Canopus.

The other exercise, conducted on March 6, 1971, simulated the launch phase. Data were provided by launch trajectory tapes supplied by the Eastern Test Range (ETR) and played from the simulation center closed loop in the SFOF. The interface between the Navigation Team and the DSN Tracking System Analysis Group was first used on this exercise.

The closed-loop SFOF simulations were followed by three major MOS/tracking data system (TDS) exercises in which the supporting DSN tracking stations participated. Engineering telemetry data, developed by the simulation center's 1108/6050 computer combination, were long-looped through the appropriate DSN station and processed by the IBM 360 and mission test computers (MTC). The DSN stations provided telemetry and command processing support. Tracking data were short-looped in the SFOF from the simulation center tapes. Voice nets were utilized from the DSN stations.

A total of six MOS/TDS telemetry and command exercises were conducted, one with each DSN station committed to support the Mariner Mars 1971 Project. The DSN simultaneously conducted operational verification tests during each of these exercises. All commanding modes were utilized by initiating commands from the mission support area through the IBM 360 to the TCP of the DSS, and confirming the transmission of the commands back to the mission support area via the simulated telemetry data. Procedures involving abortive techniques and manual commanding were practiced. A separate exercise was conducted with the Manned Space Flight Net

(MSFN) Ascension Island station because of its special configuration.

On March 11, MOS/TDS simulation of launch operations was conducted using the ETR resources, the Spacecraft Compatibility/Monitor Station, Cape Kennedy (DSS-71), and the Johannesburg, South Africa Deep Space Station (DSS-51). The test interval was from launch minus 4 h until Canopus acquisition. The interface between ETR, DSN, and MSFN was shown to be compatible.

Two MOS/TDS standard trajectory correction exercises were performed on March 13 and 30. The mission operations organization and TDS demonstrated their ability to perform the planning, analysis, and operations functions necessary to perform a successful correction maneuver. The "two tier" MOS staffing plan was exercised for the first time. The planning and analysis staff held maneuver conferences and developed the strategy, and the operations staff carried it out.

4. Operational tests. Eight operational demonstration tests were conducted to verify the capability of all operational elements to support the launch, trajectory correction, MOI, and orbital phases of the mission. Approved procedures and software were used. Simulated anomalies were introduced into the various spacecraft and the ground data system so that overall mission support readiness and ability to detect and respond to nonstandard conditions could be demonstrated.

An 84-h operational demonstration test began on April 13, 1971. This test simulated the first spacecraft cruising, while the second spacecraft was launched and commanded through the first trajectory correction. The MOS had to demonstrate the capability to handle two successive spacecraft through the various mission phases. Again, simulated spacecraft telemetry was long-looped through the appropriate DSN station, and tracking data were short-looped within the SFOF for navigation experience. Simulation provided a method for commanding the two spacecraft and for realistic data. All planning sessions, analysis reports, data flow, and computer program runs were performed according to the timeline in the sequence of events.

Similar operational demonstration tests based upon various combinations were performed, such as single spacecraft launch and trajectory correction, launch of the second spacecraft while the first cruised, trajectory correction or MOI maneuver of one spacecraft while the other cruised, and orbital operations tests.

The final training exercise of each mission phase was an operational readiness test. At this point all hardware configurations, computer programs, and staffing had been determined. Each exercise was conducted using only approved elements and procedures and no anomalies were intentionally introduced.

One operational readiness test was conducted on April 28 prior to the launch of the first Mariner Mars 1971 spacecraft, the Mariner 8. The test covered the launch, trajectory correction, and cruise phases of the mission, starting at launch minus 1 h 49 min and ending with the unwind maneuver after the trajectory correction maneuver. This exercise was repeated on May 28 before the launch of the second spacecraft.

Two operational readiness tests performed on October 21 and 27, covered the MOI maneuver and subsequent orbital operations. The tests began with the preorbital science taking sequence, went through the MOI update and maneuver, and ended with playback of the science data some 24 hours later. High-rate science data were generated by the simulation center's mathematics model at 16.2, 8.1, 4.05, and 2 kbits/s and long-looped on the wide-band data line to the Mars Deep Space Station, Goldstone (DSS-14) for telemetry and command processing. Real-time science (RTS-1) data at 50 bits/s were long-looped through the appropriate DSS over the high-speed data line.

D. Simulation Data System Operations

The simulation data system provided calibration or test pattern data to test the ground data system, and provided dynamic, realistic command responsive data to test and train the MOS/TDS operations teams.

1. Ground data system testing. Ground data system testing began during 1970 with the generation of engineering HSD blocks by the EMR 6050 routed through the GCF to the SFOF IBM 360/75 telemetry processors. Later, during October 1970, low-rate science (50 bits/s) was provided. The last addition to telemetry simulation was high-rate science (1 to 16 kbits/s) by means of tapes provided by the MTC and processed through the EMR 6050. Throughout the Ground Data System's development period, these data sources were in demand to the extent that EMR 6050 scheduling became a major undertaking.

2. Training operations teams. Training exercises, which started on January 25, 1971, were supported by the spacecraft model in the UNIVAC 1108 and by the simulated TCP in the 6050.

3. **Telemetry data.** Simulation engineering telemetry software in the UNIVAC 1108 computer was required to generate spacecraft engineering telemetry data simultaneously for each of two simulated spacecraft. During the first few training exercises, the UNIVAC 1108 simulation program was operated in the real-time mode, in which the program continuously resided in core. Only about 10% of the central processing unit time of one UNIVAC 1108 was used in this mode to simulate telemetry for two spacecraft. However, other UNIVAC 1108 users, both Mariner Mars 1971 and nonproject, were often delayed excessively while waiting for core space so that software was developed for a "super-demand" mode of operation, in which the simulation program was swapped into and out of core. This mode alleviated the problems of other UNIVAC 1108 users but proved unsatisfactory for Mariner Mars 1971 training operations because of excessive UNIVAC 1108 input/output response times, which caused the EMR 6050 to halt for lack of data. Each halt resulted in a delay in the test while the math models were manually updated.

Science engineering data were generated in the UNIVAC 1108 and commutated for science telemetry in the EMR 6050 computer. Science measurement data were recorded on magnetic tape from the spacecraft proof test model for playback during test operations through the EMR 6050. Input of data and program control were provided by the EMR 6050. A UNIVAC 1108 stand-alone mode was implemented for program testing.

4. **Command program.** The command program residing in the EMR 6050 relayed commands from the GCF to the simulation data system telemetry subsystem through the 6050/1108 interface. The minimum interval for issuance of timed commands from the stack was 30 s, which met the MOS requirement. However, the necessity to compute telemetry in advance of real time constrained the time of the commands to be no earlier than 5 min after the command was transmitted to the TCP. This resulted in a minor deviation from standard MOS practice during training.

5. **Tracking data.** Programs required for the generation of nonresponsive tracking data were DPTRAJ, a navigation program for the UNIVAC 1108 computer; PREDICTS, a navigation program for the IBM 360/75 computer; and the EMR 6050 tracking program.

Injection conditions, or a state vector at a chosen epoch in the trajectory, were used for interplanetary trajectory generation. An interplanetary trajectory, for one space-

craft at a time, was generated by the DPTRAJ program operating in the EMR 1108 computer. Using points on the resultant spacecraft ephemeris, frequency independent predicts for up to three DSS/MSFN stations were generated by the PREDICTS program operating in IBM 360/75 computers and stored on a magnetic tape for the simulation of station tracking data through the EMR 6050 computer. Because of heavy loading of the EMR 6050 during test operations, paper tapes were often punched from the magnetic tape before a test for playback during the test.

For launch simulation, the injection conditions were provided to the AFETR for use in generating near-Earth phase metric data and real-time computing system processed data.

6. **Data quality.** The quality of data was considerably improved over the data acquired by the first spacecraft mathematics model developed by JPL (for the Mariner Mars 1969 simulation data system). Many functions not formerly modeled were incorporated, and the organization of spacecraft logic was greatly improved. Except for some oversights, the model behaved very well. The data were so realistic that at times the operations teams were as deeply engrossed in following the progress of the data as they would have been in real operations.

The technique used to generate tracking data produced errors in the simulated DSN station observables resulted in doppler data residuals that were of limited usefulness for the flight path analysis team/orbit determination group training.

7. **System reliability.** System reliability was poor most of the time. Of thirty-one tests using the spacecraft model, seven were cancelled, three were rescheduled, five were delayed, and six more were terminated early because of simulation failures. Almost all of the total 203 failures were caused by EMR 6050 hardware and software problems and excessive UNIVAC 1108 response delays.

Table 6 summarizes simulation support of MOS training.

Table 6. MOS simulation support

Parameter	Hours
MOS training schedule	569
Simulation support with 1108/6050	463
Total nonsupport time	106 (19%)
Proof test model support	63
Mean time between failures	2.3

III. Flight Operations

This section contains a chronological history of the Mariner 9 flight from the completion of the midcourse maneuver on June 4, 1971, to the end of standard orbital operations and preparation for Sun occultations on April 2, 1972. Each of the subsections represents a major phase of mission operations, groupings of interrelated decisions, and events that met significant mission objectives.

The original mission plan stated that the second of the two Mariner Mars 1971 spacecraft, Mariner I (Mariner 9), would be launched 10 days after Mariner H (Mariner 8) and would arrive at Mars on November 24, 1971. The spacecraft were to perform two different but complementary missions. Mariner 8 (Mission A) was to map about 70% of the surface of Mars and study the composition, density, pressure, and temperature of the atmosphere, and the structure, temperature, and composition of the surface. The spacecraft was to have a 12-h orbital period and an 80-deg orbital inclination to optimize the mapping mission. The basic objective of Mariner 9 (Mission B) was to obtain data on the changes in surface markings, such as the seasonal darkening observed during Martian spring, and also to study atmospheric and surface properties. Its orbital period was to be approximately 20½ h and the orbital inclination 50 deg to optimize the variable features observations.

The loss of Mariner H during its launch phase delayed the Mariner I launch. Volume I of this document describes the Mariner H launch and the actions taken to recover from the failure in order to ensure a successful Mariner I launch.

Immediately following the failure of Mariner H, intensive mission design activities were initiated. With only one spacecraft remaining to be launched, neither the plan for Mission A nor that for Mission B alone was adequate

to meet all of the mission objectives. Consequently, a new hybrid mission had to be designed which would accomplish the mission objectives within the capabilities of the existing systems. During the time between the first and second launches, a single mission plan was developed that provided the necessary confidence to proceed with the launch of Mariner I. This plan reflected a concerted effort to maximize the science value for the single mission so as to lessen the impact on the experiments of the reduction of two missions to one. All of the basic elements of the single mission plan were known and understood prior to the second launch, although certain details and documentation were lacking. A complete description of the mission from launch through cruise and orbital operations is contained in the MM'71 Mission Plan Book (Ref. 13).

Mariner 9 was launched from Cape Kennedy, Florida, at 22:23:04 GMT (3:23 p.m., PDT) on May 30, 1971. After injection, the spacecraft separated from the launch vehicle, extended its solar panels, and automatically acquired the Sun and the star Canopus to provide three-axis stabilization.

All indications showed a normal mission from launch through the first midcourse maneuver, performed on June 5, 1971. The navigation to that point indicated a good trajectory requiring a correction of about 30,000 km in the target plane and a time-of-arrival correction of about 19 h. The midcourse maneuver execution resulted in a target plane error of only 79 km and time-of-arrival error of only 4 s. The maneuver was so accurate that no other correction was necessary for the entire 167-day flight to Mars (see Table 7).

A. Cruise Operations

Following the successful conclusion of the midcourse maneuver, commands were transmitted to the central computer and sequencer (CC&S) to disable the maneuver

Table 7. Accuracy of trajectory correction maneuver (performed 5:22 p.m., PDT, June 4, 1971)

Parameter	Planned	Achieved	Δ_A
<i>B</i> -plane correction ΔB^a	24,948 km	24,869 km	79 km
Time of closest approach (TCA) correction ΔTCA	19 h 06 min 36 s	19 h 04 min 28 s	00 h 00 min 04 s
<i>B</i> -plane miss distance <i>B</i> ^b	8,200 km	8,261 km	61 km
Time of closest approach, November 14, 1971 (GMT)	00 h 29 min 00 s	00 h 31 min 09 s	00 h 02 min 09 s
Orbit inclination <i>i</i>	65.0 deg	64.2 deg	0.8 deg

^a ΔB is trajectory correction maneuver (TCM) aiming point correction in *B*-plane (injection aiming point minus post-TCM aiming point).
^b*B* is distance from center of Mars to aiming point (assuming Mars gravity = 0).

sequence and place the spacecraft in a cruise configuration. Within a few days, the propulsion system was closed off, and the CC&S was reloaded with a backup program that would automatically initiate an orbit insertion maneuver and postinsertion science activity in the event of loss of ground command capability.

The cruise period was occupied with five principal activities: (1) refinement of the new mission plan, (2) management of spacecraft problems during cruise, (3) performance of cruise functions, (4) several spacecraft calibrations in preparation for later science operations, and (5) training for orbital operations (see Section II-C).

1. Single mission plan. The new mission plan, developed in detail during the months of cruise operations, contained a compromise orbit which would achieve the most significant aspects of the two-spacecraft mapping and variable features missions. A 12-h orbital period with an orbital inclination of 65 deg was selected. The plan also entailed a rebudgeting of science data-taking activities and the recording of science data to distribute the recording between mapping and observing the variable features. Because the orbital period selected was close to 12 h, the new mission plan also provided complete longitudinal mapping coverage in approximately 20-day cycles, with sequential cycles for differing latitudinal coverage. Initial science activities were programmed to begin approximately 3 days prior to orbit insertion and to continue, interrupted only by the orbit insertion and orbit trim maneuvers that were anticipated, throughout the standard mission of 90 days in orbit.

Mission and science planning continued with these objectives until September 22, 1971, when Earth-based observers recorded a bright yellow cloud that had developed over Noachis, in the midsouthern latitudes of Mars. It spread rapidly over the rest of the planet, and in a little more than 2 weeks, the entire visible globe was covered by dust; even the south polar cap had disappeared from view of Earth-based telescopes. By the fifth week, the dust storm had reached its peak, exceeding all previously observed Martian storms in obscuration, area extent, and duration.

Mariner 9 arrived at Mars on November 14, 1971, during the planet-wide dust storm. This dust storm turned out to be a bonus to scientists because it provided an unparalleled opportunity to examine at close range a phenomenon connected with Martian meteorology, topography, depositional and erosional processes, and variable features. However, it was also a major factor in the

decision to change the mission plan again, because no systematic surface picture coverage could be established to enable the start of mapping or dynamic variation objectives.

2. Cruise problems. The spacecraft performance was generally excellent during the cruise phase, but a few problems occurred that affected mission operations. Although they were not of catastrophic proportions, considerable expenditure of time and effort was required to analyze and evaluate their impact on the mission. These problems were:

- (1) The RF exciter output dropped sharply immediately after launch and continued to drop slowly. Analysis indicated that the decrease in exciter drive was not simply a shift in the telemetry signal but was a real symptom of changing spacecraft performance in the radio subsystem. After several weeks of plotting the performance of this parameter, it was concluded that the RF exciter drive was decaying in an exponential manner and would ultimately approach an asymptotic value of 2 to 2½ dB below premission predicts; however, this would have no serious effect on the basic Mariner 9 mission. The expected long-term effect would be to shorten the mission life because of a loss in downlink power, which would limit the science data rates possible as a function of mission time. The only corrective action available was to command the spacecraft to the alternate redundant exciter and hope that its performance would not degrade. Since there was a probability of degradation in the second exciter, it was decided to await a point later in the mission when the performance of the degrading exciter had reached a value limiting its usefulness.
- (2) Plots made over the first 2 to 3 weeks of flight indicated that the gas consumption rate was two to three times the rate expected from premission calculations. Continued consumption at such a high rate would have potentially severe consequences. An intensive investigation revealed a deficiency in the design of the spacecraft attitude control subsystem related to the power supply regulation for the Sun sensor network. The problem was caused by a design error in the voltage regulator circuit consisting of a zener diode and a series resistor through which power was supplied to the Sun sensor network. The series resistor selected was too large and caused the zener diode to be starved and therefore to regulate improperly. Consequently, the voltage dip associated with the operation of the gas

jet solenoids was fed back through the power supply into the Sun sensor network and back into the amplifiers driving the solenoids as a spurious error signal, causing the gas jets to remain on longer than necessary. Although no corrective action was possible, increasing heliocentric distance would allow the Sun sensor elements to increase impedance and ultimately reach the point where the zener diode could begin to regulate. This point was reached in mid-August, and the problem did not recur thereafter.

- (3) In mid-September, the observation of asymmetrical limit cycles in roll indicated that a roll jet was sporadically failing to reseat properly and was leaking at an abnormal rate. The leaks became more frequent and of longer duration, causing concern regarding mission life because of excessive gas consumption. A plan was formulated to trigger a jet valve actuation by the transient in the attitude control subsystem from starting of the roll gyros by ground command. This method seated the gas valve properly and was employed in one form or another as needed throughout the balance of the mission.
- (4) An anomaly suddenly appeared in the 41X subcommutator deck of the flight telemetry subsystem, manifested as intermittent incorrect values appearing on all measurements on this deck except one. It was concluded that the probable cause for the anomaly was a loose metallic particle floating about in a transistor can that intermittently shorted out an element in the subcommutation circuitry. No corrective action was possible, but the problem was not regarded as serious since most of the measurements on this deck were not critical and extrapolations could be made from data already available from the earlier part of the mission. The problem persisted from early July through early August and then vanished.

3. Cruise functions. Much time and effort during cruise phase was also dedicated to completing the development of mission software. Problems encountered in the IBM 360/75 development included severe telemetry backlogging caused by interactions between real-time telemetry processors and nonreal-time programs and processor delays caused by line printer failures.

Problems also occurred with the Deep Space Network (DSN) command system. A number of design changes were required to isolate and correct these problems, which

were generally associated with the telemetry and command processor (TCP) located at the deep space stations (DSSs).

During cruise, certain housekeeping functions were performed by the CC&S, including periodic updating of the cone angle of the Canopus tracker, and transferring from the low- to the high-gain antenna. The decision was made to change from low to high power on the traveling wave tube (TWT) in spite of the continuing exciter anomaly aboard the spacecraft. The time of the switch was decided by the Chief of Mission Operations (CMO) and performed by ground command.

4. Calibrations. A series of calibration exercises was performed during cruise phase, prior to initiating formal science activity, consisting of the calibration of the scan platform position in the absence of Earth's gravity and the geometric and photometric calibration of the TV subsystem. The series was preceded on September 27 by a playback of data prerecorded on the spacecraft tape recorder, and science and scan subsystem turn-on on September 30 for the first time since launch.

The initial calibration exercise on October 1 was a gross calibration of the scan platform and an initial geometric calibration of the TV B-camera. A second fine calibration of the scan platform was performed on October 7, involving television pictures of the 30 selected stars, covering the full range of motion of the scan platform in both cone and clock angles.

A third calibration exercise, TV photometric calibration using Saturn, was scheduled for November 2, 1971; however, approximately 12 h prior to that time, Mariner 9 signals suddenly disappeared. At this time, DSS-62 was tracking and was able to maintain intermittent receiver lock.* Emergency action was initiated. It was assumed that Mariner 9 had lost lock on the star Canopus, as had previous Mariners. When this occurs, the spacecraft performs a roll search, and the high-gain antenna is no longer pointed at Earth. At the time Canopus lock was lost, the science instruments were on in a warm-up mode in preparation for the upcoming photometric calibration. The spacecraft was commanded to the low-gain antenna, with engineering-only mode at 8½ bits/s. DSS-62 was then able to maintain receiver lock. The spacecraft was commanded

*Deep Space Stations mentioned in this section are: DSS-12 (Echo), Goldstone, California; DSS-14 (Mars), Goldstone, California; DSS-41 (Woomera), Woomera, Australia; DSS-42 (Weemala), Tidbinbilla Complex, Canberra, Australia; DSS-62 (Cebreros), Madrid Complex, Cebreros, Spain.

to perform a roll search, Canopus lock was achieved, and the TV photometric calibration mode was reestablished. Since the scientific instruments had been left on, the photometric calibration proceeded on schedule. The performance characteristics as a function of the position of Saturn in the field of view of the cameras were measured to obtain information regarding vidicon shading effects.

An additional calibration exercise was performed the same day to measure the galactic ultraviolet background radiation. The final calibration exercises were performed using Mars as a photometric target on November 8-9, 1971, to obtain additional information regarding the TV subsystem spectral response and light transfer function, and to provide some data on the response of the TV subsystem to Mars observations.

B. Preorbital Science

The preorbital science (POS) activities were preceded by a major CC&S update which cleared out of the spacecraft memory the programs required for the Mars TV calibrations and substituted the program needed for preorbital science. POS was then conducted as scheduled, beginning approximately 3 days prior to orbit insertion and ending at Mars orbit insertion minus 8 h.

1. POS 1. The preorbital science objectives were to obtain TV images of Mars during the approach phase and periodically photograph the planet as it rotated in the field of view of the spacecraft cameras. The photographs obtained, with suitable scaling, could be mosaiced to provide global maps of Mars. The POS 1 sequence was started 3 days prior to insertion of the spacecraft into Martian orbit, and a full tape load of approximately 30 images was obtained. The first sequence consisted of 25 pictures taken at approximately 61-min intervals with the high-resolution, narrow-angle B-camera to provide global coverage of all longitudes. Consecutive pictures differed by approximately 15 deg in central meridian longitude. The final pictures obtained in this sequence almost duplicated the first ones, except that they were separated by more than 24 h and the resolution was increased by 50%. Five pictures of the satellite Deimos were also taken to determine its orbit parameters.

2. POS 2. The POS 2 sequence consisted of 24 images of Mars taken at the same central meridian longitude as POS 1, with seven frames available for Deimos photography. The objectives were the same as in POS 1, but the resolution was superior.

3. POS 3. The POS 3 sequence took place the day prior to orbit insertion. Groups of narrow-angle pictures (B-frames) were taken of the planet, separated by about 2 h. This separation in time produced approximately a 30-deg rotation of the planet between groups. The platform was slewed between pictures in each group to provide a mosaic of all, or significant parts, of the planet. A total of 23 B-frames were devoted to this operation. A total of five B-frames were used to photograph the satellite Deimos, and three pictures were taken of the satellite Phobos. The final group of six B-pictures was interspersed with five A-camera frames, which were taken through the red, green, blue, and violet filters with one polarization filter added. POS 3 was designed so that it would give the highest-resolution pictures of the planet at the closest spacecraft approach to produce the highest-quality pictures of Mars ever obtained. An arrangement was made so that the pictures could be played back at the earliest opportunity, which occurred over DSS-62 on the morning of November 14, 1971. The pictures had to be played back at 2 kbits/s, the maximum data rate available at a 26-m-diameter station. The first photographs received were recorded at JPL, Pasadena, via DSS-62 and the associated communication network. The final frames, taken approximately 8 h prior to Mars orbit insertion (MOI), were subsequently replayed to a nationwide TV audience. The science payload was then turned off in preparation for the crucial MOI.

The analysis of the POS sequences showed that little information about Mars was obtained from the television pictures because of the raging dust storm. The three science (POS) sequences of pictures provided total global coverage of the dust-shrouded planet, but only five distinct features could be seen: the south polar cap and four dark spots. One of these was identified as Nix Olympica, and the other three were provisionally labeled North, Middle, and South Spots. The rest of Mars was veiled by heavy, but regionally variable, atmospheric dust. It was apparent that conditions on Mars were not as anticipated when the mission had been planned.

Useful information was obtained, however, by the spectral instruments, which were helpful in characterizing some of the properties of the dust in the Martian atmosphere. Pictures of the Martian satellites, Phobos and Deimos, which were obtained during POS sequences, provided new information about satellite orbits, shapes, sizes, albedos, and surface morphologies. The satellite observations were also used in the optical navigation test to demonstrate the feasibility of performing spacecraft navigation by utilizing on-board sensors. These data were

resolved in real time and compared favorably with the radio tracking data which had been accumulated since launch. It is anticipated that optical navigation will become more important in future planetary missions.

C. Second Trajectory Correction, Mars Orbit Insertion, and Orbit Trim 1 Maneuvers

The Mariner 9 mission plan specified a second trajectory correction maneuver between 10 and 30 days prior to arrival at Mars. Execution of the Mars orbit insertion maneuver was to be followed by at least one orbit trim maneuver nominally 3 days after orbit insertion, but potentially as early as 2 and as late as 8 days after insertion.

The second trajectory correction maneuver was to correct errors in miss distance and time of arrival induced by orbit determination uncertainties and spacecraft execution errors at the time of the first trajectory correction maneuver some 5 months earlier. The second maneuver would compensate for accumulated errors and set up optimal conditions for orbit insertion to produce as early as possible the ideal postinsertion orbital design values. In addition, the maneuver was to remove the first trajectory correction maneuver targeting bias, which was designed to place the spacecraft in an orbit with a periapsis altitude of 1350 km rather than the 1200-km altitude desired by the science community.

The orbital parameters principally affected by a second trajectory correction maneuver were expected to be the periapsis altitude and the orbital inclination. The orbital inclination was expected at that time to be 63.9 ± 2.7 deg, 3σ , rather than the design value of 65.0 ± 3 deg.

After weighing the mission value obtainable by correcting those parameters against the inherent risk attendant upon execution of a maneuver, the Project Manager elected to waive the requirement for the second trajectory correction maneuver, and the mission proceeded to a Mars orbit insertion maneuver on November 13, 1971 (November 14, GMT).

The Mars orbit insertion maneuver was designed to reduce the hyperbolic excess velocity and permit the spacecraft to be captured in an elliptical orbit about Mars, to increase the rotation angle, and to further reduce the orbital velocity so as to achieve a desired orbit. The design of the posttrim orbit called for an orbital period synchronous with Goldstone view periods for 90 days. The period of periapsis passage would occur between Goldstone zenith and 1 h past zenith each day. The initial periapsis

passage, closely coincident with time of arrival, was biased to occur approximately 2 h prior to Goldstone zenith on November 14, GMT, to maximize the probability of achieving the desired orbital period with a single trim maneuver. The orbit insertion maneuver was designed to impart a velocity increment of 1600 m/s, which would result in an orbit with an initial period of 12 h, 25 min, a periapsis altitude of 1350 km, an apsidal rotation angle of 140 deg, and an inclination of 64 deg. At the time the orbit insertion maneuver was designed, the orbit determination and maneuver execution uncertainties projected uncertainties in the orbit parameters corresponding to standard deviations of 20 s in orbit period, approximately 80 km in periapsis altitude, $\frac{1}{10}$ deg in apsidal rotation angle, and $\frac{1}{10}$ deg in inclination angle.

Continued tracking and orbit determination up to a few hours prior to orbit insertion showed significant changes in miss distance, which would affect the design orbit parameters unless compensated for by an adjustment in the orbit insertion maneuver. After weighing the alternative of carrying out the designed orbit insertion maneuver or altering the program for the maneuver, it was decided to do the former. The spacecraft was inserted successfully into orbit by a 15-min motor burn. The maneuver was carried out on schedule, with motor ignition occurring at 0:17:39 GMT on November 14, 1971. The resulting orbit had a period of 12 h, 34 min, 1 s, a periapsis altitude of 1398 km, an apsidal rotation angle of 139.7 deg, and an orbital inclination of 64.4 deg. The orbital period placed the spacecraft at the ideal time and place to execute an orbit trim maneuver near the fifth periapsis passage or after four complete revolutions about Mars.

Orbit trim maneuver (OTM) 1 was designed primarily to adjust the orbit period from the 12 h, 34 min obtained after orbit insertion down to the 11-h, 58-min, 48-s period needed to synchronize periapsis passages with Goldstone zenith. The OTM was accomplished as planned, with motor ignition occurring at 2:37:53 GMT on November 16, imparting a velocity increment of 15.25 m/s (see Table 8).

The period between orbit insertion and the first trim maneuver was used for planning and executing for several science-related activities. The latter consisted of the playback of the last of the preorbital science tape loads, the reloading of the CC&S for future science activities, the execution of an initial mapping sequence, and several calibration sequences regarded as precursors to the primary orbital science activity. OTM 1 was executed with near-perfect accuracy, but continued orbit determination

Table 8. Orbit maneuver results

Orbit parameters	MOI (as of 11/15/71)	OTM 1	OTM 2
Orbit period τ	12 h 34 min 01 s	11 h 58 min 14 s (mean)	11 h 59 min 28 s (mean)
Periapsis altitude h_p	1398 km (869 miles)	1387 km (861 miles)	1650 km (1025 miles)
Orbit inclination to Mars equator i	64.4 deg	64.4 deg ^a	64.4 deg

^aBy 12/29/71, the orbit had precessed so that the inclination was 64.8 deg.

indicated that the orbit period was varying with both long- and short-term components. It eventually developed that the orbit period varied harmonically in 20-day cycles but with a mean period of 11 h, 58 min, 14 s. The 34-s difference between the mean orbital period achieved and the design value of 11 h, 58 min, 48 s caused a gradual migration of the periapsis passage toward the beginning of the Goldstone view period. (This will be discussed further below.) The total variation in orbit period was eventually found to be about 78 s from maximum to minimum because of a surprisingly large triaxiality of the figure of Mars.

The initial orbits of Mariner 9 were preprogrammed to perform CC&S science sequences. Orbits 1, 2, and 3* were mapping sequences which allowed some adjustments to be made in the cone and clock angles of the scan platform. The sequences were interrupted by the first trim maneuver, which required the science to be off. Following the trim maneuver, which was performed during periapsis passage 4, a mapping sequence was commanded from the ground for periapsis 5, followed by a large CC&S update to load science sequences. Periapsis 6 was a mapping pass, and periapsis 7 consisted of a mapping swath and night-side spectra.

During this early phase of orbit operations, a problem occurred with the spacecraft performance. Upon exit from Earth occultation on November 17, 1971, during revolution 7, it was observed that the spacecraft receiver had suffered a degradation of performance as a result of the receiver phase-locked loop having shifted to a lower than predicted data number (DN) reading. Since the spacecraft was occulted when this anomaly occurred, it could

*The point of closest approach of the spacecraft to Mars during MOI was periapsis 0. After one complete orbit or revolution, the next closest approach was periapsis 1. (The terms orbit and revolution are synonymous.) Periapsis X marks the completion of orbit X. To convert an even-numbered orbit to PST date, divide the orbit number by 2 and count that many days from November 13, 1971. For even-numbered orbits, the GMT date is one day later than the PST date; GMT and PST dates are the same for odd-numbered orbits.

not be correlated in real time with any other event. Extensive testing was performed on Mariner 9 in an attempt to understand the phenomenon; in addition, tests were made on other spacecraft receivers on the proof test model (PTM) and in the receiver laboratory. The tests demonstrated that the spacecraft was still able to receive commands and that the transponder was processing information as required. The mission effect was that the radio frequency subsystem receiver best-lock frequency shifted approximately 10,000 Hz at S-band, the receiver tracking rate capability decreased, and the performance of the ranging channel was degraded. This anomaly was to remain with the spacecraft throughout its life.

A large update of ground commanded science sequences for mapping was performed at periapsis 8 and continued through periapsis 9, so that some science activity could begin on periapsis 10. In addition to the mapping photography, a phase function calibration was performed on the instruments during revolutions 6 and 7, and revolutions 8 through 22 were primary ground commanded mapping sequences.

D. Reconnaissance Missions

A mission profile of the standard mission as actually executed is shown in Fig. 16, illustrating the description of flight operations contained in the remainder of this section.

1. Recon 1. The standard mission mapping sequences were found to be ineffective because of the severe dust storm in progress. Dust obscuration varied widely from one region to another, but the mapping sequences could not be made sufficiently flexible to take advantage of regions that were relatively clear. Furthermore, periapsis was located close to the evening terminator, where the more diffuse illumination at the surface severely degrades surface contrast. It was necessary to direct the high-resolution photography to a few locations where it would be effective. Consequently, a new plan, Recon 1, was developed which emphasized planet-wide reconnaissance to detect clear spots or clearing trends in the dust storm.

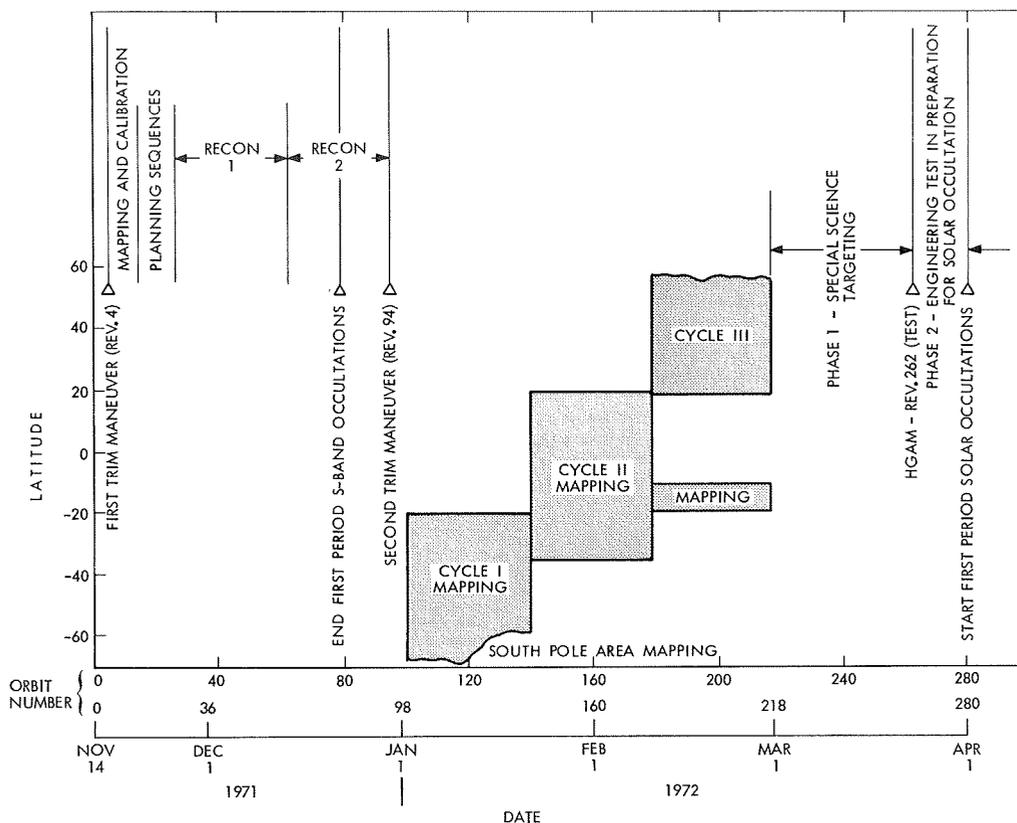


Fig. 16. Standard mission profile

Recon I was put into effect with a CC&S load on revolution 26 on November 26, 1971, PST (November 27, GMT), and was carried out with success. This mode included increased coverage of the south polar regions; global coverage each revolution, from which specific targets in relatively clear areas could be located; and two groups of four high-resolution frames each (tetrads), which could be placed on such targets.

The plan was designed so that a complete tape load would be taken on each revolution, zenith and nadir.* The first link consisted of a "setup slew" to position the platform, the second of two TV frames on the limb of the planet, and the third of four overlapping B-frames at a selected target. The target could be changed as long as it was within the viewing constraints of the spacecraft. The fourth link consisted of five global TV A-frames to mosaic

*Tape can be played back to Earth only during the zenith revolution, when Mars and the spacecraft are in view of the 64-m DSS-14 antenna at Goldstone; information taken on the nadir revolution is stored on the tape recorder for playback early in the next zenith revolution.

the lighted disk. The fifth link contained another set of four overlapping B-frames at a target selected by the TV team. The sixth link consisted of ultraviolet spectrometer (UVS) and infrared interferometer spectrometer (IRIS) pressure mapping for spectral data. The seventh and eighth links were either polar TV or variable surface features, depending on the day they were taken. The ninth was a previously planned UVS limb experiment, and the tenth was a slew to set up for mapping. The eleventh link consisted of a map link of two B/A pairs to fill out the tape recorder, and both the eleventh and twelfth links contained UVS real-time data for specific targets.

The following nadir revolution was quite similar to the zenith revolution, with the exception that no real-time spectral data could be obtained and the picture budget was adjusted accordingly. A constraint was imposed by the MOS that the CC&S loads to accommodate this plan must be minimized, one load running for several days to allow more detailed sequences to be performed downstream. The flexibility in the system was such that a single B-picture could be taken at the time requested by the experimenters or by direct commands.

Another spacecraft problem occurred on November 29, 1971, during revolution 31. A special sequence was established to photograph Phobos which required real-time commanding of the scan platform in cone angle. Because of a personnel error involving the DSN command system, the required command could not be transmitted. As a result, the scan platform was driven against the stops, and the cone actuator was slipped for approximately 1 h. Fortunately, there was no damage to the spacecraft. Modified procedures were implemented to prevent a recurrence of this problem.

On December 8, 1971, GMT (December 7, PST) on revolution 48, the radio frequency subsystem TWTA failed as evidenced by a greater than normal power demand by the subsystem and a degradation in RF power output. The corrective action consisted of switching to the redundant TWTA 1. During this same revolution, the CC&S did not issue the 21 scan steps which had been programmed, and quantitative commands from the ground were transmitted to position the scan platform correctly. There was no effect on the mission, and it is postulated that the TWTA failure on the same revolution could have "glitched" the memory, which caused the missing steps.

2. Recon 2. Evidence began to appear in early December that some of the dust suspended in the storm was settling and the surface obscuration was decreasing. To take advantage of this, the Recon 2 plan, initiated on revolution 64 (December 15, 1971, GMT), was developed to allow the experimenters more flexibility in utilization of the spacecraft, in particular, in targeting. The MOS guaranteed that a sequence could be changed if 7 days were allowed prior to the expected execution of that sequence. Also, small pointing-angle changes would be considered and executed as late as 3 days prior to the time of operations. Again, it was highly desirable to minimize the CC&S loads which would be required to run the Recon 2 program.

Although the data obtained during Recon 2 did not follow the patterns developed in premission planning, close-range data on the dynamic processes of Mars and dramatic television pictures and spectral data of the Martian moons, Phobos and Deimos, were obtained. In addition, the four dark spots which had been observed in the POS pictures were rephotographed at closer range. The spots strongly resembled volcanic calderas on Earth. The south polar region was also found to be relatively clear and susceptible to television and spectral observations through the dust haze because of the high contrast between the polar cap and the surrounding terrain.

An important added feature of Recon 2 was the satellite astronomy observations of Phobos and Deimos. The astronomy observations were constrained to use an existing link in the CC&S program. The slews for such satellite photography had to be CC&S-controlled; however, the picture-taking sequence of single B-frames or B/A pairs was performed by ground command. All satellite pictures taken in this manner automatically reduced the amount of mapping pictures that could be recorded. The tape recorder could record 32 pictures for this phase under optimum conditions; however, the maximum was not achievable on all revolutions because of the particular nature of the required sequences.

Spectral data from the dark side of the planet and ultraviolet limb crossing data were included in both Recon 1 and 2, with a constant effort to maximize the amount of recorded data. Because of the nature of the measurements, the dust storm during this period did not hinder in any way the Celestial Mechanics and S-Band Occultation experiments.

E. Orbit Trim Maneuver 2

In the latter part of December, it became apparent that the dust storm was clearing, as dramatic changes were observed in the lower regions of the southern hemisphere. With less than 2 months remaining of the original standard mission, a strategy was developed to fully utilize the remaining useful lifetime of the spacecraft and initiate the mapping mission as soon as possible. This required a second orbit trim maneuver to be performed on December 30, 1971, to increase the period of the orbit by 78 s so as to assure synchronization with the DSS-14 station view period at Goldstone (see Fig. 17). Also, the altitude of the orbit at periapsis was changed from 1387 to 1650 km to allow for contiguous TV mapping pictures of 70% of the planet's surface during the remaining time of high-rate telemetry.

F. Mapping Cycles 1, 2, and 3

After completion of orbit trim maneuver 2 and verification that the spacecraft was performing satisfactorily, the systematic mapping of the planet Mars was initiated. Because of the orbit period and geometry of Mars, the spacecraft took 39 revolutions (or slightly less than 20 days) to complete one longitude band of the planet.

The mapping swath for map 1, consisting of 32 pictures per revolution, covered Mars from 65°S to 20°S latitude. This plan was implemented on revolution 100, which began on January 2, 1972. The map 1 cycle continued

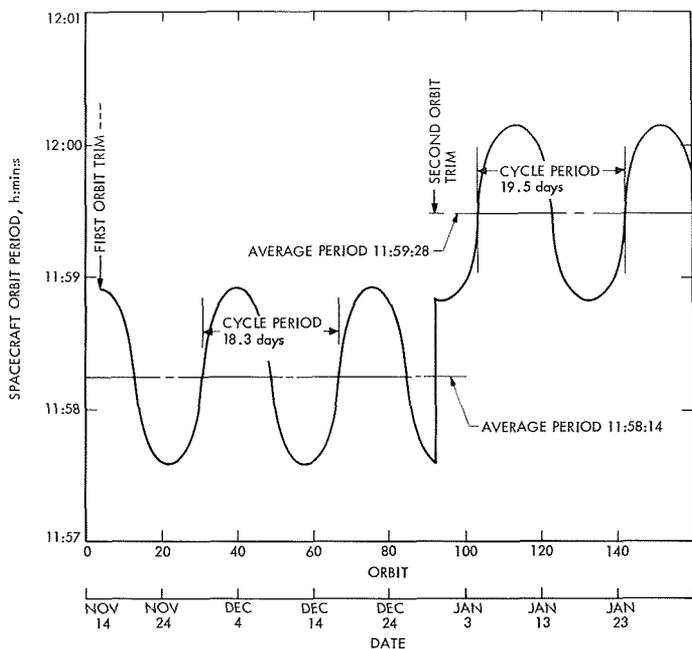


Fig. 17. Orbit period variation

through 39 orbits (revolution 138), yielding high-quality data. Because of the rise in the periapsis altitude, "gores" were not encountered until about 30°S latitude, and excellent mapping of the planet resulted.

On January 11, 1972 (PST), on revolution 118, a TV A filter wheel anomaly occurred when the filter position readout from the Data Automation Subsystem (DAS) indicated that the filter could not step on command and that its position was fixed. On January 19, analysis of the TV A filter wheel anomaly indicated that the wheel was stuck, probably in position 5, which contains polarizing filter P2. To minimize the impact of the frozen filter wheel, pentad and tetrad picture groups in revolutions 130 through 138 were revised to substitute three B-frames for A-frames previously assigned for recording the same areas with different filters. The mission effect was that only the 60-deg polarizer filter could now be used, but the results continued to be satisfactory.

The map 1 cycle sequence was conducted under the following mission guidelines:

- (1) 32 pictures per revolution were assumed for the tape recorder.
- (2) The basic timing and structure of individual links and overall sequences remained constant from revolution to revolution.

- (3) The pointing of certain links was optimized periodically at nadir (N) and zenith (Z). Links considered for such optimization were:

- (a) Global TV (N and Z).
- (b) UVS limb scans (Z).
- (c) UVS/infrared radiometer (IRR)/IRIS morning spectral mapping (Z).
- (d) IRR morning terminator scans (N).
- (e) UVS/IRR/IRIS evening spectral mapping (N and Z).
- (f) TV mapping (N and Z).

- (4) Links considered retargetable on a daily basis were:

- (a) Pentad (Z) (five pictures).
- (b) Tetrads (N and Z) (four pictures).
- (c) Dyads (N) (two pictures).
- (d) UVS targets.
- (e) Single B-frame.

- (5) Satellite astronomy was carried out by using existing targetable links, where possible, without changing the timing and structure of the link, or by ground commanding the shuttering of single B-frames or single B/A pairs. All slews for such satellite photography were CC&S-controlled. Satellite frames automatically reduced the northern hemisphere reconnaissance budget by an amount equal to the number of satellite frames in a revolution.
- (6) Planning for a two-revolution sequence was completed 7 days prior to the execution of the sequence; however, changes were considered up to 3 days prior to execution.

The map 2 cycle was designed to cover Mars from 30°S latitude to 20°N latitude. This cycle started on revolution 139 (January 22, 1972) and continued through revolution 177. Because some gores existed in map 1 between 30°S and 20°S, map 2 started at 30°S. The map 2 cycle sequence was conducted as follows:

- (1) 32 pictures per revolution were assumed for the tape recorder, with 8-kbit/s playback to supplement 16-kbit/s playback of both revolutions. Playback ended at 60 min after periapsis (P + 60 m).
- (2) The basic timing and structure of individual links and overall sequences remained constant from revolution to revolution (at least until revolution 142),

except for slews identified as floating slews in the detailed orbital sequence plan.

- (3) Certain links were considered for periodic pointing optimization:
 - (a) UVS limb scans (Z).
 - (b) UVS/IRR/IRIS morning spectral mapping (Z).
 - (c) IRR morning terminator scans (N).
 - (d) UVS/IRR/IRIS evening spectral mapping (N and Z).
 - (e) TV mapping (N and Z).
 - (f) Geodesy (N and Z).
- (4) Links that were considered retargetable on a daily basis were:
 - (a) Single B-frames.
 - (b) Triads (N and Z) (three pictures).
 - (c) UVS targets.
- (5) Satellite astronomy was carried out by using existing targetable links wherever possible, without changing the timing and structure of the link, or by ground commanding the shuttering of single B-frames or single B/A pairs. All slews for such satellite photography were CC&S controlled. Satellite frames automatically reduced the northern hemisphere reconnaissance budget by an amount equal to the number of satellite frames in a revolution.
- (6) Targets for single B-frames were chosen periodically to optimize a UVS limb scan on zenith revolutions.
- (7) Targeting for single B-frames 2 and 3 was chosen in conjunction with ultraviolet pressure mapping (UVPM) scans on the zenith revolution and IRR scans on the nadir passes.
- (8) Early tape recorder start capability was exercised on the nadir pass after the map 2 sequence.
- (9) Late slew (B-frame shutter + 48 s) capability was exercised only on single B-frames 1 on nadir and zenith passes.
- (10) Planning for a two-revolution sequence was completed in 7 days prior to the execution of the sequence; however, changes were considered up to 3 days prior to execution.

The map 3 cycle was designed to complete any areas not recorded by map 2 in the 20°S to 10°S latitude band

and to cover Mars from 20°N to between 45 and 60°N latitude. The map 3 cycle started on revolution 178 (February 10, 1972, PST) and continued through revolution 216. The sequence was conducted as follows:

- (1) A variable picture budget was assumed for this plan because of the lowering telecommunications margins that occurred throughout this cycle. The cycle began with over 30 pictures per revolution and ended with about 13 to 14. Two assumptions were made to account for the diminishing picture return. The plan first allowed for one major CC&S update to occur some time during the cycle to remove selected frames. Secondly, it was assumed that adjustment of the time of playback and position of the recorder for the start of playback could be accomplished on a daily basis to bias those pictures which were to be played back. The plan also assumed that playbacks would end at the time the planet came into view.
- (2) The basic timing and structure of the individual links and overall sequences remained constant from revolution to revolution before and after the one major CC&S update.
- (3) The pointing of the TV mapping link was optimized periodically.
- (4) Links considered retargetable on a daily basis were:
 - (a) Tetrads and dyads (N and Z).
 - (b) The last picture (Z).
 - (c) UVS limb scans (Z).
 - (d) UVS/IRR/IRIS spectral scans (N and Z).
 - (e) UVS Lyman-Alpha targets.
- (5) Satellite astronomy or other target photography was carried out by using existing targetable links wherever possible, without changing the timing and structure of the link, or by ground commanding the shuttering of single B-frames or single B/A pairs. All slews for such satellite and additional target photography were CC&S controlled. These frames automatically reduced the northern hemisphere reconnaissance budget by an amount equal to the number of such frames in a revolution.
- (6) Early tape recorder start capability for A-frames existed for the entire nadir and zenith revolution sequences; however, this capability was exercised at the beginning of the cycle only on the nadir pass.

- (7) Although the plan did not specifically include a floating dyad, this link was desirable for the last part of map 3. A floating dyad—two B-frames on a single target—replaced dyad 1 and tetrad 1 on the zenith pass and dyad 1 and dyad 2 on the nadir pass. It was assumed that this floating dyad would be fixed in either one of two possible times on a daily basis.
- (8) Planning for a two-revolution sequence was completed 7 days prior to the execution of the sequence by the spacecraft; however, changes were considered up to 3 days prior to execution.

With the completion of maps 1, 2, and 3, over 70% of the planet's surface had been mapped with wide-angle TV-camera pictures taken when the spacecraft was near periapsis. Thus, in spite of the 45-day delay caused by the global dust storm, all basic objectives of the standard mission, including the mapping objective, had been accomplished by March 1, 1972.

G. Termination of Standard Mission

The activities of Mariner 9 from March 1, 1972, to the start of solar occultation on April 2, were devoted to special science targeting, understanding a CC&S anomaly, and preparing the spacecraft for the upcoming period of solar occultations. Phase 1, special science targeting, was initiated to record selected targets, mainly with narrow-angle (B-camera) pictures. The number of pictures that could be recorded daily became less because of the increasing distance of the spacecraft from Earth; therefore, the picture count varied daily, as did the rate at which the pictures were played back. Although these variations caused mission planning to be more complicated, the planning continued on schedule.

A unique scientific opportunity presented itself when the moon Phobos was eclipsed by Mars. To take advantage of this event, the scan platform was pointed so that it would track Phobos into the Mars shadow. The IRR data were of great value in understanding the structure of Phobos. Performance of this unprecedented experiment in space was made possible by the flexibility of the Mariner 9 spacecraft and the adaptive mode design of the Mission Operations System.

Also during this phase, engineering tests were scheduled to assess the performance of the spacecraft. A solar-array test was performed on February 29, 1972. The spacecraft was operating at 451 W, which showed that the solar panels had not suffered degradation. It was also

concluded from the tests that battery sharing would not be necessary during high-gain antenna (HGA) maneuvers to return science data late in Phase 1. An additional test was performed for approximately a 24-h period on March 5 to determine the gyro drift in the three spacecraft axes. The results of this test showed that the spacecraft was capable of performing HGA maneuvers for an extended period of time. The test results were used to bias the turns during the HGA maneuvers to optimize pointing.

In conjunction with the gyro drift test, a photometric calibration of TV cameras was made during revolution 225 (March 5, 1973). This calibration consisted of recording seven B/A pairs with varying exposures while the cameras were aimed at a specific spot on the north pole.

On March 6, the last of the 8-kbit/s data were received without maneuvering. Thereafter, all pictures had to be played back at a rate of 4 kbits/s or less without a HGA maneuver. An illustration of how rapidly the data rate was falling off is the fact that it was necessary to switch to 2 kbits/s on March 7 to obtain IRIS data.

As of March 8, the entire surface of Mars had been mapped except for the 15% still obscured beneath the north polar hood. The 26-m DSS-12 communications support for Mariner 9 ended on February 29, and DSS-41/42 support for Mariner 9 was discontinued on March 15. The use of the 26-m stations was discontinued because they could no longer track the spacecraft. On March 13, the 50-bit/s science data threshold was reached at the 26-m stations, and thereafter, 50-bit science data could only be received when the 64-m DSS-14 was tracking. This was the first time in the mission that Mariner 9 did not have 24-h/day tracking coverage.

It was planned to perform five HGA maneuvers in Phase 1 before starting the engineering test prior to the initiation of solar occultation (Phase 2). The objective of the maneuvers was to provide approximately 12 h of science playback. However, Mariner 9 began to react in a nonstandard manner. On March 9, the DC-52 ground command produced an unexpected result during revolution 233. The computer flag 7/flag 4 routine reacted spuriously, and the A-frame picture was not obtained. The DC-52 commands specified for revolution 234 caused unpredictable selections of TV A- and B-camera combinations, and a moratorium was placed on DC-52s.

On March 14, during an update to program the CC&S to perform the first HGA maneuver, an error occurred in

the CC&S. For unknown reasons, the CC&S failed to checksum (a process by which the CC&S certifies that its program is correct). An extensive investigation was immediately started to determine the cause of the problem before the HGA maneuver was performed.

Readouts were obtained and tests were made of the DC-84 checksum word routine. Contingency plans for straight TV mapping sequences were placed in effect. On March 16, a DC-84 checksum command triggered an internal CC&S readout which placed the readout mode in an internal loop. After investigation of all words, a commonality with a previous DC-52 ground command trouble was noted.

The five HGA maneuvers were postponed. All science instruments were turned off to prevent the occurrence of any unexpected results which could cause damage to the instruments. Extended support from DSS-42 was obtained in an attempt to fill the data gap. Special tests of computer flag settings were performed; in addition, the CC&S was loaded with an abbreviated solar occultation sequence, and four checksums were processed normally. Observations were taken of the noise environment with science on and off.

Confidence was established that the spacecraft was usable for Phase 2—preparation for solar occultations. The Spacecraft Team delivered an update to accomplish science recording on revolutions 260 and 261, and a good checksum was received. Playback of data at 4.05 and 8.1 kbits/s was scheduled concurrently with a supporting HGA maneuver to confirm the spacecraft science-gathering capabilities under CC&S control. Both objectives were accomplished on March 23. The only departure from normal occurred when the command detector lost lock briefly during commanding, causing the loss of three pictures at the beginning of playback.

Several engineering tests were conducted to determine spacecraft subsystem status prior to solar occultation on April 2, 1972. The successful performance of these tests were concluded the Mariner 9 standard mission.

IV. Science Data Handling Operations

A. Introduction

Mariner 9 science data return and processing needs were of a magnitude not approached by any previous JPL mission. Processing was required for analyses related to mission and sequence design, for recommendations to the Viking Project, for science analysis, and for reporting.

The significant accomplishments included:

- (1) Support for science analysis that affected and directed mission and sequence design.
- (2) Support for early reporting of significant science results, such as imagery of the moons of Mars and ultraviolet spectrometer (UVS) topographic profiles.
- (3) Development of extensive cataloguing and searching capability.
- (4) Production of TV reduced data record (TV-RDR) and rectified and scaled data (R&S) processing.
- (5) Production of the supplementary experiment data record (SEDR), the master data record (MDR), and experiment data record (EDR) on a time scale compatible with the analysis schedule.
- (6) Quality evaluation of the data products and feedbacks compatible with the production schedules.

The following insights were gained and problems recognized:

- (1) Processing can be accomplished in a cost-effective manner, but the resources required are nevertheless substantial.
- (2) Planning and preparation for science data processing must be parallel with other project activities.
- (3) The user scientists must involve themselves in the planning and preparation to become aware of possible data products, and to ensure their availability prior to actual need.
- (4) A training scheme should be devised to replace the training accomplished by default on MM'71 during the first period of real operation.
- (5) A flexible and user-responsive processing and information transfer network is required.
- (6) The record keeping required to keep track of the processing needs greater emphasis, including status documentation of production processing available directly in machine-readable form.

The following sections (B through H) will discuss requirements, accomplishments, problems, and lessons learned in science data handling.

B. Science Evaluation Team

The Science Evaluation Team (SET), also called the Science Experiment Team, was established to assist the

NASA-appointed experiment teams with their data analysis and to promote a high level of interaction among the teams. The SET was primarily concerned with the analysis and dissemination of results and was intended to play a distinctly separate roll from the Science Recommendation Team (SRT) and the Mission Design Team (MDT). Thus, the SET function was purely scientific and relatively isolated from the day-to-day engineering details of the mission.

The participants on the Science Evaluation Team were

- (1) Team Chief.
- (2) Principal Investigators and Co-investigators.
- (3) Experiment Representatives.
- (4) Viking Data Analysis Team representative.

1. Experiment interaction. The SET promoted interaction among experiment teams in several ways:

- (1) By identifying those instances in which data from one experiment were useful to another experiment team.
- (2) By holding regular weekly seminars at which new results were presented and discussed.
- (3) By establishing and running working groups for specific interdisciplinary problems.

Data from one experiment that were useful to another team were identified in a document prepared prior to launch known as the *Data Interrelationship Matrix**. This document helped to clarify understandings, identify the need for certain data products, and in some instances, to encourage new uses of the data.

Prior to orbit operations, the Project Scientist chaired a quarterly SET meeting in which mission design decisions were confirmed and project status and problems were discussed. The experiment representatives convened periodically on an informal basis with ground data handling and Image Processing Laboratory (IPL) members to discuss data handling design and implementation, operations planning, Science Team Analysis Facility (STAF) design, and data interrelations. However, SET functions and activities were essentially established after orbit insertion, when the investigators established residence at JPL. In weekly SET meetings, spokesmen from the various TV discipline groups and from the other teams

reported progress on data analysis and discussed the implications. Since attendees were committed to keep all new information in strict confidence, the experimenters felt free to talk about their ideas and theories at an early stage. Teams were not obliged to give reports if their progress did not warrant it.

At the end of the standard mission, working groups were established under the SET to focus attention on specific problems which required particular interdisciplinary attention. The working groups were

- (1) Physical Properties and Topography.
- (2) Atmospherics.
- (3) Volatiles.
- (4) Satellites.

Publications resulting from working group activities were subject to the approval of the Principal Investigators, who were at liberty to delay publication until after November 15, 1972, if they felt that earlier release would compromise the work of their own team. Similarly, they were at liberty to object if contributions to the document were not adequately recognized.

2. Videotaped reports. Once orbital operations began, the Mariner Mars 1971 Project reported to NASA each week on the progress of the mission. Because the science results formed the most important part of this report, the Science Evaluation Team assumed the responsibility of filming a weekly videotape. Reports by the Project Manager, Chief of Mission Operations, the SRT and MDT Chiefs were included in the videotape. Pictures, mosaics, charts, and graphs were also presented.

The videotape method of reporting was found to have distinct advantages over alternate forms of regular reporting and is recommended for future projects. It requires less preparation, and the contributors are heard verbatim, avoiding the risk of error which can occur if contributions are pre-edited and submitted as a written report. Furthermore, the tapes can be delivered in a more timely manner.

3. Public information. The SET performed a role in insuring that the Public Information Office and the public received a balanced and accurate picture of the significant results from the Mariner Mars 1971 mission.

The Mariner 9 display which was prepared for the COSPAR meeting in Madrid, Spain, in May 1972, contained material generated by the SET. This display was

*JPL internal document.

subsequently exhibited at a number of other locations inside the United States and in foreign countries.

4. Science Team Analysis Facility. The STAF was provided as office and working space for the SET and for the experiment teams. The experimenter working space consisted of a mosaicking room, three large rooms that were shared by the TV discipline groups, and office space for the TV team leaders.

The conference facilities proved to be an essential aspect of STAF. TV Team and Mission Design meetings were often impromptu and involved 15 to 20 people, so it was imperative that a suitable meeting place be constantly available. Larger meeting facilities were arranged when the SET meetings included a videotape report, since approximately 40 people attended the SET meetings and additional space was needed to accommodate the TV cameras and lights.

A library was provided for the experimenters in STAF that contained the 20×25 cm (8×10 in.) prints of each picture, 70-mm strip contact prints, and negatives. In addition, the latest catalogues of picture data, picture footprints, and coordinate overlays were available.

C. Infrared Radiometer Experiment Data Processing

Science data processing for the Infrared Radiometer (IRR) was carried out sequentially at three separate locations: the Jet Propulsion Laboratory, where the majority of the real-time or near-real-time processing took place; the California Institute of Technology, where the detailed decalibration, merging of data, and correction for instrumental effects were handled; and the University of California at Los Angeles, where detailed analysis of the data was aimed primarily at the determination of the thermal parameters of the Martian surface and their spatial and temporal variations. A summary of the IRR science data flow is presented in Fig. 18.

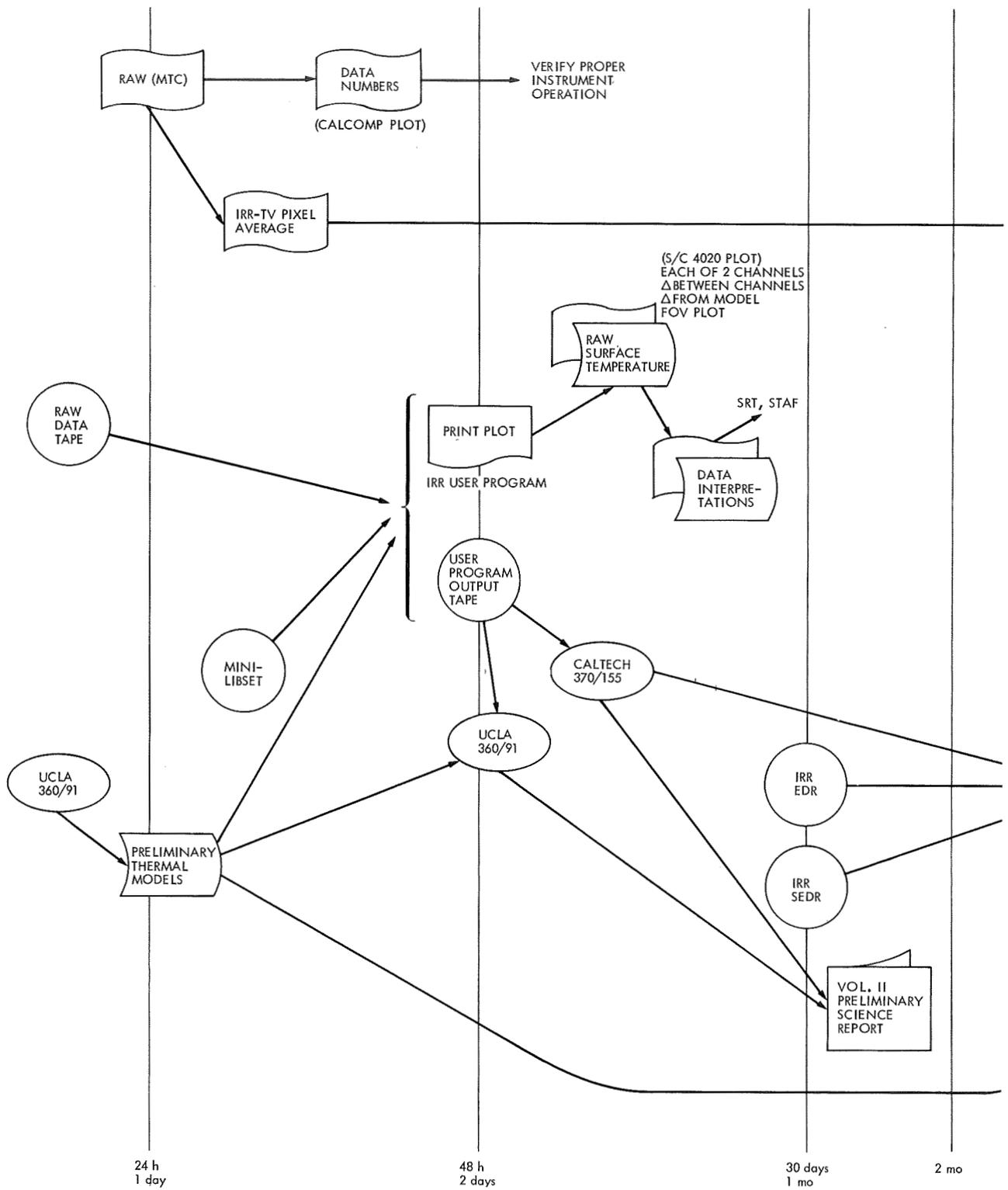
1. JPL IRR operations. The analysis of IRR data in terms of thermal parameters of the Martian surface was severely hampered during the early weeks of orbital operations because of several unforeseen problems. The planet-wide dust storm had a radical effect on the infrared brightness temperatures measured by the IRR. The most obvious result was a 50% reduction in the observed daily temperature variations compared to the predictions based on Mariner 6 and 7 IRR measurements. In addition, infrared atmospheric obscuration was present in amounts which varied with time and location. The dust storm

necessitated delaying the start of TV mapping of the planet, thus nullifying a major portion of preorbit data sequence planning. The subsequently planned sequences did not initially provide sufficient time-of-day coverage at any given latitude to permit an analysis of daily temperature variations. To further complicate the matter, the IRR analysis software, designed to provide "quick-look" temperature and position data, was inoperative during the first 6 weeks of orbital operations. The more detailed long-term analysis was also impossible because of the unavailability of EDR and SEDR tapes during the first months of orbital operations. Data analysis was thus reduced to laborious hand reductions, using raw data numbers and predicted planetary positions.

To overcome these difficulties, plans were made for more efficient IRR data acquisition, detailed sequence plans were reviewed, software problems were analyzed and corrected, and the scientific findings of the IRR and other science experiments were discussed.

The data products used in the analysis of IRR data were

- (1) Mission planning documents.
- (2) SCOUT computer runs and plots.
- (3) Orbital sequence plans.
- (4) SEQGEN outputs and sequence of events.
- (5) POGASIS predict packages.
- (6) Thermal model printout, plots, and IBM cards.
- (7) Digital TV displays.
- (8) Hardcopy (0420) from the mission and test computer (MTC) (printer 18).
- (9) Histograms (CTABS) of raw data.
- (10) Calcomp plots (CLOTS) of raw data.
- (11) MINILIBSET printout (TV B mark).
- (12) Data automation subsystem (DAS) time vs Earth-received time (ERT) and spacecraft GMT printout.
- (13) Spacecraft chronology.
- (14) Data outage summaries.
- (15) TV strip contact prints and selected 20×25 cm prints.
- (16) TV picture element average data.
- (17) IRR analysis program products.
- (18) IRR EDR tapes.



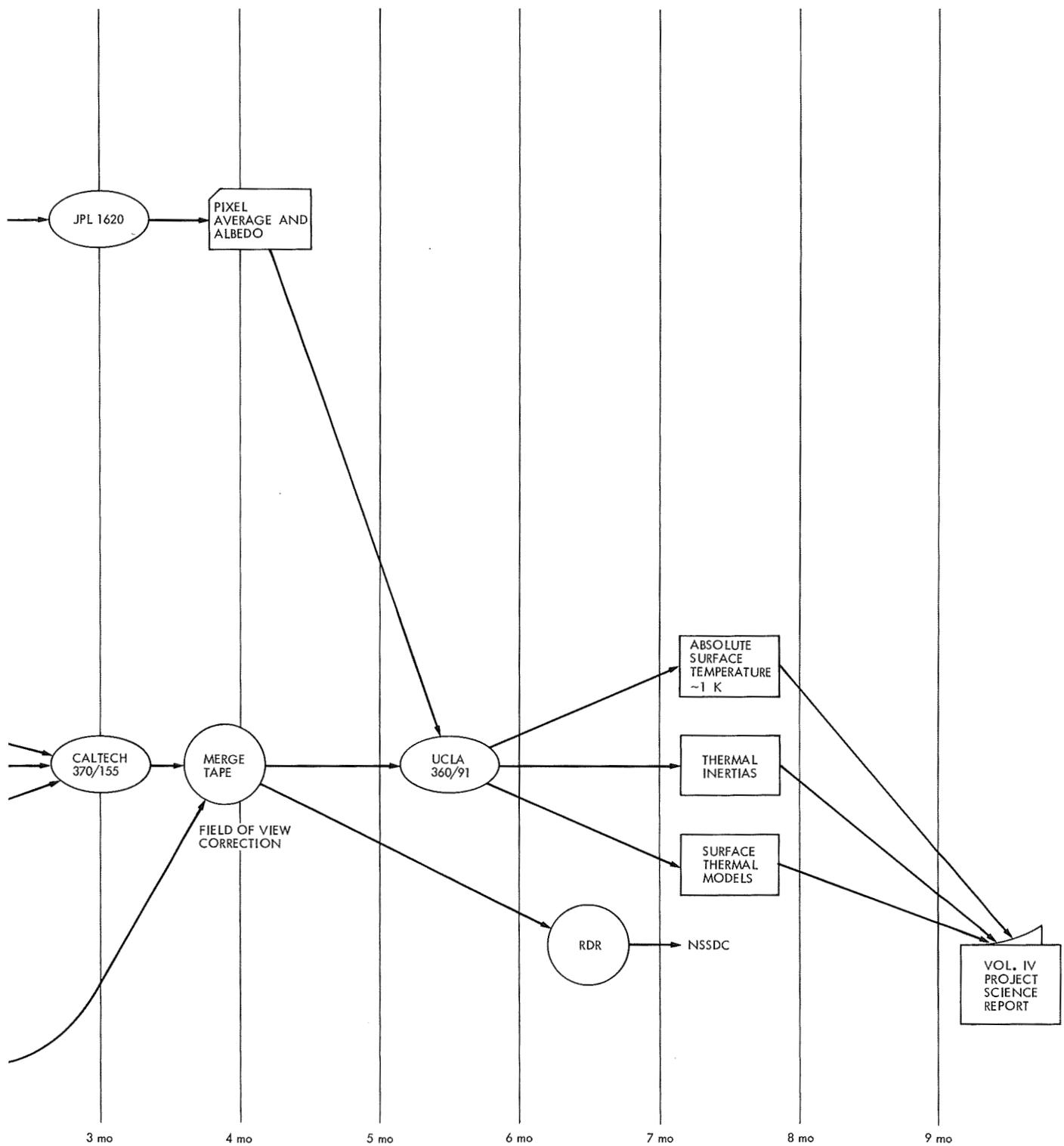


Fig. 18. IRR science data flow

- (19) IRR SEDR tapes and printouts.
- (20) TV picture catalog.
- (21) TV mosaics and maps.
- (22) Special MARK IV library searches.
- (23) Special products from UVS and infrared interferometer spectrometer (IRIS).
- (24) IRR data products from the California Institute of Technology (Caltech) and the University of California at Los Angeles (UCLA).

The first six items were available prior to actual acquisition of data from the spacecraft. The remainder were based on analysis of the data transmitted from the spacecraft via the DSN.

When the IRR analysis program became operational, it provided (within about 48 h after receipt of data) printouts of temperature data and the associated planetary positional information, magnetic tapes containing the same data, Stromberg-Carlson (SC4020) plots of Channel 1 and 2 brightness temperatures in Kelvins (Fig. 19), plots of the differences of these temperatures from temperatures predicted from a thermal model of Mars based on Mariner 6 and 7 measurements, and latitude/longitude plots of the IRR track across the Martian surface (Fig. 20). The latitude/longitude plots of the IRR track were later mosaicked by the Science Data Team (SDT) and dis-

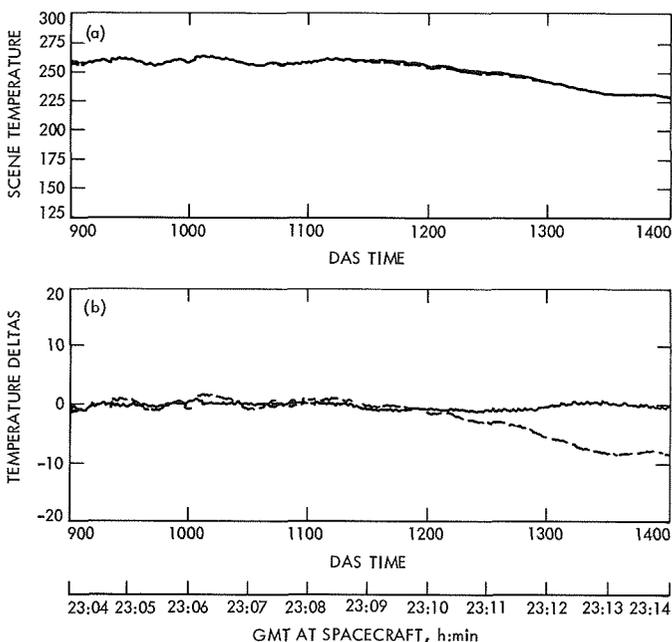


Fig. 19. Plots of brightness temperatures and temperature differences: (a) DAS time, (b) GMT at spacecraft

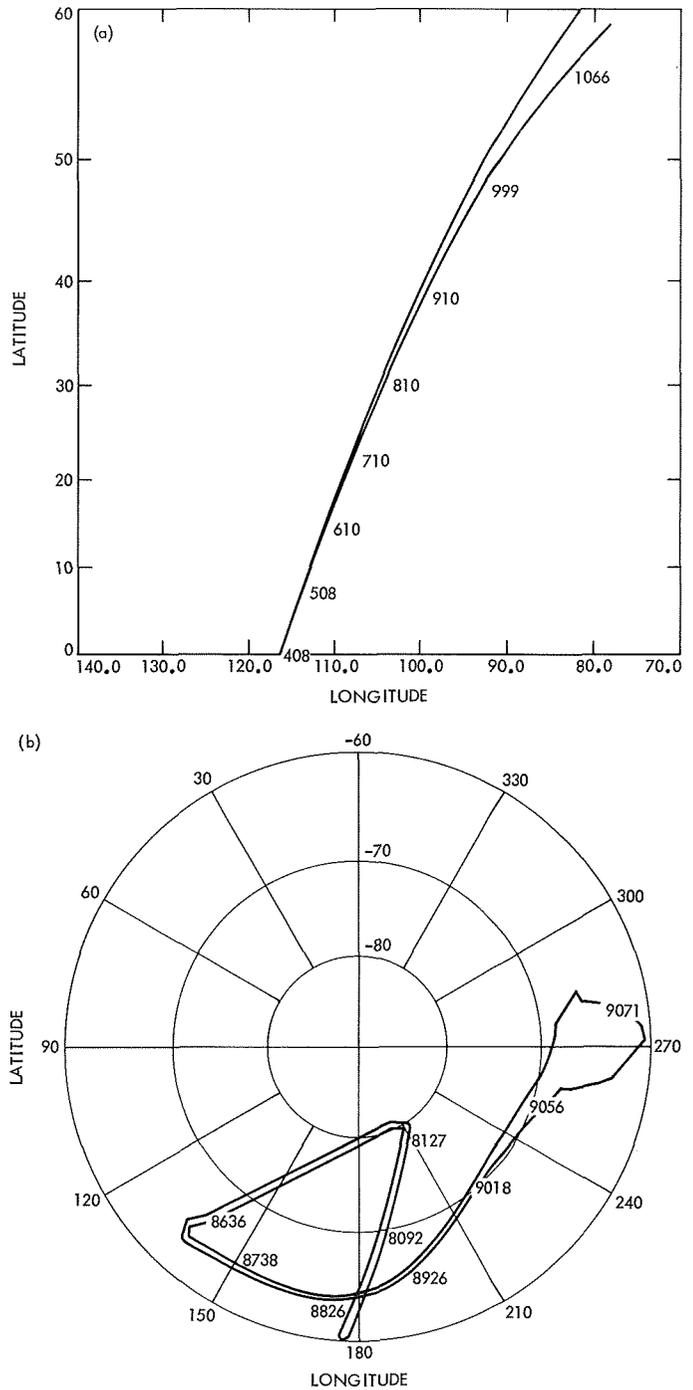


Fig. 20. Latitude/longitude plots of IRR track across the Mars surface: (a) Mercator projection, (b) Polar projection

tributed to the other science experimenters to facilitate intercomparison with visual features in the TV pictures of Mars.

Because of inaccuracies in the planetary surface positional data, direct and precise correlation of IRR thermal

data with TV images was possible only when both were obtained simultaneously. Information concerning the offset of the IRR line-of-sight with respect to both the wide-angle (TV A) and narrow-angle (TV B) cameras and the relative "shuttering" times of TV and IRR was available from prelaunch calibrations. Hand plots of IRR-derived surface temperatures could then be superimposed on a series of contiguous TV pictures, providing there was no intermediate slewing of the science scan platform. An example of the resultant plots is shown in Fig. 21. A computer program has since been developed to make these plots automatically.

MARK IV Science Library search routines developed at JPL provided a means of determining times during the mission when a particular area on Mars was viewed. Such information was used to construct diurnal temperature variation curves for selected areas (Fig. 22).

Additional functions performed at JPL include searches of daytime data for areas which appear anomalously warmer or colder than their surroundings, analysis of the relationship of surface temperatures to local topography, processing of a special TV picture element average to obtain rough albedo values for areas corresponding to the size of the IRR field of view, and coordination with other experiment teams and the Viking Data Analysis Team. A preliminary analysis of the variation of surface emissivity with surface viewing angle was also made.

2. Caltech IRR operations. Preflight calibration data were reduced at Caltech. Values obtained were used for the "quick-look" decalibration done in the IRR analysis program at JPL. In-flight calibrations provided a means of updating the preflight values and increasing the accuracy of the decalibration process. An IBM 370/155 computer system was used for this and all other computer processing done at Caltech. An additional, more comprehensive check of data completeness was done. Various methods were used to try to determine the accuracy of IRR supplementary experiment data record values, such as comparing the times of maximum signal from Phobos and Deimos to the computed SEDR positions for those times and comparing estimated Mars limb-crossing times with the SEDR limb-crossing times.

The magnetic tape output from the IRR analysis program (called "USER" tape) involved some special processing which salvaged some IRR data omitted by the IRR experiment data record. On the other hand, some of the data outages in the USER tape were corrected prior to production of the IRR EDR tape. The SEDR tape con-

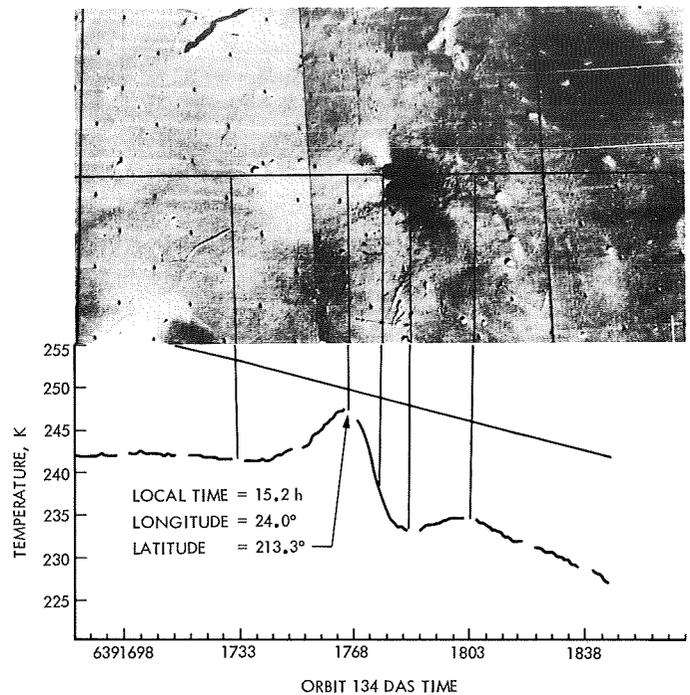


Fig. 21. Hand plot of IRR-derived surface temperatures superimposed on a series of contiguous TV pictures showing volcanic crater in Elysium

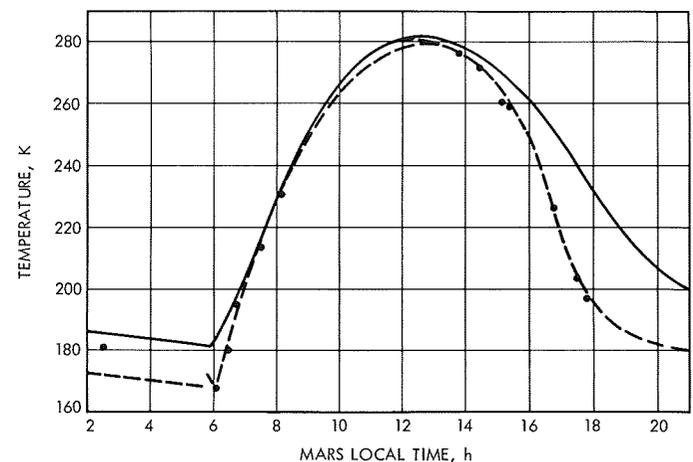


Fig. 22. Temperature variation curves (-9.5°S , 120.5°W)

tained more accurate positional data than did the USER tape. It was therefore advantageous to merge the three tapes into a single, more complete and accurate tape. An attempt was then made to correct all the data for the effects of the finite size and extended wings of the field of view (FOV), which proved to be much larger than anticipated from preflight data. The correction was negligible except for areas near the limb of the planet or near

sharp thermal boundaries (polar cap edges). When it was discovered, however, that SEDR values near the planetary limbs might be in error by amounts comparable to the size of the FOV, it was decided to discard all readings where FOV corrections were found to be large. Decalibration of the remaining data then proceeded, resulting in a tape with corrected brightness temperatures and associated planetary coordinates and other identifiers. It is from this latter tape that the RDR for the IRR is produced for transmittal to the National Space Science Data Center (NSSDC).

IRR measurements of the satellites Phobos and Deimos did not lend themselves well to computer reduction because the satellites never fill more than a small fraction of the IRR field of view. Hand reduction of these data was handled by Caltech.

3. UCLA IRR operations. UCLA was responsible for calculating and tabulating the thermal models used for comparison in the USER program analyses at JPL. These models still seem to be descriptive of an "average, clear Mars," and were used to provide temperature information to spacecraft thermal control personnel, Viking scientists, and to scientists from other Mariner 9 experiments. A major portion of the effort in correcting and improving USER program software also came from UCLA, in addition to other software used to depict IRR data and results.

Special attention was given to analysis of IRR polar cap data, particularly of the south polar cap. Analysis of the effects of the dust storm on IRR measurements also fell largely to UCLA. The most striking thermal anomalies were observed for times on Mars just prior to local sunrise. These were not associated with visual features on Mars and are perhaps another indication of large-scale differentiation of materials at the surface of the planet. Most of the above analyses were dependent on USER tape output.

The "merge tape" produced at Caltech was used by UCLA to determine the most reasonable values of thermal emissivity of the surface of Mars. Relative values of the emissivity for Channels 1 and 2 of the IRR were obtained directly from the data. Calibration data obtained by UCLA, using the flight spare IRR to observe simulated martian soils in a JPL thermal-vacuum chamber, were used to provide a best estimate of the absolute values of surface emissivity. IRIS data were also used for this purpose. Once the thermal emissivity is determined, brightness temperatures can be converted to kinetic (actual) surface temperatures.

The next step in the analysis of the data involved sorting the thermal data into small aerographic areas according to latitude and longitude on the surface of the planet. Thermal models were constructed to best fit the data in each of the areas, taking into account time of day, Martian season of the year, and possible effects of residual dust in the atmosphere. From these models, the thermal inertias of the various areas were determined. The thermal inertia of an area not only provides a measure of the diurnal and seasonal temperature variations but is indicative of the thermal conductivity of the surface material, thus giving an indication of approximate surface particle size.

D. Ultraviolet Spectrometer Experiment Data Processing

The real-time science data analysis for the Mariner 9 UVS took place in the Space Flight Operations Facility (SFOF) at JPL, and the Laboratory for Atmospheric and Space Physics (LASP) at the University of Colorado in Boulder, Colorado, was used for nonreal-time analysis by the Principal Investigator. The unified data flow plan, which was conceived prior to orbit insertion, is shown in Fig. 23. This plan was modified slightly during mission operations.

1. SFOF operations. Data transmitted from the 64-m-diameter antenna Goldstone tracking station to the SFOF were logged and decommutated by the mission and test computer system. The bit stream was converted from digital to analog and sent to the UVS cognizant engineer in the Spacecraft Team area, where a two-channel analog recorder portrayed the data in close-to-real time with respect to its receipt at the Goldstone antenna. Analysts, who were familiar with the operation of the instrument, could examine the spectra by eye, ascertain the status of the spectrometer, and verify that the operation was satisfactory. The engineering information available at the beginning of each spectral scan was also decommutated and its digital format tabulated or plotted on a TV monitor, where the instrument analysts could maintain an overview of spectrometer operations and recent history.

Another analog recorder operated in parallel in the science analysis area of the Science Recommendation Team so that scientists could examine the analog information for distinctive features and make note of the time of their receipt. These temporal notations were used to direct specific off-line analysis programs (in the near-real-time period of 4 to 24 h after receipt) for the examination of particular items of interest.

After formatting the real-time data records into a science quick-look tape, a UV science display program,

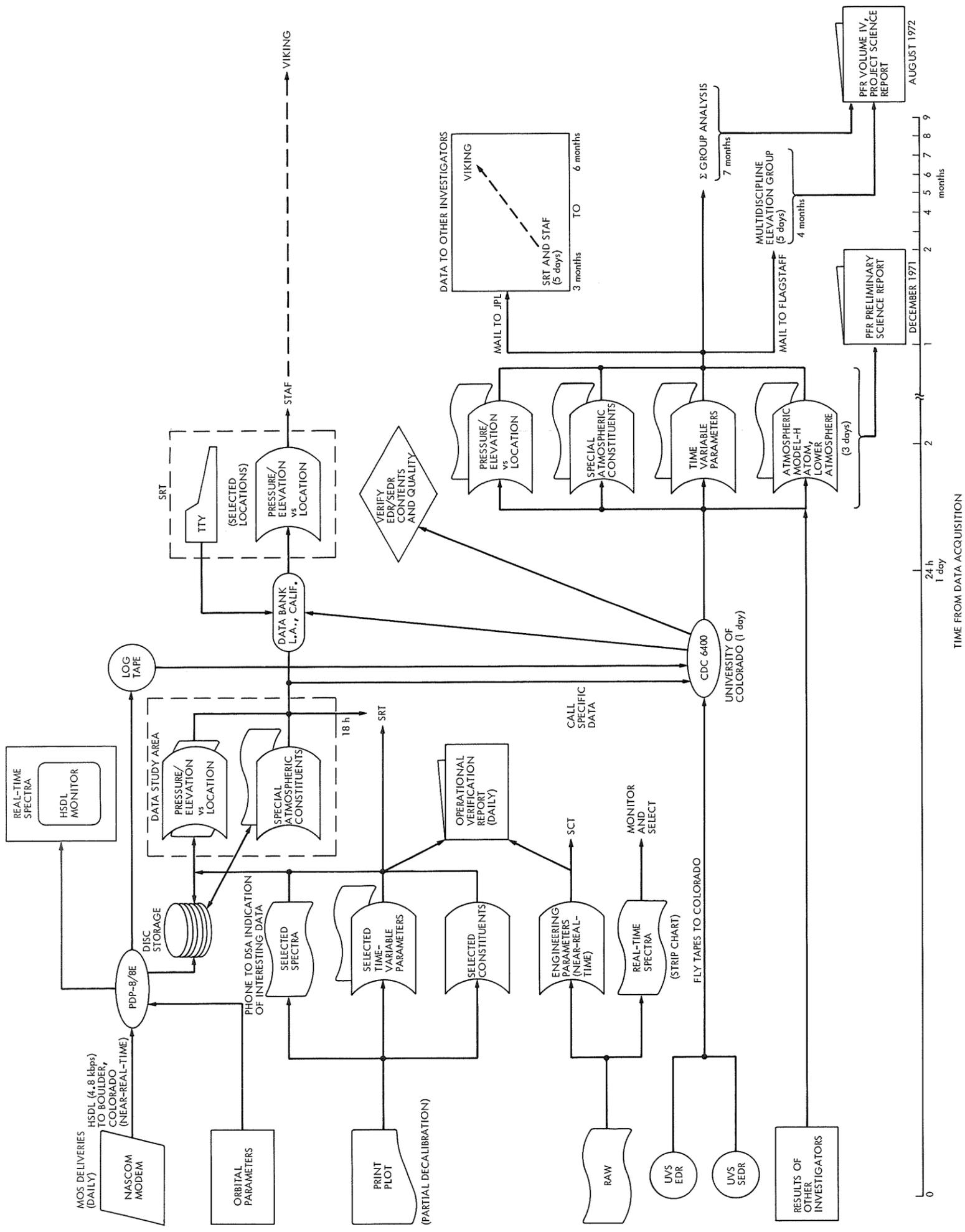
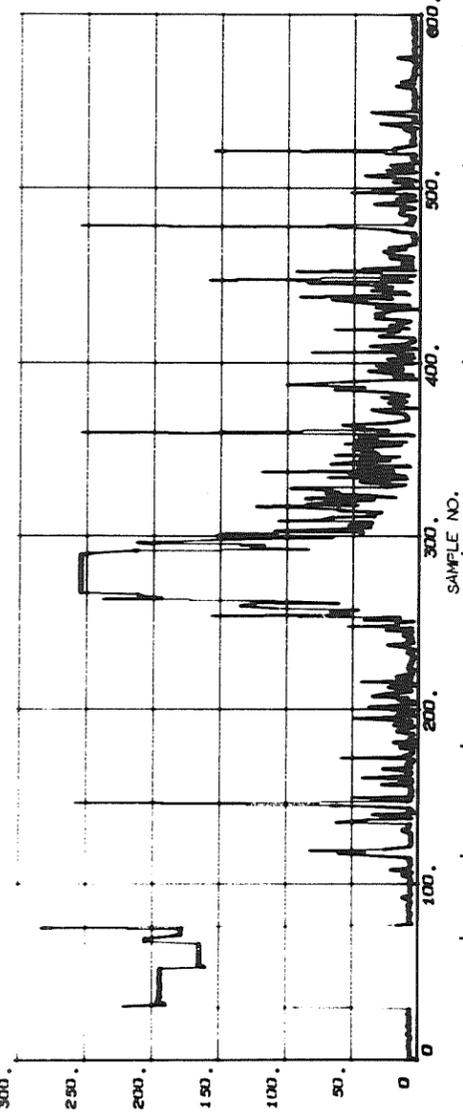


Fig. 23. UVS science data flow

MAR 1971 FLIK 152
 S/C ID 1
 DAS TIME 825 9576
 ER GHT 45 23 1 11
 SOURCE 0420
 EPHEM ID

G-CHANNEL SPECTRUM

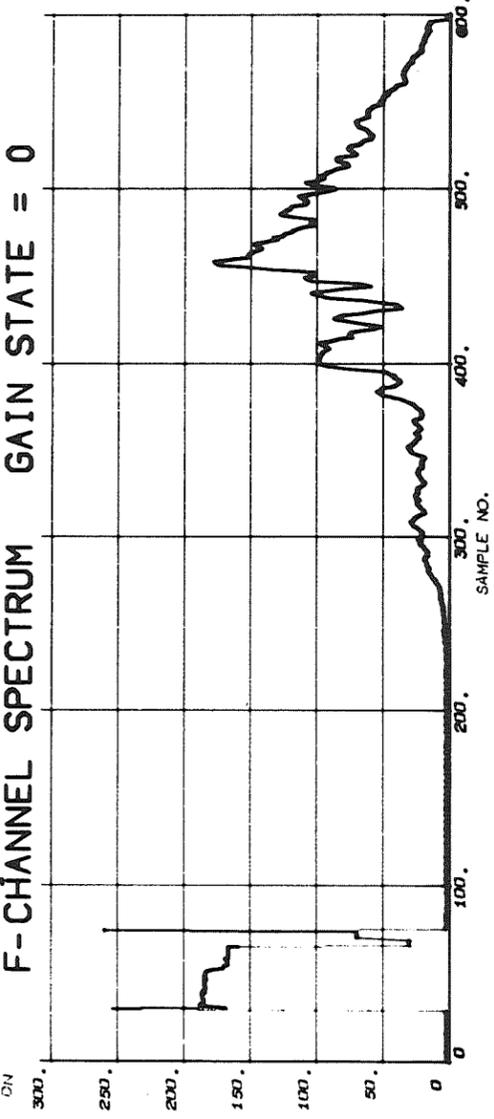


UVS 1
 ZERO CAL 7
 GAIN CAL 194
 TEMP-S/C 165
 +15 VOLT 178
 HI VOLT 182
 UVS 2
 ZERO CAL 3
 GAIN CAL 184
 GN-ST. (DN) 186.
 HI VOLT 70

NAVIGATION

MOTION F 0. 0
 LAT F1 -5.44
 LAT F5 -2.63
 LAT F9 -2.84
 LON F1 62.81
 LON F5 63.14
 LON F9 63.40
 SLRNG G5 5890. 0
 ALT OPAX 15.84
 SLIT ANG 18.79
 SLITSURF 157.59
 SLITATHF 52.33
 SLITATMG 124.58
 SLITBLUR 1.35
 DCLATION 55.55
 ASCNSION 314.61
 MAP QUAL -8.70
 SHAD LEN 0. 0
 SHAD HGT 0. 0
 UNDR LEN 0. 0

F-CHANNEL SPECTRUM GAIN STATE = 0



11770 1570 2000 2500 2800 3000 3300 3900
 WAVE LENGTH

Fig. 24. One 3-s frame from UV FLIK

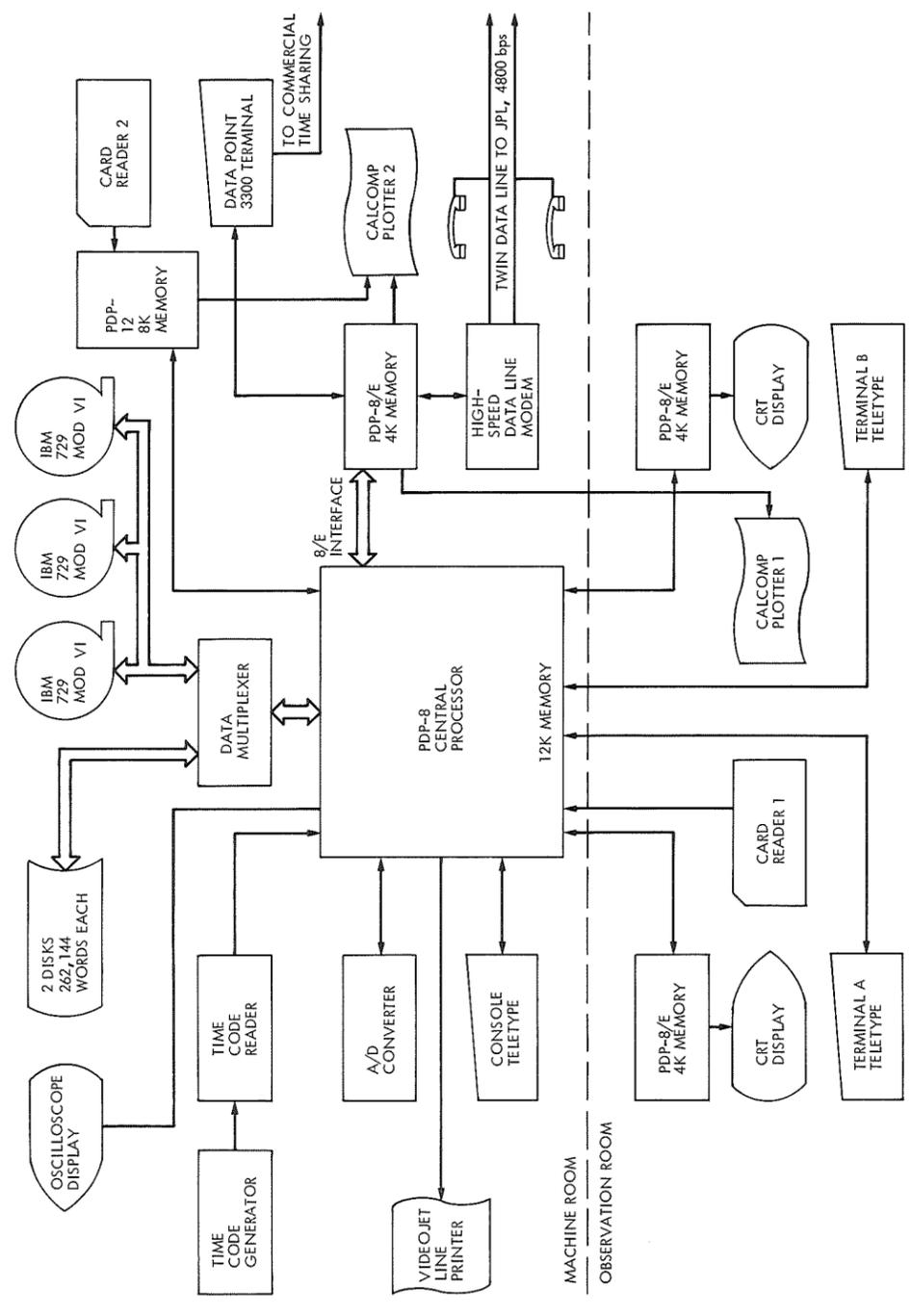


Fig. 25. LASP interactive data analysis system

called UV FLIK, accessed the quick-look tape, and produced a 35-mm frame-synchronized movie, where each frame displayed one spectrum of the F- and G-channels (Fig. 24). (The trace between the two spectral blocks shown in Fig. 24 is the F-channel data divided by the solar flux and is a measure of reflectivity vs wavelength.) This film, with its annotated engineering and measurement information for each 3-s frame, could be examined by use of a 35-mm movie projector or an automated film editor. This data product was available about 18 h after the Goldstone pass. Thus, the individual spectra could be quickly located and studied in detail, and the UV characterization of the planet could be observed as a movie, with the subtle temporal or spatial variations more perceptible to the eye than otherwise possible. This analysis product became a very effective tool for the analysis of variations with area and time, and in addition, condensed more than 300 km (about 1 million linear feet) of analog records into one cabinet of modest storage space.

Other programs which utilized the deductions from UV FLIK produced integrated wavelength band sums, averaged any number of spectra for improved signal-to-noise ratio, or plotted the intensity of a spectral feature vs planet location or time. The outputs of a number of these simple analysis programs were used to alert the Colorado UVS Team to items requiring special attention, or to assist other Mariner 9 scientists in interexperiment data correlation.

These same data were manipulated in a separate engineering analysis program to present strip plots of the variations of the instrument parameters as a function of time, and hence, as a function of position in orbit. For example, the instrument gain state changes, which were designed to occur with a variation in scene brightness, were easily noted in the plots. The constancy of the calibration and primary voltages, and any deleterious variations to which the instrument might have been subjected were also determined from the strip plots. These products permitted the engineering analyst to make detailed reports on the performance and status of the spectrometer. All the engineering analysis items were available about 12 h after the Goldstone pass and were analyzed prior to the next day's data transmission from the spacecraft.

After about 1 or 2 weeks in orbit, a more useful UV FLIK product was generated by the addition of one extra step in the processing. This additional trace was the result of the division of each F-channel spectrum by the solar flux. It permitted an examination of subtle variations in the intensity of the dust storm. The resultant ratio was

proportional to the effective atmospheric scattering function, and its variation with time and position on the planet was a useful monitor of the dust storm. This function later determined the presence of the minor constituent ozone, which subsequently proved to be a most important tracer for the activity and changes within Mars' lower atmosphere. Because the UV FLIK program was designed for use in the IBM 360/75 computer in a multiprocess mode, small changes to its structure had large impacts on the overall program organization in the computer. Also, during the initial few days of orbital operations, no changes to the program were permitted. In this instance, separate mini-computers for science data processing would have been more responsive to the scientific needs of the project investigators.

2. LASP operations. The MTC complex prepared a formatted log tape of the digital science data stream, and after Goldstone set, when the high-rate telemetry was no longer being received and decommutated by the MTC, these tapes were replayed at the slower rate of 4 kbits/s over a NASA Communications Network (NASCOM) line to the Principal Investigator's facility at the University of Colorado. The data entered a complex PDP-8 system, which involved the use of four mini-computers. The received spectra were examined visually as they arrived from the data line (Fig. 25). They were also logged on digital tape for future reference. Trained analysts at the Colorado facility examined the data in their real-time domain, making notations of those items which appeared unusual or worthy of immediate consideration. The DAS spacecraft time of these special items was recorded such that the flagged spectra could be studied more thoroughly outside of the realm of the standard routine analysis programs which processed each batch of received data after the logging operation was completed.

At the termination of transmission of each day's high-rate telemetry pass, the data line was terminated, and the computer system in Colorado began the detailed examination of that day's received data. An analysis program automatically accessed a spectrum from the magnetic tape record prepared from the data line, and examined particular wavelength intervals in order to generate pressure-elevation maps vs location of the data received. Calculations were performed sequentially on each spectrum, and the data were stored on a magnetic disc associated with the central PDP-8 computer. The slower, automated analyses were examined by an operator sitting at one of the consoles which was equipped with a display monitor to verify that the operation was being executed properly, and that no totally unexpected spectra

were present. This analysis block was completed approximately 6 h after the data had arrived at LASP. The estimated cone and clock coordinates of the scan platform were sent to Colorado daily so that the latitude and longitude coverage of the UV spectrometer on the Mars surface could be estimated. Together, these data generated an approximation of the contour map of elevation and pressure. The UV data merged with the aerographic positional information were then transferred on an internal data line to the University of Colorado's large CDC 6400 computer and stored there for future reference and large-scale contouring and model analyses.

At the completion of the pressure-elevation analysis, the data were replayed for specific subprograms of particular topical interest to the scientists. These included measurements of atomic hydrogen and its variations with altitude, and searches for minor constituents such as ozone and atomic oxygen. By the end of the Colorado day, 18 h after LASP had received the data, these preliminary analyses were completed, and the data were stored on tape. The data were also available in printout form from a line printer attached to the same computer complex.

3. Interactive communications. What has been described above represents two stand-alone systems operating on the same data almost in parallel but to differing levels of sophistication. This was necessary because there were UVS scientists at both locations with the need for various types of analyses on the data. The entire system became more unified after orbit insertion when, in addition to telephones, a Xerox Telecopier was installed at each end of the system: one in the Science Recommendation Team's UV science analysis area in the SFOF at JPL, and the other in the LASP Space Observatory at the University of Colorado. With this device, data products could be telecopied from one location to another within 4 to 6 min, and during subsequent phone conversations, both scientists could be examining the same particular piece of hard-copy data product. This technique made possible very quick interaction on unique and unusual observations. In addition, the science products mission and sequence planning information and scan platform printing data were frequently sent between the two centers to optimize the total UVS involvement in the Mariner observations of Mars. Joint experiments among the IRR, IRIS, and UVS Teams, and also between TV and UVS were accomplished via this link by making minor modifications to planned operations and telecopying items back and forth until a satisfactory solution was achieved. This telecopy link, which proved to be inexpensive, was one of the strongest supports that tied the system together and per-

mitted the scientists at Colorado to be in constant touch with the SFOF Operations Area. Graphs of processed data output showing topographic features, and even pictures, could be relayed back and forth with measurements made for scaling the necessary coordinates. In this way, almost instant data analysis was possible, and the resulting scientific conclusions were available to the other scientists of the Mariner mission and to the public much more rapidly than would have been feasible otherwise. There is no doubt that this link markedly improved the total performance of the UV data analysis system.

For the vast amount of data generated by the UVS with respect to topography, observations of the dust storms, ozone measurements, and atmospheric profiles, the telecopier was an inefficient means of transfer of information. Therefore, a data bank was established in Denver via a time-share system by which data from the LASP PDP-8 or the University's 6400 computer could be loaded into the special files in Denver, and then accessed via a Federal Communications System (FTS) call from a remote terminal in the SFOF Science Area. The computed pressures and elevations for an orbit were deposited in Denver, interrogated from JPL, overlaid on the picture sequence for that particular mapping swath, and displayed within about 24 h. In this manner, the Project was able to get its first look at the topography of the Hellas basin, the deep canyon lands, and the volcanoes shortly after the measurements were obtained. These data products were made available to the TV and other experimenters in the STAF area and then were transmitted to the Viking Project for analysis with respect to landing site selection for the Viking 1975 Mission.

4. Summary. Although the UVS data analysis and management system may seem complex and somewhat cumbersome, it functioned extremely well in actual practice. The Colorado facility responded rapidly to changing planetary conditions and their resultant impacts on preconceived analysis schemes. The periodic written reports and release of scientific findings (about 16 items in the first 120 days) demonstrated the sophistication and maturity of the entire system. The remote science facility concept permitted more cognizant scientists to have immediate access to the raw data than would have been possible had they come to JPL. For experienced space science experimenters, this method proved to be both productive and cost-effective.

In retrospect, a dedicated mini-computer operation at JPL for the UVS analysis efforts might have been more responsive to the changing needs of the analysts at JPL

and would have provided more support for the TV topography and geology studies, which depended in part on UVS data.

E. Infrared Interferometer Spectrometer Experiment Data Processing

The objectives of the IRIS experiment were to measure the spectral radiance of the thermally emitted radiation from Mars, to extract the geophysical information inherent in the planetary spectra, to generate physically realistic models that are consonant with the data, and to inform the scientific community and the general public about the results of the experiment and the conclusions. The prime data processing objective was to develop software that would result in the attainment of the scientific objectives.

It was intended that the Mariner Mars 1971 mission be carried out adaptively: i.e., that data acquired on one orbit be used to influence subsequent data acquisition plans. The sequence of events required that data be processed and that recommendations, based upon interpretation of the data, be formulated within several hours after receipt of the data. Thus, another data processing objective was that the software enable the IRIS team to participate in adaptive mission operations.

Ancillary objectives of the IRIS data processing included testing and verification of the program capabilities, and verification of instrument performance.

1. System description. Several factors markedly influenced the nature of the IRIS data processing system. As the scientific data had to be processed and analyzed within relatively few hours after receipt, and the computer time available at JPL to the IRIS investigators was sufficient only for a "quick look" at the data, the extended, in-depth analysis had to be performed at Goddard Space Flight Center (GSFC). Furthermore, the knowledge of Mars extant in mid-1971 did not permit the IRIS team to completely define the computational techniques prior to the mission. Figure 26 shows the flow of information that evolved.

The quick-look data were processed and analyzed in near-real time at JPL and used to formulate mission tactics. The processing consisted of generation of calibrated planetary spectra and the determination of the surface temperature, the pressure at the base of the atmosphere, and the atmospheric temperature profile for each of the spectra. The analysis also included an assessment of the performance of the instrument and an evaluation of the downlink telecommunication performance insofar as

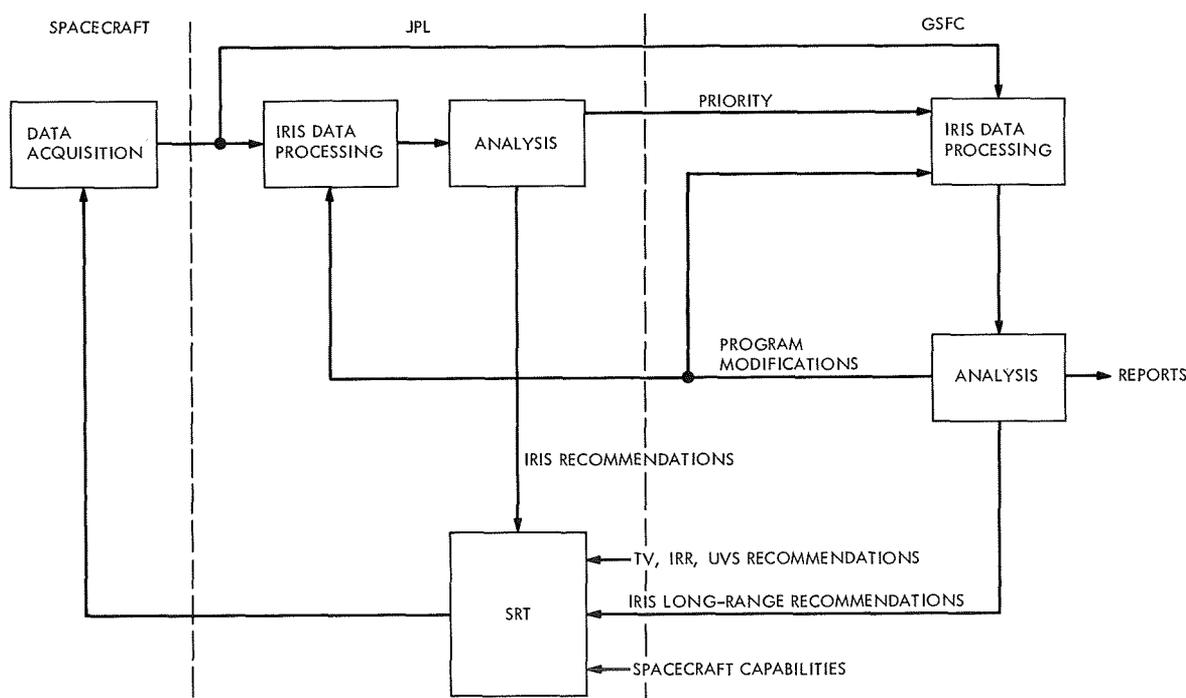


Fig. 26. IRIS information flow

it pertained to the IRIS experiment. The formulation of mission tactics pertained to such questions as target selection, optimization of viewing conditions, and playback rates.

The data were sent to GSFC simultaneously, together with priorities for extended analysis. The extended analyses formed the bases for software modifications, long-range recommendations regarding mission strategy, and scientific reports.

The IRIS EDR and SEDR, which reflected attempts to minimize data record gaps and to improve navigational information, became available several weeks after receipt of the original data and were forwarded to GSFC for final analysis. The overall data processing task is illustrated in Fig. 27.

To understand the nature of the major program and the basic problem experienced by the IRIS team, it is necessary to describe the instrument and its data. The IRIS is a Fourier transform spectrometer: the science data generated by the instrument (an interferogram) are related to the Fourier transform of the planetary spectrum. Reconstruction of a planetary spectrum involves a Fourier transformation of the interferogram and removal of the instrument function. This is the objective of the calibrated spectra program (CSP).

CSP accepts magnetic tapes with the Mariner Mars 1971 IRIS experiment data record format. The data tapes are interferogram-synchronized and contain the following information: IRIS science data extracted from the S486 and R7938 telemetry streams; DAS and ground-receipt time of each interferogram; IRIS engineering data from the O420 and E140 telemetry streams; and quality flags which summarize the status of the ground system and the quality of the telemetry.

The data are processed on an orbit-by-orbit basis. An instrument status word and the data quality indicators are examined to determine whether the operation of both the instrument and the ground system was normal. The data are then subjected to several tests, of which more will be said later, for errors in telemetry. If the interferogram is of acceptable quality, it is transformed to an uncalibrated power spectrum with the Cooley-Tukey Fast Fourier Transform algorithm. The uncalibrated power spectrum is then converted to absolute radiance units with the calibration data that are acquired periodically during operation of the instrument. CSP also calculates the noise equivalent radiance and responsivity for the

orbit; the noise equivalent radiance is a measure of the short-term repeatability of the instrument. Comparison of responsivities from orbit to orbit indicates the long-term stability.

CSP is written in Fortran IV and IBM assembly language. The program requires approximately 375 kbytes of unpartitioned core and 4 s per spectrum of central-processing-unit (CPU) time on an IBM 360/75.

Two variants of the program were used at JPL: a preliminary version, to support the instrument testing effort, and a final version, to support mission operations. The latter version was modified several times, although never extensively, to rectify minor problems and to facilitate the use of the data.

The calibrated planetary spectra from CSP are input to the science analysis program, together with supporting measurements descriptors. The science analysis program calculates the surface temperature by examining "window" regions of the spectrum where surface effects are dominant. The pressure at the base of the atmosphere (the surface pressure) is derived from the attenuation of surface radiation by the wings of the 15- μ m CO₂ absorption band. The temperature profile of the lower atmosphere is obtained from an inversion of the radiances in the 15- μ m region. The original conception of the science analysis program included a subroutine that would determine the total amount of atmospheric water vapor; this subroutine was never implemented because of difficulties with the transmittance of water vapor as a function of temperature and pressure.

The science analysis program is written in Fortran IV. The program requires approximately 300 kbytes of unpartitioned core and 4 s per spectrum of CPU time on an IBM 360/75.

Both the CSP and the science analysis program evolved from programs that were used for the analysis of data from the IRIS instruments on board the meteorological satellites Nimbus-III and -IV. The programs were formulated and written at GSFC by programmers under the direct supervision of the Principal Investigator. Both programs were extensively tested with realistic data at the subroutine level and at the program level.

2. Problems. A major problem associated with the IRIS data processing was the fact that the telemetry bit error rate was often too high for the IRIS experiment. Since the

PROCESSING OF COMPLETE DATA SET WITH
 SCHEDULE TO COMMENCE JULY 1972 AND
 DURATION OF APPROXIMATELY 1+ years

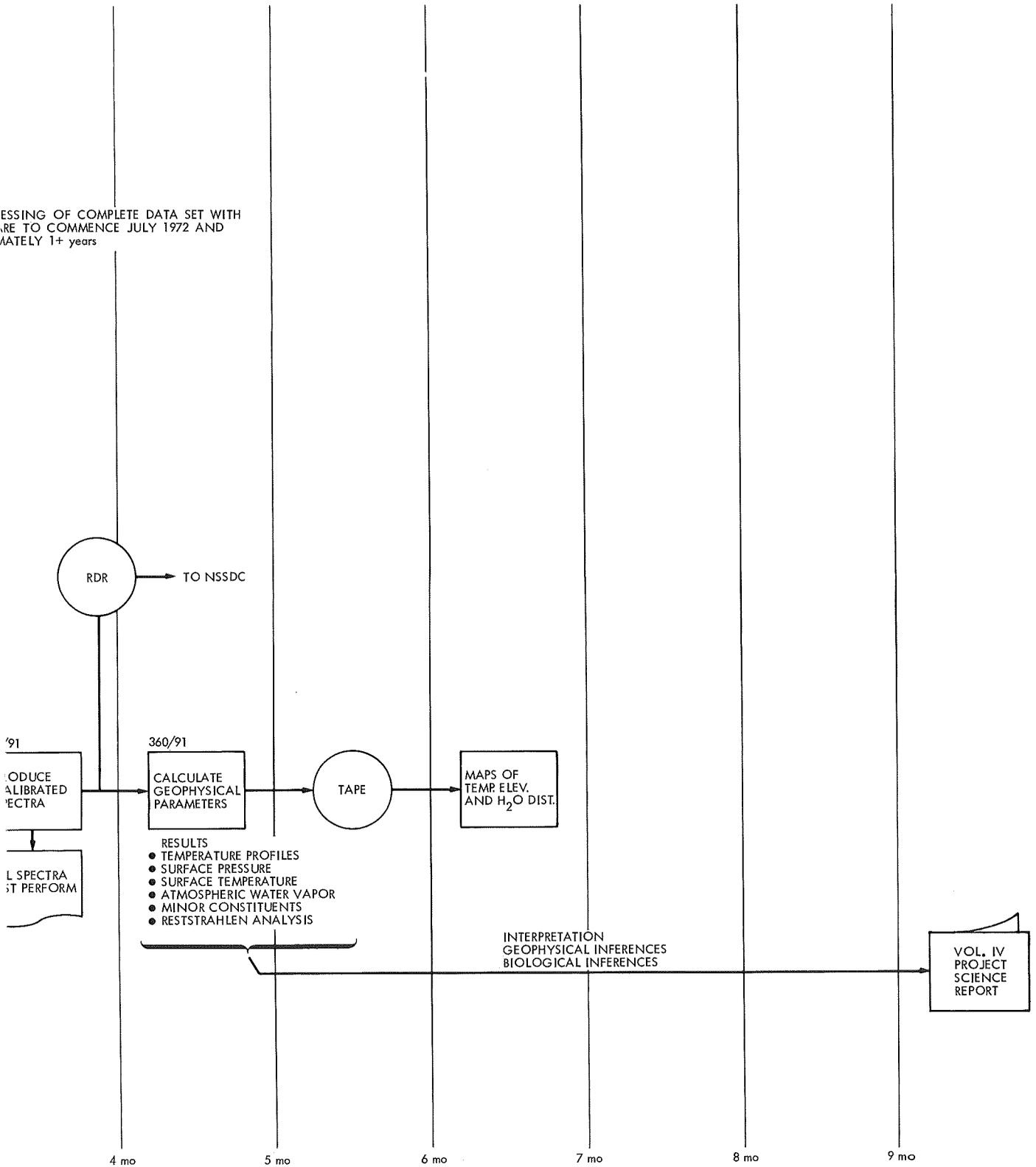


Fig. 27. IRIS science data flow



error rate was appropriate for the other experiments, the marginal telemetry had to be accommodated for the IRIS in order to maximize the total value of the science data returned by Mariner 9.

As was indicated previously, reconstruction of a planetary spectrum involves the Fourier transformation of the interferogram. Thus, the reconstructed spectrum is convolved with the Fourier transform of any noise or anomalies in the interferogram: bit errors in one interferogram word cause a sinusoidal modulation of the entire spectrum; bit errors in two interferogram words cause a beat modulation of the entire spectrum; more complex anomalies can make the spectrum unrecognizable.

Two types of data anomalies were encountered during the mission: bit errors, and losses of data. The inevitability of bit errors in transmission was recognized, and attempts were made to combat them: the IRIS instrument was designed to generate parity words for the most sensitive part of the interferogram; CSP employed the redundant information in the parity words to detect and, in many cases, to correct bit errors. The technique worked remarkably well and resulted in the salvaging of numerous spectra. The portions of the interferogram not "protected" by the parity scheme were subjected to spike suppression by CSP: each interferogram word outside the central-512 words was compared against a standard value; interferogram words exceeding that value were replaced by an interpolated value. If the number of corrections exceeded three in either of the two tested regions, the record was discarded. As the telecommunication performance deteriorated during the standard mission because of increased range and antenna misalignment, the number of bit errors per interferogram soon increased to the point where the data were unusable, despite the efforts to salvage them.

A second-order effect of bit errors had not been anticipated. The IRIS data were imbedded in a composite data stream. Each frame of composite data was preceded by a PN word that was used for frame synchronization. When the PN word contained bit errors, the ground system tended to lose synchronization and the entire frame, which contained several IRIS words, was lost, making the interferogram unusable. Outages were also caused by the design of the tape recorder, by its timing with respect to the television and to the IRIS, and by an anomaly on the tachometer control track. Had the problem of data outages been recognized earlier and the resources been available, an alternate version of CSP might have been prepared to minimize their impact.

The bit errors and data outages resulted in the loss of approximately 60% of all the IRIS data. The loss was exacerbated by the increasing loss of data as the dust storm waned and as the viewing opportunities moved northward on the planet.

The difficulty in the early definition of the Mariner Mars 1971 computing environment did lead to some wasted effort. However, it had no significant effect on the achievement of the experimental objectives. Such questions as the nature of the scientific computer, the amount of core available, and the amount of processing time available were resolved shortly before launch.

3. Lessons learned, biases reinforced, and recommendations. Since the instrumentation and the analysis techniques associated with flight science experiments tend to be rather specialized, the software should be formulated and implemented by the Principal Investigator and his associates, as should the testing and evaluation of science software. The IRIS team expended considerable time and effort to verify all aspects of the CSP and the science analysis program. The fact that the software was available to support mission operations can be attributed to testing and simulation at GSFC. Science software cannot be controlled in the same sense as a program such as POGASIS.

The IRIS data processing effort benefited from the "pressure cooker" aspect of mission operations. The data processing for the adaptive mode progressed faster and perhaps further than, for example, the data processing for the Nimbus-III and -IV IRIS experiments.

The Science Data Team served a very valuable function. The team worked with the experimenters throughout the Project, thereby acquiring a knowledge about the experiment and its data processing that facilitated the attainment of the experimental objectives. A similar, science-oriented data team should be employed in the future.

The quality of the data on the IRIS EDR was not sufficiently better than the quick-look data to warrant the extra bookkeeping, data management, and data processing that were expended on it. Future projects might consider abolishing the equivalent of the EDR; i.e., they might provide the experimenters with the best possible telemetry in near-real time and upgrade the data quality only when specifically requested and justified. On the other hand, the final version of the IRIS supplementary EDR did represent a considerable improvement over the preliminary versions that were used for the quick-look analyses.

F. Television Experiment Data Processing

1. Organization. The 26 television experimenters (the TV Team) chosen by NASA were the prime users of the TV data generated by Mariner 9. In the Mission Support Area (MSA) of the SFOF, TV Team members participated in logging incoming pictures and applying Principal Investigator identification symbols to each frame. Other members of the TV Team participated in daily Science Recommendation Team and mission analysis meetings to plan future operations. All mosaicking in the early phase of orbital operations was performed in the MSA using 70-mm strip contact prints (SCPs).

A second area of operations was the Science Team Analysis Facility, where data analysis and mission planning work was performed by the TV Team. During the early phase of orbital operations, all mission-planning work was done in the MSA and SRT areas of the SFOF; however, later in the mission, much of this work was accomplished in the STAF. While the STAF was set up as a facility for science analysis for the various experiments, it was learned that for orbital operations of this type, analysis and planning are closely coupled and cannot be conveniently done in separate physical locations.

Secondary users of the video data were the non-TV experimenters, NASA Headquarters, and NASA-JPL Public Information Offices.

To support the TV Team mission planning and data analysis functions, JPL provided staffing both at the MSA and in the STAF. The support personnel in the SFOF assisted in monitoring the data coming from the spacecraft and in maintaining a limited data library. A larger support group was provided in the STAF, where a more extensive TV data library was maintained, secretarial and mathematics services were provided, and mail and data distribution was made to the experimenters. Also, STAF personnel provided an active interface function among the experimenters, the Science Data Team, and the Image Processing Laboratory for the purpose of delivering special data products and processing.

2. Data products and distribution. The data made available to the TV Team were composed of video data processed in various manners for each picture taken, and of support data to define the conditions under which the pictures were taken. The various processings were generally sequential refinements of the data, such as decalibration, and rectification and scaling (Table 9).

The video and support data were delivered to the experimenters in the form of volatile TV-monitor displays, picture products, duplicate tapes, and computer listings. These products are described in Table 10.

The first permanent video products distributed after transmission of the pictures from Mariner 9 were the near-real-time pictures produced in quantity by the Mission and Test Video System (MTVS) from tapes generated by the MTC. This distribution was generally made in less than 24 h, with some products being delivered to the TV Team at JPL within a few hours. On the other hand, the products delivered to the National Space Science Data Center (NSSDC) did not require delivery until 30 days after ground receipt of the pictures.

Second-generation processing of the video data by the IPL and the Artificial Intelligence Laboratory (AIL) at Stanford University resulted in data products for which a preliminary distribution was made. The STAF served as a distribution point for a large portion of these data, as well as for data received from the U.S. Geological Survey (USGS).

At that point in the mission when preliminary distribution of near-real-time and IPL data no longer required a major effort, the resources of the MTVS were used to generate data products for shipment to the various TV experimenter home institutions. These data consisted of decalibrated reduced data record pictures, rectified and scaled pictures, computer printouts, and microfiche data cards.

Early in 1972, it was decided that microfiche cards offered an economical way of providing complete Mariner 9 picture libraries to all of the TV experimenter home institutions. Production and distribution of microfiche card libraries was started in mid-1972.

During the mapping phase of orbital operations, variable-scale mosaics were assembled by USGS personnel on a near-real-time basis and copies distributed. Photographic "chips" cut from the 70-mm SCPs were pasted onto variable-scale latitude and longitude grids which were distorted to accept the nonscaled pictures. One set of variable-scale mosaics (16 mosaic boards) contained spatial-filtered versions of the Mariner 9 photographs; the other set used the shading-corrected (albedo) version of the pictures.

Groups of special mosaics containing three or four contiguous A-frames were mounted on "railroad" boards during the early exploratory phase of the mission. Later,

Table 9. Types of data used by the TV experimenters

Type	Description
<i>Video data</i>	
Near-real-time pictures	Pictures produced generally within a few hours after transmission. Each TV frame was produced in (1) a raw version; (2) a contrast-stretched version, corrected for nonuniform response across the field of the camera; (3) a high-pass filtered, contrast-stretched version which removed low spatial-frequency photometric information in the horizontal scan direction; and sometimes, (4) a vertical-automatic-gain-control (VAGC), contrast-stretched version, which removed low spatial-frequency photometric information in the vertical direction. (Produced by MTC/MTVS.)
Reduced data record	Decalibrated TV data, which have had TV camera transfer characteristics, including geometric and photometric distortions, removed. Pictures were made from these data in both the contrast-stretched and the high-pass filtered version. (Produced by IPL.)
Rectified and scaled data	TV data, geometrically projected by digital computer to simulate vertical photography from one of several standard altitudes. Pictures were generally produced in the high-pass filtered version; however, some were also produced in a contrast-stretched version corrected for solar lighting angle. (Produced by IPL.)
Special processed TV data (experimenter analysis support data)	Special <i>ad hoc</i> computer processed TV data for either quantitative listings of data in the TV frame or pictures containing special effects. The process was sometimes applied to a single picture, sometimes to a class of pictures. (Produced by IPL and by AIL at Stanford University.)
<i>Support data</i>	
	Engineering data indicating when the picture was taken, where the camera was pointing, what exposure time and filter were used, etc. These data were available in either predicted (POGASIS predicts) or telemetered (MINILIBSET data and SEDR) form.

Table 10. Data products used in the TV experiment

Product	Description
<i>Volatile displays</i>	High-resolution and standard TV presentation of the real-time pictures in all real-time processed versions and digital TV displays of processed telemetry engineering support data.
<i>Film products</i>	
SCP	Strip contact prints for near-real-time data, generally containing all versions of TV pictures taken on a given orbital revolution on one 70-mm roll; for RDR, R&S, and special processing may contain very few images.
Duplicate negative	Third-generation negative containing same data as an SCP; 70-mm roll.
Positive transparency	70-mm film transparency containing same data as SCP; also called "master positive."
20 × 25 cm (8 × 10 in.) prints	20 × 25 cm prints (the STAF and SFOF libraries contain 20 × 25 cm prints of all pictures contained on the SCPs).
Slides	35-mm, 5 × 5 cm, or lantern slides generally made by copying data from duplicate negative or 20 × 25 cm print.
Microfiche cards	Positive transparency cards containing 60 micro-images per card of TV pictures, predicted picture geometry data, camera engineering telemetry data, and final picture-geometry data.
<i>Computer products</i>	
LIBSET data	Computer listings of the latitude, longitude, solar illumination angle, viewing angle, spacecraft position, camera identification, time at which picture was taken, shutter speed, etc., for all pictures taken. (Ref. 14)
MINILIBSET data	Preliminary, abridged LIBSET data.
SEDR summary	Abridged LIBSET data.
TV picture catalog	Computer listing of all pictures taken by Mariner 9, periodically updated; contains information on where to locate picture in library.

Table 10 (contd)

Product	Description
<i>Computer products (contd)</i>	
IPL enhancement catalog	Computer listing of all frames which have received IPL computer processing, periodically updated; coded summary of the enhancements applied to each frame is included.
MARK IV searches	Computer listings of Mariner 9 photographs selected on the basis of arbitrary classifications of pictures or on the basis of arbitrarily selected values of one or more geometric or processing parameters relevant to the pictures (e.g., a list of all rectified and scaled B-camera frames taken below latitude -60° after revolution 242, with a solar illumination angle less than 30 deg).
<i>Tapes</i>	Duplicate tapes containing either TV picture data or supplementary data such as latitude, longitude, view angle, etc., duplicated from PTV (preliminary unprocessed video data), TVE (final unprocessed video data), TVR (reduced or decalibrated video data), TQL (preliminary engineering support data), and SEDR tapes (final engineering support data).
<i>Graphic data</i>	
Maps	Mariner Mars 1971 Mars Planning Chart, produced by G. de Vaucouleurs from ground-based observations and Mariner 6 and 7 pictures; the Aeronautical Chart and Information Center (ACIC) Mariner 1969 map, also produced from Mariner 6 and 7 pictures; and Mariner 9 air-brush maps, produced by the USGS.
Mosaics	Various types of mosaics produced by the USGS, some covering major portions of the planet in various stages of data refinement, others showing selected small areas in detail.
Overlays	Computer-produced transparent data sheets which can be overlaid onto near-real-time TV pictures to show either (1) latitude and longitude grid lines relevant to each picture or (2) Sun-elevation and view-angle contours.
Footprint charts	Computer-generated plots showing the outline of coverage for various subsets of Mariner 9 TV pictures, plotted either on Mercator or polar-stereographic coordinate grids.
Globes	0.92-m (3-ft) plastic globes on which picture coverage outlines (footprints) were plotted, and 1.22-m (4-ft) aluminum globes on which rectified and scaled Mariner 9 photographs were mosaicked.

similar mosaics of contiguous B-frames were assembled showing interesting landforms. Copies of these were distributed.

At the USGS facility in Flagstaff, Arizona, uncontrolled photomosaics were made and copies sent to JPL for distribution. These mosaics used scaled but unrectified pictures assembled onto Mercator, Lambert-conformal, and polar-stereographic grids. Twenty-nine such mosaics covered all of the planet, except for the south polar region, which was depicted by an air-brush map rendition. Unlike the other 28 mosaics, the north polar mosaic made use of rectified and scaled photographs. Eighteen semi-controlled mosaics (containing rectified and scaled pictures) were produced by March 1973. The balance of twelve semi-controlled mosaics will be completed by June 1973. Subsequently, five quadrangles of controlled mosaics will be completed. All pictures used in these mosaics will be scaled to fit a geodesy control network of reference locations.

A set of 96 picture boards containing picture chips from the 70-mm SCPs, sorted for various sectors of the planet, were also produced by the USGS. These boards were

divided into three groups: B-frames taken during mapping runs, A- and B-frames not taken during mapping runs, and geodesy frames. For the most part, these photographs were not mosaickable, but were arranged on the boards in columns, each column related to an orbit. Copies were produced by the MTVS and distributed.

Final map products include an updated 1:25,000,000 scale air-brush rendition, utilizing a Mercator projection for the latitude range of zero to $\pm 65^\circ$ and a polar-stereographic projection from ± 60 to $\pm 90^\circ$ based on spatially filtered photographs and a similar map showing the planet's surface contrasts.

The picture-differencing processing was done almost entirely at the AIL at Stanford. Data tapes generated at Stanford were sent to the IPL for conversion to film products on the video-film converter, the film products distributed, and the data tapes returned to the AIL.

The above discussion of data products describes only permanent-copy data. Volatile data displays were used to monitor the video pictures and telemetered support data as they were received from the spacecraft. Four high-

resolution video monitors in the TV MSA and two standard-resolution monitors in the STAF allowed the TV experimenters to view the Mariner 9 pictures within a few minutes after they were received on Earth. Processed telemetry engineering support data on camera and transmission conditions, etc., were viewed on a numerical display TV monitor in the TV MSA and were also available on the two standard-resolution monitors in the STAF.

Other displays utilized for TV analysis in the TV MSA were a teletype printout of the picture processing status of the MTC, Polaroid photographs of a high-resolution monitor, and a real-time paper camera which produced low-quality prints of the incoming TV pictures. Because of the low quality, these photographs were used only until the MTVS film products were available (within a few hours).

Variable-scale mosaic boards, uncontrolled mosaic copies, special mosaics, picture boards, and special enlargements of pictures were hung in the display area of the STAF for experimenter use and display purposes. Footprint globes were also exhibited there. Hand-drawn, real-time footprint plots on 1:50,000,000 Mars planning charts and copies of special mosaics and variable-scale mosaics were displayed in the SFOF science operations area during the first half of the mission.

3. Planning tools. To assist the experiment teams in planning data-taking sequences, three planning tools were used: an analog geometry model containing a planet-simulating globe; a spacecraft model, which could be moved quite precisely in the orbital plane; and a simulated scan platform with projector, which could cast a beam of light onto the globe along the simulated instrument line of sight. Little use was made of this analog model because of the unexpected availability of the SCOUT program.

The SCOUT program is a digital computer program which can generate footprint plots on the basis of inputs regarding orbital parameters, picture-taking event times, and camera parameters. When used with Tektronix remote terminals in the SFOF, it provided volatile and permanent displays of the footprint plots. The program was run on a time-sharing basis on the UNIVAC 1108 computer system.

A more sophisticated program, POGASIS, was used by mission analysis and engineering personnel for the official sequence-planning operations. POGASIS contained the Mariner Mars 1971 mission constraints and could plan portions of a data-taking sequence, given initial conditions

by the operator. It also was run on the UNIVAC 1108 computer system.

Both SCOUT and POGASIS were extremely valuable for planning data-gathering sequences. SCOUT was used by the experimenters and operations personnel for preliminary planning to check the feasibility of various sequences, and POGASIS was used to verify the feasibility and to work out the details of, and adjustments to, the sequences finally adopted.

Although intended to serve mainly as an analysis tool, the latitude/longitude overlays proved useful during the latter part of the mission for targeting high-resolution B-frames. The latitude and longitude of interesting terrain features and clouds seen on A-frames could be determined with sufficient accuracy by means of overlays to make intelligent targeting requests to the Navigation Team.

4. Data product use. During the early part of the mission, nearly all TV experimenter activity was concentrated in the TV MSA. This was a result of constant, hurried sequence replanning necessitated by evolving computer capabilities and the variable obscuring effects of the planet-wide dust storm in progress at that time. After the Martian atmosphere became sufficiently transparent so that sequence planning could be done in a more routine manner, part of the TV Team operations were moved to the STAF. Still later in the mission, all operations of the TV Team were conducted in the STAF or at home institutions, with the exception of interfacing with the Navigation and Science Data Teams, operation of the SCOUT program, and occasional sequence planning meetings held in the SFOF. By mid-1972, data usage had shifted largely to home institutions.

The data usage in the MSA is outlined in Table 11, which shows that mosaicking was done there only during the early part of the mission. After about 2 months, this function shifted to the STAF; and a few months later, the mosaicking activity was centered mainly at USGS, Flagstaff. Data usage cannot always be differentiated between 70-mm SCPs and 20 × 25 cm prints. Some experimenters preferred to use the SCPs, while others preferred the 20 × 25 cm prints for the same purpose.

Data product usage in the STAF is presented in Table 12. A master library was maintained there for TV Team usage containing all TV data products except tapes, IPL and AIL special-processing negatives, and mosaic negatives. Three smaller libraries containing a lesser variety of products were maintained by STAF personnel in the experimenter analysis rooms and team leader offices.

Table 11. Data product use in TV MSA

Type of product	Use
<i>Picture displays</i>	
Volatile display (video) and paper camera	Monitoring MTC processing quality and selecting enhancement parameters Logging incoming pictures Coarse, preliminary overview of data playback
70-mm SCPs	Monitoring MTC processing quality Overview of data playback Special and variable-scale mosaicking (early in mission) Logging incoming pictures (late in mission)
70-mm SCPs and 20 × 25 cm prints	Monitoring clearing of atmosphere Monitoring success of targeting operations Analysis aid for planning new picture-taking sequences
Polaroid prints	Science Recommendation Team analysis Early selection for special processing
<i>Listings</i>	
Teletype printer	Logging incoming pictures Monitoring status of MTC
Digital TV monitor	Logging incoming pictures Monitoring camera operation
SEQGEN	Logging incoming pictures
POGASIS predicts	Mosaicking aid (early in mission) Support material for analyzing pictures received from spacecraft
<i>Graphic displays</i>	
Overlays	Mosaicking and picture analysis
SCOUT footprint plots	Picture sequence planning aid
POGASIS predicts	Support material for analyzing pictures received from spacecraft
Picture logs	Initial frame description Sequence verification
Mecator footprints	Sequence verification Target selection

Table 12. Data product use in STAF

Type of product	Use
<i>Picture displays</i>	
Volatile display (standard TV monitors)	To determine whether playback was in progress Occasional overview of data playback
70-mm SCPs	Overview of data playback Special and variable-scale mosaics (later in mission) Picture-board layouts Data analysis Library files
70-mm negatives	Occasional preparation of slides and prints Library files
70-mm positive transparencies	Data analysis where maximum picture quality was required Library files
20 × 25 cm prints	Overview of data playback Data analysis Special mosaics Monitoring success of targeting operations Aid for planning new picture-taking sequences Library files
Variable-scale mosaics and uncontrolled photomosaics	Large-scale coverage display Planet coverage assessment
Picture boards	Relating isolated pictures and small picture groups to proper area of planet
<i>Listings</i>	
POGASIS predicts, MINILIBSET, and LIBSET quick-look report	Mosaicking aid Support material for picture analysis Library files
MARK IV searches	Picture sorting aids Picture locating aids Picture analysis aids Picture accounting aids

Table 12 (contd)

Type of product	Use
<i>Graphic displays</i>	
Overlays	Picture analysis aid Targeting aid Library files
POGASIS footprint plots	Preliminary picture analysis aid Library files
SCOUT footprint plots	Targeting aid
Globes	Planet coverage accounting
Footprint charts	Planet coverage accounting and assessment Library files

As previously mentioned, during the early and middle parts of the mission, mosaicking was performed by USGS personnel stationed at JPL. When the data rate lessened, these personnel returned to Flagstaff to finish up preliminary mosaics and to develop the more sophisticated uncontrolled mosaics and, finally, air-brush maps. RDR duplicate tapes and other film products were also sent to Flagstaff for data analysis.

The use of data by other TV experimenter institutions is summarized in Table 13.

Table 13. Institutional use of data (excluding mosaicking)

Institution	Products used	Studies
University of Texas	SCPs, 20 × 25 cm prints, listings, MARK IV searches, special processing	Albedo mapping
Cornell University	20 × 25 cm prints, positive transparencies, listings, special processing	Variable surface features, satellites
California Institute of Technology	Positive transparencies	Geology, polar phenomena, data retrieval
U.S. Geological Survey, Menlo Park	20 × 25 cm prints, positive transparencies, listings, special processing	Geology
U.S. Geological Survey, Flagstaff	Negatives, positive transparencies, listings, tapes	Geology, polar phenomena
Jet Propulsion Laboratory	SCPs, 20 × 25 cm prints, listings, special processing	Atmosphere, geology polar phenomena, photometry
Stanford University	SCPs, tapes	Special processing for satellites and variable surface features
Ames Research Center	20 × 25 cm prints, listings, special processing	Satellites, atmosphere
Rand Corporation	20 × 25 cm prints, listings, special processing	Geodetic control network
University of Washington	20 × 25 cm prints, listings, special processing	Atmosphere
New Mexico State University	20 × 25 cm prints, listings	Atmosphere

5. Data problems. Before the spacecraft was established in orbit around Mars, the development of data processing and distribution systems was of lower priority than for such pressing matters as building, testing, and launching the spacecraft, and redesigning the mission plan after the launch failure of Mariner 8. As soon as video data started streaming back from the orbiting spacecraft, a number of unanticipated problems became apparent. Table 14 lists these problems and their effects on the TV experiment. While the problems caused some inconvenience in the mission, solutions to most of them were eventually found.

G. Image Processing Laboratory Data Processing

The IPL at JPL was assigned the responsibility for six tasks in support of the Mariner Mars 1971 television experiment:

- (1) Support of television subsystem developmental testing and generation of selected calibration test targets.
- (2) Support of television subsystem calibration and system test activities.
- (3) Removal of camera-system-induced distortion from each returned Mariner 9 television image (decalibration).

Table 14. Early data problems and their effects

Problem	Effect
MTC/MTVS software not ready before orbit insertion	Early data products (including preinsertion pictures) did not contain data blocks and provided poor renditions of photographed scene
Delays in getting LIBSET operational	Support data for pictures were not readily available during early part of mission, impairing analysis
Process control deficiencies	Early decalibrated picture products were of poor quality; rectified and scaled pictures were distorted, resulting in cessation of spherical mosaicking effort (see Section 3)
Reduced data record delays and changes required by TV Team	Unavailability of reduced data record photographs to experimenters when needed necessitated work-around solutions and caused delays in data analysis
IPL turn-around time on special processing requests	Extensive priority negotiations were required to utilize available staffing
"Special photo reproduction" requests and priority changes	MTVS capabilities were often loaded up and certain products delayed
LIBSET accuracy unknown	Picture analysis was impaired
Overlay process control deficiencies	All view-angle overlays and many latitude/longitude overlays had to be remade

- (4) Transformation of several thousand processed Mariner 9 images to standard mapping projections for use in generating the final cartographic products from the mission (rectification and scaling).
- (5) Support of daily image processing and enhancement requests received from the Television Experiment Team (experimenter support).
- (6) Monitoring of camera system performance during flight operations, reporting on camera system status and performance, and modifying preflight calibration files as necessary (process control).

IPL support of developmental, calibration, and system test activities is dealt with only briefly here; the results of the calibration activity are to a large extent contained in Ref. 15. The remaining four activities were the subject of extensive pre-mission planning, conducted jointly by the Mariner 9 TV Experiment Team and JPL. In each of the four areas, considerable modification of preflight planning was necessitated by operational realities, changes

in philosophy, and problems encountered with some elements of the ground data system, and only the decalibration and experimenter support tasks emerged resembling the preflight conception of those activities. This section describes the adaptive process of modifying preflight planning based on flight operation experience gained during the Mariner 9 mission. Preflight planning is documented in Ref. 16; detailed discussions of the actual image processing techniques utilized by IPL may be found in Refs. 17-23.

1. IPL support of TV subsystem calibration. IPL activities in support of TV subsystem calibration and system test activities consisted of four tasks: (1) development of hardware interface with the TV subsystem bench checkout equipment and support of camera developmental activity, (2) generation of the archival magnetic tape record of TV subsystem calibration, performed by generating a line- and frame-synchronized magnetic tape record of each calibration image from data tapes recorded on the TV subsystem bench checkout equipment, (3) data reduction and analysis to produce data products and records summarizing camera performance and characteristics in support of engineering evaluation of the TV subsystem, and (4) generation of data files for use in processing of flight data.

A total of approximately 1000 archival data tapes were generated during the Mariner 9 calibration activities. The data products generated by the IPL were used extensively in the final camera calibration report (Ref. 15). The calibration data files were used during flight operations by the IPL, and portions of the data were also provided to other activities. For example, the shading correction performed for mission operations real-time image display was based on an extract of the more precise and complete camera photometric data files generated by the IPL. Selected camera geometric distortion data were also used in the optical navigation demonstration.

2. Decalibration. The image decalibration task had as its objective the removal of the photometric and geometric distortion induced by the camera system from every television image returned by the spacecraft. The decalibration processing was designed to:

- (1) Remove geometric distortion caused by nonlinear vidicon scanning and local image detail.
- (2) Reduce "residual image" for all images in which the previous image was also recorded and received on the ground. (A residual image is a remnant of past images superimposed on the current image).

- (3) Remove photometric distortion caused by non-uniform, nonlinear camera system photometric response.

The techniques for performing the computer processing are discussed in Refs. 17-23.

The corrections described above can be performed in a variety of ways, depending on the accuracy requirements of the specific application. The science objectives of the Mariner 9 mission included extensive cartographic and variable surface features analysis, which dictated that photometric and geometric distortions be modeled as accurately as possible. The accuracy requirements dictated that geometric distortion be removed on a per-frame basis, and that an accurate automated reseau location algorithm be developed. In addition, photometric response was calibrated on a per-picture element basis as a function of temperature in vacuum conditions. A reliable method of reducing vidicon residual image effects was also developed and implemented. Finally, the mapping and image differencing requirements were so extensive that removal of camera-induced distortion from each of the several thousand television images was required. The result was a digital image processing task of unprecedented scope; decalibration processing of Mariner 9 television images was performed on a dedicated 360/75 computer that was capable of performing processing at the rate of three frames per hour. The decalibration task used approximately 14 h per day of 360/75 computer time from November 1971 until July 1972, during which time over 7000 images were processed.

Decalibration processing was continually adjusted during the mission operations period to accommodate changing requirements, problems that arose because of the dust storm, and other considerations. To enhance the inherently low contrast in the Mars surface images, a high-pass filter was designed for use in hard copy display versions of the decalibrated data that would suppress gross albedo variations but make visible local image detail. An automatically contrast-enhanced hard copy version of each image was also planned. Because of the dust storm, the image detail during the early mission was at or below the coherent noise level of the camera system. Thus, a new filter was designed to remove the camera system noise while still enhancing local detail. As the dust storm cleared, the degree of the automated stretch was continually adjusted until severe enhancement was no longer required.

During the latter phases of the mission, the bit error rate in the raw telemetry increased significantly; the effect

of bit errors in coded data on the imaging data is the appearance of single picture-element "spikes" that deviate significantly in intensity from the local intensity level. These spikes are distracting, and cause anomalies to be introduced during additional processing (e.g., high-pass filtering will cause streaking of the spikes and destroy valid imaging data). As the bit error rate increased, the preflight decision that picture-element spikes be ignored was reversed, and spike removal was incorporated into the standard decalibration processing.

As the TV Experiment team began to receive products and react to them, the definition of quality requirements for image hard copy resulted in iterations during mission operations. Also, before Mars encounter, several JPL facilities had made assumptions regarding format and display of the imaging data, and the hard copy products had to be readjusted based on TV Experiment Team inputs received during orbital operations.

During decalibration processing, only two modifications of preflight calibration data files were made. The first, an update of the reseau master data file to incorporate the effects of the raster shift that occurs after launch because of the change in the spacecraft's magnetic environment, was anticipated before mission operations. This change was made prior to orbit insertion. The second change was not anticipated; the photometric data file for wide-angle (A) camera filter position 2 contained a discontinuity that was discovered after approximately 200 frames had been decalibrated. The discontinuity, which caused a visible artifact in all A-camera filter position 2 frames with raw data numbers above about 350 near line 500, was corrected. None of the affected frames were reprocessed, mainly because they were taken early during the dust storm and were of little interest for photometric purposes.

3. Rectification and scaling. This task underwent a complete redesign during orbital operations based on the impact of the dust storm on mission planning, and the late readiness of certain elements of the ground data processing system. The original concept had involved the orthographic projection of selected returned imagery within 48 h of receipt for use in a first-order global mosaic that could be used for mission planning purposes. The images were to be high-pass filtered to show topographic detail, and an additional image that was contrast-enhanced would also be mosaicked to indicate gross albedo effects. The imaging data would not be decalibrated but would have only gross corrections for camera geometric and photometric distortions. The orthographic projections would be performed using camera pointing and spacecraft

position data contained in the TV supplementary experiment data record, which would be produced in time to meet the 48-h time limit.

The TV SEDR was to be a product of a complex series of mission operations computer programs, called LIBSET. However, at the start of orbital operations, this program was not fully operational. The Science Data Team developed a set of substitute software, called MINILIBSET, which used hand input to generate a preliminary version of the TV supplementary record. It took almost a month before this product began to appear, and during this period, the computer time that was to have been used for rectification and scaling was used for decalibration.

At about the same time as the preliminary TV SEDR began to appear, the TV Team reevaluated their requirements and determined that the orthographic products should be generated from fully decalibrated images rather than from images with only gross corrections for camera distortion. This necessitated redesign of the production processing system, and the decalibration processing was reordered to conform with the orthographic projection frame requirements.

Production of the orthographic products using the preliminary SEDR generated by LIBSET began in January 1972. It was found that the projected images were not sufficiently accurate for use in precise mosaics because of the accuracy limitations in the preliminary TV SEDR. It was decided to use IBM 360/75 computer time to complete decalibration while awaiting production of the final TV SEDR, which was completed by July 1972. The initial delay was used to advantage for evaluation of existing mission data, running tests, and determining optimum enhancement parameters. These activities resulted in the development of an efficient computer processing method whose products were sufficiently precise for use in the final cartography.

4. Experimenter support. The activities of several image processing analysts and a significant amount of time on the IBM 360/44 computer were devoted to image processing in response to the daily requests of the TV Team. Preflight planning in this area was centered around attempts to predict the types of digital processing needed to support the Mariner Mars 1971 science objectives and to ensure that the level of effort at JPL would be sufficient to support anticipated requests. Although most anticipated types of processing in fact materialized, the number of required data products escalated significantly during the mission. In addition, the priorities determined

before orbit insertion were continually adjusted during the mission.

One significant change that occurred during the mission was in the picture-differencing task anticipated in support of the variable surface features investigation. The IPL had produced a digital image registration program which could be run interactively using the Laboratory computer. However, most of the image differencing performed on Mariner 9 data was done at Stanford University's AIL using first-order corrections for camera shading and geometric corrections, whereas preflight considerations dictated that only decalibrated data be used. Additional changes to preflight planning were due mainly to underestimation of the quantity of data products; in many areas (geodesy and cartography, in particular), the number of frames processed and enhanced exceeded the preflight guesses by factors of 3 to 5.

In the period from September 1971 through July 1972, over 5000 enhancements of individual images were performed by the IPL, ranging from easily produced routine enhancements (e.g., linear contrast) to complex products requiring several weeks of analysis and processing. The many tasks performed by the IPL included (1) generating maximum discriminability versions of over 1000 images, with picture-element reference grids superimposed, in support of work directed toward generating an improved geodetic control grid of the planet; (2) special enhancements of images of the Martian moons, Phobos and Deimos; (3) development of new software to generate limb brightness profile plots automatically, using the TV SEDR data; (4) mapping projections of several hundred frames for use in color and polarization analysis, and as input to small mosaics of particular regions of the planet; (5) removal from selected frames of shading caused by solar illumination geometry to allow analysis of surface albedo; and (6) listing of the data values for each picture element in selected areas of selected pictures.

Of particular importance was the adaptive work conducted during the first few weeks of orbital operations, which produced the first imaging data products from the Mariner 9 mission in which limited surface detail was visible. In general, the first month of this activity was directed toward subjective enhancement. As the dust storm cleared, it became possible to begin additional types of quantitative processing.

5. Process control. With the exception of the IPL planning activities, the subject of quantitative TV subsystem performance monitoring received little attention before

the start of mission operations. Several procedures were established by IPL which would be followed during mission operations to evaluate camera performance and to report to the TV Team on camera status and performance. The IPL was concerned mainly with the photometric response and geometric distortion parameters of the camera system rather than those monitored by TV engineering personnel relating to its overall condition. The preflight assumption was that the process control activity would continually monitor and report the accuracy of the IPL decalibration algorithms; if changes occurred which were serious enough to require updating of the basic camera calibration files, then the decalibration processing plan would be reviewed and revised.

However, since the computer time purchased by the Mariner Mars 1971 Project for decalibration processing was given to the IPL on a block time basis, and the Project paid for the computer time whether it was used or not, there was some chance that many frames would not be processed if the decalibration processing were halted or delayed for an appreciable amount of time. Thus, after an initial analysis determined that the camera noise, residual image, photometric response, and geometric properties were not grossly different from prelaunch calibration data, the master reseau location data file was updated to accommodate the raster shift which occurred after launch; and production decalibration processing began 1 week after orbit insertion. Following the early intensive camera evaluation activities, process control analysis at the IPL was performed only sporadically during and after the 120-day nominal operating period. The extensive efforts required to accommodate the changing requirements in the rectification and scaling area; the extreme pressure to generate useful pictures from the early mission data for use in press briefings, science reports, and early mission planning; and the continual renegotiation of hard copy requirements with the TV Team used the talents of analysts who had originally been scheduled to support process control analysis activities.

By June 1972, it had become apparent that there were some discrepancies between the camera photometric performance as observed in flight and the prelaunch calibration performance. Early and frequent calibration could have helped diagnose these problems earlier, but the calibration sequences during the mission were limited to orbits 76 and 225. The diagnosis of small but important differences in camera shading characteristics and a change in camera response to input light came so late in the mission that the decalibration processing could not be modified because it was nearing completion and the computer

had been reassigned to rectification and scaling activities. The apparent changes are small and may not interfere with relative photometric analysis of decalibrated data wherever extreme photometric precision is not needed. However, for accurate and precise photometry, the changes are significant, and by July 1972, efforts were underway to characterize the changes quantitatively and to provide correction tables for use in accurate photometric interpretation of the data.

Similar problems were encountered in attempts to perform precise photometric analysis of the Mariner 6 and 7 data, and it also took several months to understand their effects and the impact on data analysis activities. Any future mission with stringent photometric analysis requirements should (1) delay precise photometric data processing until a complete analysis of in-flight camera performance has been completed, (2) provide adequate in-flight calibration data, and (3) project adequate resources to evaluate camera performance and update data files.

H. Science Data Team

The types and volume of the tasks completed by the Science Data Team are discussed in this section. Some historical information is included where appropriate. Details of procedures can be found in Refs. 6 and 24-29, and supplementary instrument information is given in Ref. 30. The SDT Final Report is contained in Ref. 31.

1. Group responsibilities and functions. The SDT was organized to process, distribute, store, and retrieve science data from the Mariner Mars 1971 mission. These tasks were accomplished by a set of groups within the SDT:

- (1) Distribution group.
- (2) Analysis support group.
- (3) Library group.
- (4) Real-time operations group.
- (5) Data records group.

a. Distribution group. This group maintained a product accountability system and filled requests for products and completed products. Because of the high data volume of the mission, such a system was an absolute necessity. The number and variety of products handled by the group exceeded by a considerable margin those of past JPL missions and is expected to approximate that of future missions.

b. Analysis support group. This group provided an operations interface between the science users and the data processing machinery, which included a large variety of computer and data systems. The success of the group was in a large measure due to the high motivation, combined with intensive computer school training, of the analysts who conducted the analysis programs.

Because of the requirements of the adaptive mode on Mariner 9, the SDT effort included support for quick turn-around preliminary data analysis, which was accomplished in three different ways:

- (1) The data were transmitted in nonreal time to the experimenter (LASP, Boulder, Colorado), who was funded to develop analysis programs and operate them at his home institution. A backup capability was maintained at JPL which, in some areas, exactly duplicated LASP capabilities, and in others, provided unique display capabilities. In the case of LASP, the data line proved to be a good tool for getting data to the experimenter.

There was a small group of experienced programmers at LASP who were familiar with the equipment as well as the instrument and its data. In addition, there was strong leadership to design and implement the system.

- (2) JPL accepted a major software package (the IRIS Fourier Transform Program) from GSFC, interfaced it with JPL's near-real-time data formats, and operated the program during system test and mission operations. This approach was cost-effective in that a complex analysis program was created over a period of a year and a half by the experimenter, was tested on spacecraft system test data, and was proven satisfactory during mission operations. The program development was started prior to system test and went through seven iterations before a frozen flight version was achieved.
- (3) JPL analysis programs were prepared for the Principal Investigators (PIs) based on program requirement inputs from them. About the time of orbit insertion, several major changes were requested by the PIs and implemented. These late changes forced the program validation into the orbital operations period.

c. Library group. The operational approach in this group centered about a general-purpose data management system. A number of major catalogs were created

to serve as record-keeping tools and sources of information for various users. The original purchased package, while possessing great flexibility and reliability, was not oriented toward interactive capability. A revised program reduced turnaround time from 24 h to minutes.

The weak point of the record-keeping operation was the generation of the input to the data management system. Although the IPL and the MTC were requested to provide much of the input in computer-compatible format, only hand input was provided because of the late development of the various systems. The cost of the library effort would have been reduced if both IPL and MTC had automatically generated computer-compatible records of their picture processing activities.

The library made heavy use of microfilming as a technique for data storage and retrieval. The microfilm could have been even more useful if it had been possible to order all the like outputs rather than all the outputs from one time period onto one film. Microfiche may be a more suitable medium. Certainly, it would have been cheaper to have microfilm printers attached directly to the computers rather than first developing hard copy and then microfilming.

d. Real-time operations group. Generating a suitable log for science data analysis was a major data handling task on previous Mariner missions. The difficulty was that numerous logs were kept in the MOS, but no one compendium of these logs existed. One of the functions of the real-time operations group was to assemble such a log using its own records and six other logs gathered from the MOS. This combined record proved indispensable to the science data users.

Another real-time operations function was to monitor incoming data and generate DSN requests for data replays. Two problems occurred in this area:

- (1) The MTC occasionally failed to record data that it received and displayed in real time.
- (2) There was not sufficient flexibility in the assignment of messages to printers to allow only those messages which concerned the real-time data group to be displayed. To obtain messages of interest, many of no interest had to be accepted.

e. Data records group. The entire data records system was revised some 6 months before the first flight science data were received. As a result, validation and preliminary training for the personnel responsible for analyzing the

master data record (MDR) and experiment data record (EDR) printouts were abbreviated. The experiment data program provided a constant interface to the experimenters even though the bulk of the MDR/EDR system was revised. The MDR system was designed primarily to (1) remove redundant coverage, (2) patch holes in the data stream caused by wideband or high-speed data line outages, (3) keep a quality check on the operation of the MDR and EDR software, (4) examine and summarize the contents of the magnetic tapes sent to the experimenters, and (5) set up the inputs for the MTC master data record operations.

2. Supplementary Experiment Data Record generation.

There were two basic efforts to generate SEDRs: LIBSET and MINILIBSET. The requirement for LIBSET was identified late in the Project development phase, and eventually resulted in the development of MINILIBSET.

The philosophy behind LIBSET was making use of existing models of spacecraft subsystems (COMGEN, SCISIM) and navigation software (POGASIS) to produce a record of navigation data that had a one-to-one relationship between measurements taken by the spacecraft and sets of navigation data. LIBSET used only portions of the capabilities of the spacecraft subsystem programs. A plan to use command files generated by AMPS and COMGEN was impractical. These files were often nonexistent, incomplete, or inaccurate because of last-minute sequence changes, and there was no capacity in the system for updating them to match actuality. Each of the 25 LIBSET runs made required considerable manipulation to provide accurate input command files.

The second approach to the SEDR, MINILIBSET, substituted human efforts for those functions LIBSET was designed to perform automatically. The circumstances of MINILIBSET's creation forced simplicity on the software. However, because it depended on humans for setting up the data input decks, there was considerable flexibility as well as occasional human errors. MINILIBSET could be regarded as a second-generation LIBSET. Its products were in many ways more satisfactory than those developed by LIBSET, although the accuracy of the SEDR produced by the simplistic approach was not as good as that of LIBSET (because of LIBSET's inclusion of the SPOP attitude control model). Changes in the way engineering data are handled on board the spacecraft could compensate for the difference.

A positive feature of both supplementary experiment data systems was the use of the MARK IV data manage-

ment system as the final storage and output technique for the data. The use of that system allowed the Science Data Team to meet the numerous changes and new requirements that developed when the experimenters were determining the method of handling the TV data. At the same time, other requests, such as the production of specially formatted printouts, punched cards, tapes, etc., were met with an expenditure of several man-hours of time rather than man-weeks or man-months.

3. Mission and test computer capabilities. The MTC provided essentially all the real-time science data processing capabilities that the MOS did, plus a set of very useful nonreal-time data analysis programs. MTC features of particular value were (1) the nonreal-time daily processing, (2) the utility operations (tape dumps and tape duplications), (3) the preservation of most of the system test capabilities, (4) the special instrument-oriented data display formats (including the analog displays), and (5) logical magnetic tape formats, which included recordings of the data in blocks associated with other instrument measurements in addition to the TV data frames.

MTC-related problems that affected the Science Data Team were:

- (1) There was a lack of flexibility in selecting measurements associated with data quality, frame synchronization and decommutation, and MTC system statistics.
- (2) Key displays were late (the analog plots were first available on the morning the first UV and IRIS data were received). The MDR development did not follow the committed schedule. Key items were not formally documented (magnetic tape formats).
- (3) Feedback was inadequate regarding the actual implementation. An effort was made to document most of the MTC capabilities, and, when this documentation was current, it proved invaluable.
- (4) Certain MTC messages related to operations were lacking, such as log tape swaps, which would have helped keep track of outages. A computer compatible record of MTC picture processing parameters for each image would have been useful.

4. Additional data processing concepts

a. Data day. The data day was chosen as the unit of information to be isolated and processed at one time. It contained 24 h of telemetry data, starting and ending at two successive Goldstone telemetry view period sets.

Although there were difficulties, it was useful to isolate a particular period of data for processing for all the data tapes. The end of the data day signified the closing of logs, the start of analysis program operations, and several other operational events.

b. Dedicated analysis computer. The dedicated IBM 360/75C made possible a very close interface between the computer and the Science Data Team. By allowing a representative of the SDT to participate in the operation of the programs during the SDT block time, the team was assured of getting useful data outputs every day. Errors in deck setups caused only minor time delays because the SDT representative could correct the deck immediately.

c. Software control. The SDT experienced no difficulties in maintaining control over the approximately ten major programs and numerous minor programs in the system. A validated version of every program was kept on a single disc pack (with appropriate backup tapes), which could be updated by only one individual. The experimenters were given essentially complete freedom to request changes to their software. The changed versions of the programs were used immediately in place of the validated versions. If the new versions failed, the job was restarted on the validated version with high confidence of its running to completion. The latest approved versions of the programs were transferred to the validated program file.

d. Adaptive mode cost. The adaptive mode cost was relatively small as far as SDT efforts were concerned. To avoid delays in providing preliminary reduction products to the experimenters, each day's worth of data was processed in one day. This was no more expensive than it would have been to accumulate data and process them later.

V. Performance and Problems

A. Introduction

In performing the standard mission and achieving its objectives, Mariner 9 transmitted about 50 billion bits of science data to Earth. This wealth of data has led to many significant and surprising discoveries concerning the planet Mars.

Even though highly successful, the complex Mariner 9 mission was not without problems and challenges. Some of the difficulties encountered have been mentioned in earlier sections, where they fit into the discussion natu-

rally. In addition to flight performance information, this section contains a review of all significant anomalies, including specific discussions of spacecraft and data processing system performance and anomalies in Sections B and C, respectively. General types of difficulties affecting the mission operations function are summarized in the following paragraphs.

Recognition of the need for, and establishment of, the Mission Sequence Working Group (MSWG) occurred relatively late in the development of the Mission Operations System (MOS). The importance of the function provided by this group was demonstrated by the fact that mission planning was needed throughout the standard and extended missions rather than being limited to the early phases.

In addition to the computer difficulties discussed in earlier sections, a number of problems were associated with the IBM 360/75 project computer. Many of these problems could be traced its utilization. Because of the heavy computational demands of the Mariner Mars 1971 Project (MM'71), all real-time data stream (telemetry, command, and tracking) computations and some nonreal-time planning and analysis programs were run in the same computer. While this was a necessity for MM'71, every effort should be exerted in future MOS planning and design phases to avoid mixing real-time and nonreal-time programs in the same computer.

Mission operations were complicated by certain inherited spacecraft/telecommunications designs. The Mariner 9 command rate of 1 bps (or 26 s per command) was the same as that used for past Mariner spacecraft. However, during the 1971 standard mission, 37,500 commands were processed, compared to a total of 2249 for both spacecraft during the 1969 missions. The relatively large amount of Mariner 9 mission time consumed in command sequences left less time than desired for science operations. Furthermore, the inherited spacecraft design necessitated the sending of coded commands (CCs) in real time to control the TV cameras when they were operated in the manual mode. Had the on-board central computer and sequencer (CC&S) been capable of controlling those functions, the strain of real-time, time-sensitive commanding would have been significantly lessened.

Simpler mission operations for future projects could benefit from Mariner 9 experience in the area of spacecraft timing. Instead of a single on-board clock, Mariner 9 had two independent timing sources for the CC&S and the Data Automation System (DAS). Considerable effort was expended in correlating these two clocks to optimize

control of the spacecraft and interpretation of the data received.

B. Spacecraft

1. Radio Frequency Subsystem. The radio frequency subsystem (RFS) receives ranging signals and commands on the uplink carrier transmitted from deep space stations (DSSs), and transmits ranging signals and telemetry data on the downlink carrier to the DSSs. The uplink is received on a low-gain antenna/medium-gain antenna (LGA/MGA) system; the downlink is transmitted either on the LGA/MGA system or on the high-gain antenna (HGA) during the various phases of the mission. A de-

scription of the RFS and operations up to launch is given in Ref. 32.

a. Performance. Although several anomalies occurred during flight, the RFS performed its functions satisfactorily with minimal operational difficulty throughout all phases of the standard mission.

Observed telemetry data variations as a function of time were invaluable indications of the trends in RFS performance throughout the mission. Curves of exciter drive, LGA drive, and HGA drive were plotted on a daily basis, beginning at launch (Figs. 28 and 29). Because these

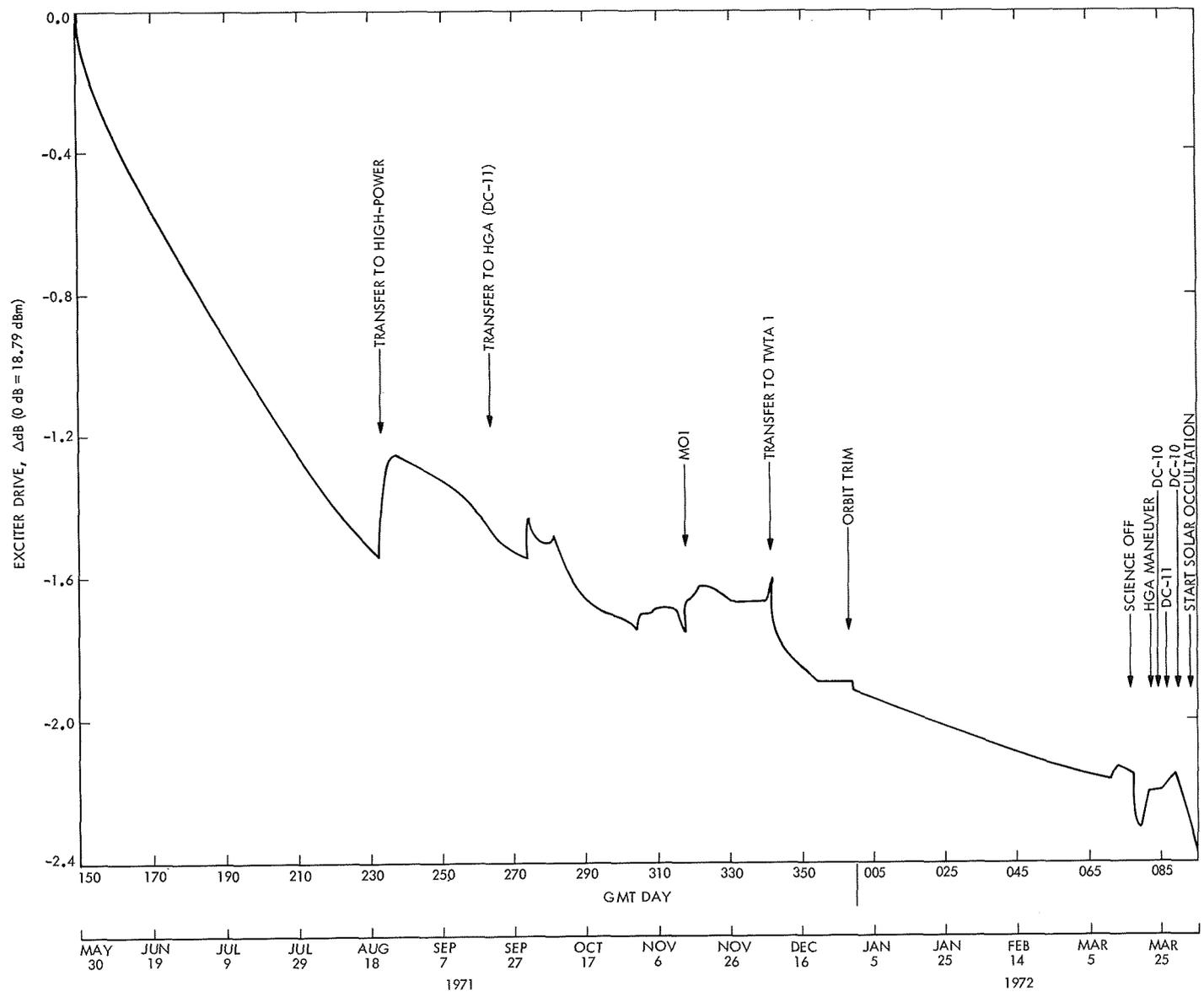


Fig. 28. Exciter drive vs GMT day

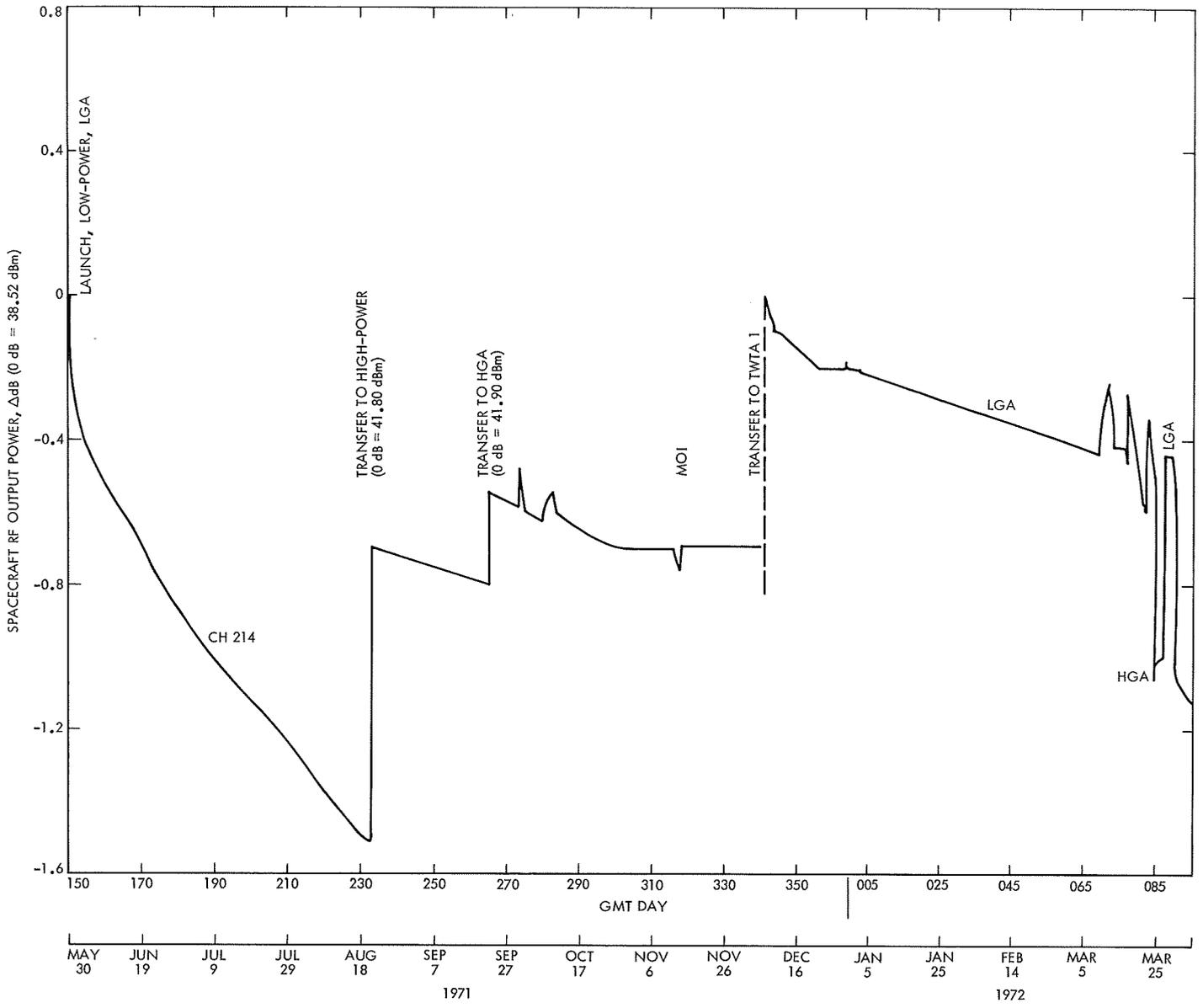


Fig. 29. Spacecraft RF output power vs GMT day

channels were temperature-sensitive, the curves were corrected for known temperature effects, using the voltage-controlled oscillator (VCO) temperature as a reference.

Prelaunch. Before liftoff, critical functions of the RFS were checked and verified. These included data sources and outputs, communication data links (up and down), application of spacecraft internal power, CC&S diagnostic events, and the various RFS functional measurements related to radio modes. Baseline or calibration values for all RFS telemetry channels were established.

Launch. At launch, the RFS LGA was transmitting one-way data to DSS-71 at the Air Force Eastern Test Range (AFETR), in the low-power mode, using exciter 2 and traveling-wave tube amplifier (TWTA) 2. Approximately 1 h later, DSS-51, near Johannesburg, South Africa, turned on its uplink transmitter and acquired the spacecraft downlink in the two-way mode. The first two-way data were received at 23:23:33 GMT on May 30, 1971.

The initial RFS telemetry values, in data numbers (DN), after lift-off were:

Exciter drive channel	92
LGA drive channel	38
VCO temperature channel	70

These data numbers serve as reference values (0 dB) in Figs. 28 and 29.

At 23:39:59 GMT on the same day, the first DC-9 (DC = direct command) was transmitted from DSS-51 to turn the RFS ranging channel on. Subsequently, at 14:09:58 GMT on May 31, the CC&S issued the first RFS cyclic 2A to turn the ranging channel off. Both of these events were executed and responded to correctly. Subsequently, the RFS responded correctly to all 2A and DC-9 commands.

Cruise. The first midcourse maneuver was executed on June 5, 1971, with satisfactory performance by the RFS. No significant changes occurred in any of the RFS telemetry channels.

The RFS remained in its launch mode (low-power, LGA) until August 21, 1971, when a DC-42 command was transmitted to effect a transfer of the TWTA to the high-power mode. After the switch, and after thermal transients had died out, the telemetry data showed that the reference VCO temperature had increased by 7°C, the exciter output power had increased 0.27 dB, and the spacecraft RF output power had increased by 4.1 dB.

The second RFS state change occurred on September 21, 1971, with the transmittal of a DC-11 command to switch the RFS from the LGA to the HGA. As a result of this switch, the RF output power registered a gain of 0.25 dB in addition to the apparent power increase seen on the downlink because of the higher antenna gain of the HGA. No appreciable changes were observed in the telemetered values of the VCO temperature or the exciter drive.

In close succession, on September 30 and October 8, 1971, two science calibration tests, the TV geometric scan calibration 1 and 2 tests, were completed (see Section III). Each had the effect of temporarily raising the temperature in the radio bay. The reference VCO temperature increased 4°C by the end of each test. This transient temperature increase resulted in apparent increases in the exciter drive of 0.05 to 0.14 dB and in the HGA drive of 0.1 dB during the two tests. Following the completion of the tests, a small net permanent gain in exciter drive occurred, but there was no appreciable change in HGA drive. These temperature transients made continuing

analysis of the exciter and HGA drive difficult. Accurate determination and prediction of these values were important because HGA drive directly determined the signal level received on the downlink, and exciter drive determined what the HGA drive would be.

On November 2, 1971, another preinsertion science test, the TV photometric calibration of Saturn, was performed. As a result of this test, the radio bay temperature rose by 5°C; this induced a 0.08-dB increase in exciter drive but no apparent change in HGA drive.

Mars orbit insertion. The Mars orbit insertion (MOI) was accomplished successfully on November 14, 1971. During this maneuver, the RFS output was switched to the LGA/MGA system, and the MGA was oriented toward Earth for the first time. The switch from HGA to LGA was done by means of a DC-10 command. Shortly after the 15-min motor burn, the spacecraft entered its first Earth occultation. Upon exit occultation, the RFS was in one-way transmission, but soon afterward an uplink was received, and the RFS went back into two-way transmission. As soon as it was determined that the spacecraft was operating normally and had reacquired the Sun and Canopus, a DC-11 command was transmitted to switch the spacecraft back to the HGA.

By the end of the MOI, the RFS experienced a transient 4°C increase in temperature. A 0.05-dB perturbation in exciter drive resulted, but there was no change in the RFS output power (LGA or HGA drive).

Switch to RFS TWTA 1. On December 8, 1971, the RFS experienced an anomaly in TWTA 2, and a switch to TWTA 1 was made by transmission of a DC-7 command at 04:33:00 GMT, approximately 2 h after the anomaly was first observed. The net effect on RFS performance (from before the anomaly until after the switch) was a decrease of less than 0.1 dB in exciter drive and an increase of 0.58 dB in spacecraft RF output power. There was also a shift in the radio bay temperatures caused by the different temperature distribution existing in the bay after the switch.

Orbit trims. Both orbit trims required a switch from the HGA to the LGA/MGA, roll and yaw maneuvers, a short-duration motor burn, turn unwinds, and a switch back to the HGA. A CC&S-issued 2B event transferred the downlink from the HGA to the LGA/MGA. (A DC-10 had accomplished this function during MOI.) Following the successful completion of the trim, the CC&S issued a

2E command to transfer the downlink back to the HGA (accomplished by a DC-11 during MOI).

As a result of the trim, there was a 2°C thermal transient decrease in reference VCO temperature, and a consequent 0.04-dB decrease in exciter drive, but no apparent change in the spacecraft RF output power (LGA/HGA drives).

CC&S checksum anomaly. On March 17, 1972, the science instruments were turned off for the first time since the second orbit trim (December 30, 1971) to permit the resolution of a possible CC&S problem. The turnoff caused the temperature of the radio bay to decrease by 5°C over a period of 5 days. As a result of the temperature change, the exciter drive decreased temporarily by 0.2 dB and the RF output power by 0.2 dB. Because the science turnoff temperature effect indicated the daily temperature transients to be expected during the solar occultations, there was some concern that they could have an adverse effect on the RFS.

Pre-solar-occultation engineering test period. Between March 24 and 30, 1972, the spacecraft operated alternately on the HGA and on the LGA. Each transfer between the two antennas caused step changes of approximately 0.56 dB in the RF output power. This was about twice the change which had occurred at the initial switch to the HGA during the Earth-Mars cruise.

b. Anomalies

Abrupt losses after launch. During the first 3 days after liftoff, unpredicted decreases occurred in exciter drive (0.16 dB), local oscillator drive (0.29 dB), and LGA drive (0.17 dB). The cause of these decreases was believed to be differential cooling of the various portions of the radio bay following the change from Earth environment to the vacuum of space. The rates of cooling of the level sensor detectors for the three channels were different from the rate of cooling of the receiver VCO reference temperature transducer. As a result, the drops in the channels were not real, i.e., the actual engineering unit (EU) values in dBm did not change although the DN values, as transmitted, did change, primarily because of a temperature calibration problem rather than any actual loss in RF output power.

Exciter degradation. Following the relatively abrupt decreases in the exciter drive and LGA drive channels at launch, there were additional decreases in these channels which appeared to be real rather than caused by temperature effects. Later, when the switch to HGA occurred, the

HGA drive channel was observed to decrease in the same manner as the LGA drive channel. The decreases in these three channels were slow and gradual, with small transients only, and occurred at a diminishing rate.

The degradation of exciter drive decreased after the switch to high-power operation, possibly because of "healing" effects of higher temperatures. Similarly, after the science calibration tests just before MOI, small decreases in the rate of degradation were discernible after several days' data were plotted.

Extensive analyses (Ref. 33) were done at JPL and at Motorola, Inc., the RFS subcontractor, to determine the nature and cause of the exciter drive anomaly and to predict the future behavior of exciter 2, which was on at the time, and exciter 1, which was quiescent. First, through careful study of the actual rate of degradation of exciter drive and of spacecraft RF output power, it was determined that, except for the short transient immediately after launch caused by differential cooling, the decrease in spacecraft RF output power could be attributed to the exciter drive degradation based on the known input/output transfer characteristic of the TWTA; i.e., there was no separate TWTA problem at that time.

The cause of the exciter drive degradation was a zenering effect on transistors Q2 and Q4 in the $\times 2$ portion of the $\times 30$ frequency multiplier module. As predicted by one aspect of this model, the actual power output of the Mariner 9 exciter 2 continued to decrease, but the rate of decrease slowed. It was also found that transistors Q2 and Q4, in a zener-degraded state, were particularly sensitive to temperature changes. As verified by Mariner 9 flight data, spacecraft state changes raising the temperature of the radio bay and, consequently, that of the $\times 30$ module produced an increase in exciter drive. This effect could be reproduced in ground tests. The Mariner Mars 1971 proof test model (PTM) exciters and a flight spare $\times 30$ module were used for these tests, and all exhibited the same type of degradation, although at different rates.

It was predicted that the zenering effect on the transistors in the $\times 30$ module would not in itself be catastrophic to the spacecraft or the mission. Should the exciter 2 drive degrade by more than 5 dB from its launch value, the CC&S radio cyclic 2A event would automatically transfer the signal to exciter 1. The evidence was that the rate of degradation of exciter 2 was higher than that of exciter 1 (as was later confirmed in flight after the May 30, 1972, switch to exciter 1). It was further believed that should the 2A command not switch exciters at the -5 dB

level, the zenering effect would begin to cause spectral breakup in the $\times 5-\times 3$ multiplier chain, which would be characterized by noncoherent oscillations and spurs modulating the RF carrier, rather than by complete failure of the exciter.

RFS static phase error (SPE) anomaly. On November 17, 1971, after the seventh periapsis and Earth occultation, a 2-h uplink frequency search was required before the receiver could be two-way locked. The receiver acquired at a receiver SPE channel reading of 74 DN. After this behavior was repeated a number of times upon exit occultation, it was determined that the receiver best-lock frequency had shifted from a normal SPE channel reading of 64 DN to 74 DN. In addition, ground tests showed that the flight command subsystem (FCS) was affected by the anomaly, and that the receiver automatic gain control (AGC) curve had shifted from its prelaunch value over some range of signal levels and was sensitive to uplink signal level.

A number of tests with the Mariner 9 RFS and FCS determined the "new" characteristics of the RFS. The AGC curve was no longer stable, particularly at levels of -130 dBm and above, such as were available from DSS-14. The deviation from prelaunch calibration was as much as 2 to 3 dB. The rate-tracking capability of the receiver was also reduced. This facet of the anomaly was discovered when the 26-m-diameter antenna stations could not acquire the uplink at accustomed rates. In addition, at least some of the time, the returned ranging power was less than predicted. The deviation from predictions seemed to be a function of uplink power level or, more particularly, uplink carrier level. It was found also to be a function of uplink frequency offset from best lock at some power levels. Tests showed that a "pushing effect" existed with respect to the FCS VCO when the uplink was present but unmodulated by command modulation. This pushing effect was a shift in the FCS VCO free-run frequency, which varied with uplink signal level.

Even with critical examination of flight data, ground testing, and analysis, no single unmistakable cause for the anomaly was isolated. A number of possible failure modes were deduced, and one was simulated in ground tests, which produced effects resembling the observed anomalies in the Mariner 9 receiver. This failure mode involved the shorting of a tantalum capacitor in the 9.56-MHz IF amplifier. The effects of this short circuit included a loss in overall receiver gain and, consequently, in output amplitude to the FCS, a dephasing of both the AGC loop and the ranging channel, and a reduction in the tracking rate

capability of the receiver. Analysis of the magnitude of the FCS VCO pushing effect indicated that a net loss of 20 to 25 dB in receiver gain existed at strong signal levels, and that receiver gain was almost normal at threshold.

The flight tests confirmed that the FCS threshold remained essentially unchanged from its prelaunch value despite the reduction in both signal amplitude and noise voltage from the RFS. Hence, normal commanding continued. The pushing effect in the FCS VCO frequency was compensated for operationally by adjustment of the command subcarrier frequency from the DSSs. Empirically, the loss in ranging performance could be compensated for either by increasing the ranging modulation carrier suppression to 18 dB or by using the normal 9-dB suppression but with the uplink S-band frequency offset by approximately $+35$ kHz from best lock. The lower frequency-rate capability was taken into account by slower uplink tuning by the DSSs, and no operational problems resulted.

TWTA 2 anomaly. This anomaly was first observed when the spacecraft exited from orbit 48 Earth occultation. The anomaly occurred during the occultation (between 02:16 and 02:30 GMT on December 8, 1971). The TWTA anomaly was first made evident by multiple alarms on the temperature and dc power channels associated with the TWTA. There was also a loss of 0.5 dB in RF output power, as monitored by telemetry on the HGA drive channel and confirmed by the downlink AGC at DSS-14. The TWTA helix current channel indicated a 9.5-mA increase; the TWT anode 2 voltage channel showed an increase between 0 and 6 V; and power telemetry channels indicated a 24.2-W increase in the power provided to the RFS. At the time of the anomaly, TWTA 2 was operating in the high-power mode, and the exciter drive was down -1.8 dB from the launch value because of the anomaly described previously.

Analyses were conducted by JPL and the subcontractors (Watkins-Johnson Company for the TWTA and Hughes Aircraft Company for the TWT) to determine the cause for the TWTA 2 anomaly, to predict whether TWTA 1 would be subject to the same failure mode, and to offer a prognosis of what would occur if it were necessary to switch back to TWTA 2 because of a subsequent problem in TWTA 1. Although the Watkins-Johnson Company tests (Ref. 34) determined that the cause of the anomaly was either in the high-voltage converter or in the TWT itself, the exact cause was not identified. However, it was agreed that any switch back to TWTA 2 should be done in the low-power mode, because the lower stresses would increase the probability of survival.

RF output power transient drop. On February 16, 1972, an anomaly was observed in the telemetered RF output power. The HGA drive channel first lost and then regained 0.27 dB in RF output power during an 18-min period, while all other RFS telemetry channels continued to be normal. This change in RF output, if real, was too small to be observed in station AGC or in engineering channel signal-to-noise ratio (SNR), and it had absolutely no effect on the mission. Nonetheless, a problem/failure report was assigned to the anomaly because the phenomenon was not understood, and larger deviations might result in the future. However, the anomaly did not recur, and its cause is unknown at this time.

2. Flight command subsystem. The FCS functioned normally throughout the mission. The total number of commands processed by the Mariner 9 FCS was much greater than that processed by previous Mariners—approximately 37,500 through March 31, 1972, compared to 948 for Mariner 7 and 1301 for Mariner 6.

Two measures of FCS performance are the threshold and the drift rate of the VCO. Based on the probability of false in-lock, there were no detectable changes in the FCS threshold throughout the mission. The actual VCO drift rate was very close to the prelaunch predicted rate. The tracking stations adjusted the uplink command subcarrier frequency periodically to correspond to the drift of the VCO, and thereby kept the loop stress in the FCS to a minimum.

The RFS receiver anomaly which occurred shortly after Mariner 9 insertion into Mars orbit degraded the signal to the FCS significantly. However, command capability was not affected. One effect, the “pushing” of the VCO frequency as a function of uplink carrier level, described previously, was quickly corrected and never became a serious operational problem.

Fewer than 0.06% of all commands transmitted were aborted through ground system malfunctions. Any lost command was retransmitted, so that there was no effect on mission operations. There was one false command caused by a ground problem. This command was rejected by the spacecraft and had no effect on operations.

a. Operations. One indication of the intensity of FCS operations is the cumulative total of commands processed by the FCS through the standard mission. Of the total of 37,577 commands processed, 1823 were DCs; 26,037 were CC-1s or CC-2s; 9 were CC-3s; 5910 were CC-4s; 2604

were CC-20s; and 1193 were qualitative commands (QCs), and one false command.

b. Performance

Threshold. The threshold was measured periodically throughout the mission. Routinely, during an RFS/FCS threshold test, the uplink power level was decreased until the FCS dropped pseudonoise (PN) lock. This was a gross indicator of threshold, but because of the statistical nature of the noise and the PN system, it required a “two-out-of-lock” test to ascertain the threshold with some degree of confidence. Such a test was run shortly after the RFS receiver anomaly occurred and confirmed the gross estimates from the routine threshold tests. A second two-out-of-lock test was planned for the end of mission.

Threshold also can be deduced from the false in-lock rate (Fig. 30), which is a measure of the lock channel threshold value. The false in-lock rate was slightly higher than specifications prior to FCS delivery to the spacecraft assembly facility; however, this was accepted by waiver. Figure 30 shows that the false in-lock rate has had little overall variation during flight. The large spread in the data from point to point is due mainly to the small number of samples available for each point.

VCO drift rate. Tests performed during development and spacecraft integration showed that the free-run frequency of the FCS VCO drifted continuously with time. The predicted drift was calculated on the basis of an exponentially decaying rate. VCO free-run averages were obtained periodically throughout the mission to assure that the drift rate remained as predicted. Figure 31 shows the good agreement between predicted and measured VCO drift rates. The VCO drift rate required nothing more than periodic adjustment of the uplink command subcarrier frequency.

Effect of RFS receiver anomaly. Among the symptoms of the RFS receiver anomaly was a 25-dB decrease in gain, which caused both the signal and the noise voltages to the FCS to be decreased greatly. In fact, the amount of shift in receiver gain was confirmed by determining that the FCS VCO frequency as a function of uplink carrier power had changed so that the VCO was pushed to a higher frequency with strong (-140 dBm and greater) uplink carrier power. This “pushing” effect was compensated for by changing the ground subcarrier frequency. Without such a change, the FCS phase-locked-loop (PLL) lockup time would have been considerably increased, and in extreme cases, the loop might not have locked at all.

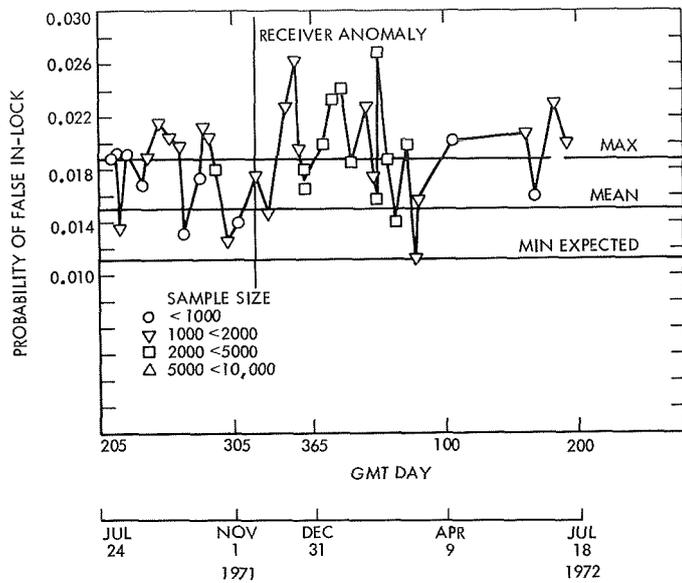


Fig. 30. Probability of false in-lock vs time in flight operations

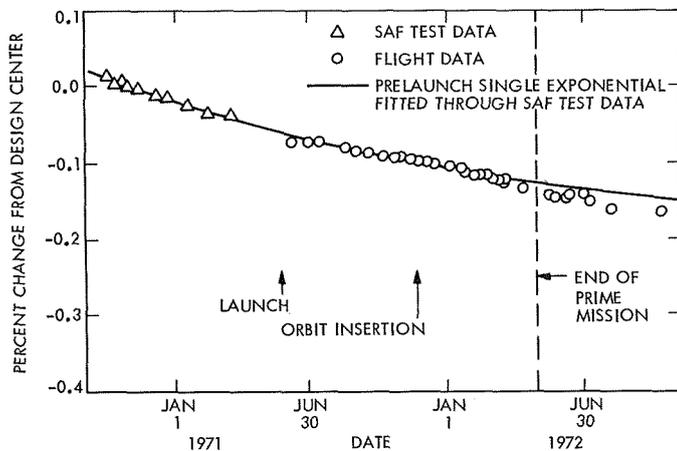


Fig. 31. Predicted vs measured FCS VCO free-run frequency

c. Commanding problems

Commands aborted at the station. Ground command aborts occurred sporadically throughout the mission. The 22 aborts through April 1, 1972, are listed in Table 15, together with their probable cause. The first seven were related to a design deficiency in the command software at the tracking stations. This problem was solved, and the remaining aborts occurred as a result of equipment failures or operator errors.

False command. One false command occurred when the station clocked out a "word-start" pattern (1 1 0), followed by a 1 and all 0s. Because of the word-start, this

Table 15. List of command aborts from launch through April 1, 1972

Abort No.	Day	DSS	Command	Type
1971				
1	169	41	CC	Bit verify failure
2	169	41	CC	Bit verify failure
3	169	41	CC	Bit verify failure
4	169	41	CC	Bit verify failure
5	169	41	CC	Bit verify failure
6	216	41	DC-9	Bit verify failure
7	232	41A	DC-9	Bit verify failure
8	224	51	DC-9	Bit verify failure (exciter frequency problem)
9	256	42A	DC-9	Symbol rate limit, also drop lock
10	270	62B	CC-4	Bit verify failure (bit rate error alarm)
11	271	12A	CC-1	Manual abort button
12	271	12A	CC-1	Bit verify failure
13	328	12		PN quality failure (operator error)
14	328	12		PN quality failure (operator error)
15	328	12		PN quality failure (operator error)
16	328	12		PN quality failure (operator error)
17	345	12A	DC-19	Commercial power interrupt turned ground station exciter off
18	355	12A		Bad command modulation indicator switch
19	358	12A		Station turned modulation off early (sequence of events error)
1972				
20	46	41A	CC-20	Bit verify failure
21	51	41A	CC-20	Bit verify failure, telemetry command processor (TCP) failure
22	51	41A	CC-20	Bit verify failure, TCP failure

false command was processed by the FCS; however, since the remainder of the command was invalid, no switches were closed to any user subsystems.

3. Telecommunications flight operations. The Mariner 9 telecommunications system design is described in

Ref. 35. Telecommunications flight operations through March 31, 1972, are summarized in the predicted and actual values of downlink AGC shown in Fig. 32. Most of the significant telecommunications events appear as changes in either predicted or actually recorded AGC. Automatic gain control is a measure of the carrier power

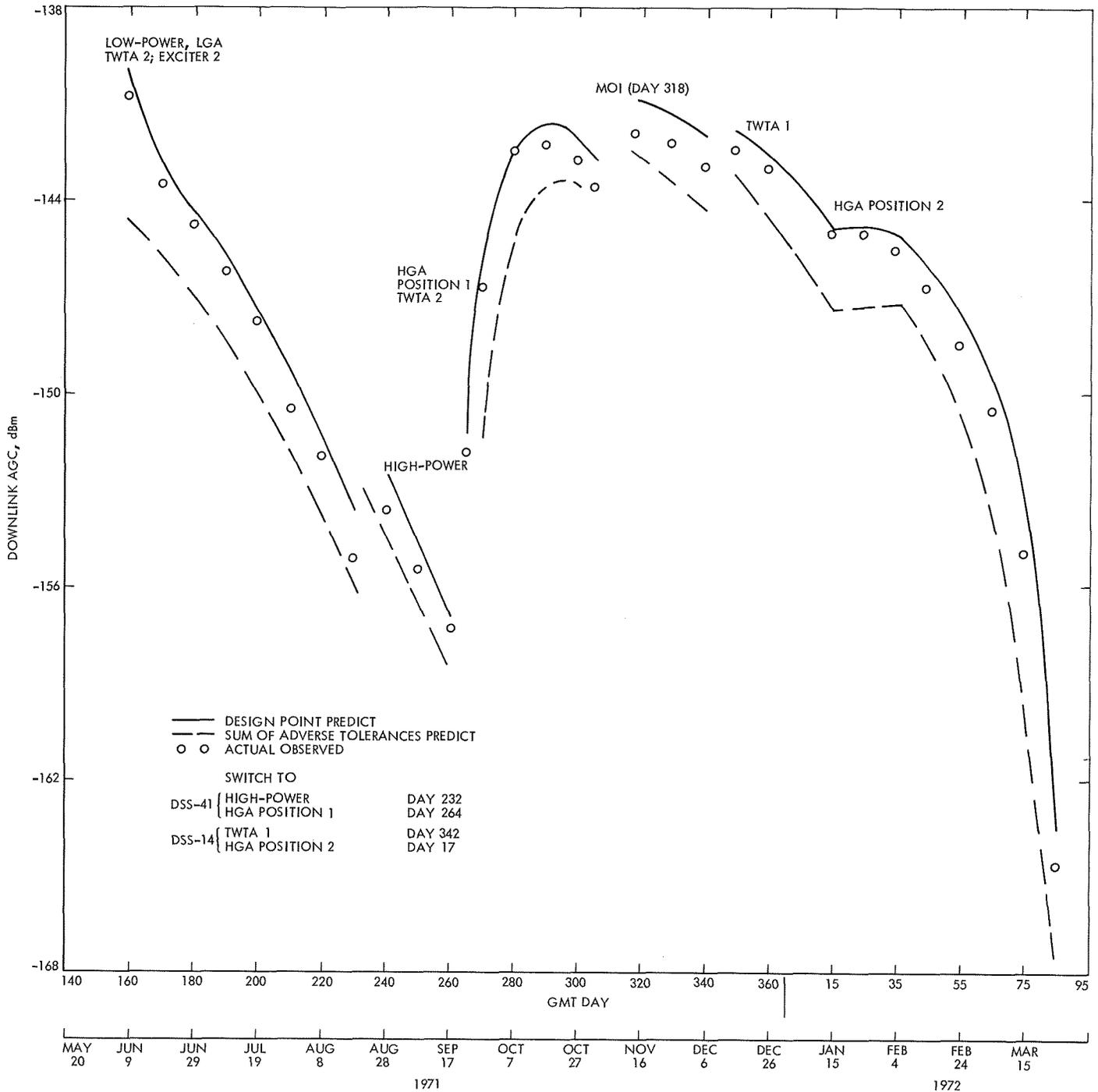


Fig. 32. History of downlink AGC from launch to April 1, 1972

received at the tracking stations and is thus affected both by changes in total power received from the spacecraft and by telecommunications mode changes which alter the ratio of carrier to total power.

a. Switch to TWT high power (August 21, 1971, day 233). When launched, the spacecraft was transmitting in the low-power mode, using RFS exciter 2 and TWTA 2, from the LGA. Approximately 80 days out, when thermal conditions permitted, a DC-42 was transmitted to switch to the high-power mode. The switch was normal and increased the RF output from the spacecraft by 4 dB.

b. Switch to HGA (September 21, 1971, day 264). One month after the switch to high power, the Earth came into the beamwidth of the HGA (about 10 deg between the -4 dB points). Because the isolation between LGA and HGA ports on the RFS was known to be imperfect, there was concern that a "transmit interferometer" effect might cause loss of the downlink as the power "leaked" by the HGA equaled in magnitude the power transmitted by the LGA. Such an interferometer effect would result in periodic enhancement and reduction of the signal level received at Earth. The date of the switch was selected so that received signals from the two antennas would be approximately equal, and the leaked signal would still be too low to create an objectionable amount of interferometer effect. Up to the time of the switch, no interferometer effect had occurred over several consecutive ground station tracks. This indicated that the isolation between RFS ports was at least 20 dB, which was better than expected.

c. Mars orbit insertion (November 14, 1971, day 318). The medium-gain antenna, designed to permit telemetry during the insertion motor burn, was oriented toward the Earth for the first time during MOI. Because there was little margin for error and no opportunity to repeat the maneuver, insertion required elaborate contingency plans to allow the maximum possible time for commanding the spacecraft in the event of an emergency. These sequences accounted for the "blackout" times that occurred on both the uplink and the downlink while the Earth was in the region between the LGA and MGA patterns, as well as for the FCS relock time of slightly less than 10 min. The insertion went according to plan, and no commanding was required. The telecommunications events included a switch back from the HGA to the LGA (via CC&S-programmed 2B event) during the maneuver at a time chosen to avoid the transmit interferometer effect, and a switch back to the HGA (with a DC-11) 2 h after the motor burn, when it had been ascertained that the maneuver was normal.

d. First orbit trim (November 16, 1971, day 320). The first trim was a virtual repetition of the insertion, with one important difference: quick reestablishment of command capability after blackout was not required because the trim could be repeated at a later time if necessary. The trim was normal.

e. RFS receiver anomaly (November 18, 1971, day 322). When Mariner 9 exited from Earth occultation after the seventh periapsis, DSS-14 was not able to acquire the downlink immediately. After several orbits, it was determined that the apparent best-lock frequency of the RFS receiver had shifted about -8.5 kHz. An intensive analysis was conducted on the RFS and the FCS to ascertain the effects of the failure on future operations. The failure (possibly a shorted tantalum capacitor) resulted in the loss of gain in one stage of the 9-MHz limiter-amplifier, which caused (1) the shift in best-lock frequency, (2) a change in the signal and noise characteristics in the output to the FCS, and (3) a change in receiver tracking capability which affected the maximum uplink tuning rate capability at the ground stations.

f. RFS TWTA failure (December 8, 1971, day 342). Three weeks after the RFS receiver anomaly, again upon exit from Earth occultation, several of the temperature and power channels associated with the operating TWTA were in alarm. Two hours after the first alarm observation, and based on analysis of the situation, a DC-7 was transmitted to switch to the redundant TWTA 1. The analysis showed that the faulty TWTA had drawn about 24 W excess dc power after failure and that the RF output from the spacecraft had dropped 0.5 dB; these conditions were stable until the switch, at which time, the spacecraft returned to normal. TWTA 1 has operated normally since the switch. The cause of the TWTA 2 failure is not known with any degree of certainty.

g. Second orbit trim (December 30, 1971, day 364). The telecommunications profile for this trim was similar to that for the first trim. Because of the receiver anomaly, the uplink AGC channel showed a shift during acquisition tuning at the beginning of the DSS-14 track. Later, during the exact time of motor burn, the channel again shifted. Analysis showed that the shift was most likely caused by doppler rate induced by the motor burn and not by an actual change in RFS characteristics. The latter would have suggested "healing" of the RFS anomaly; twice later during the mission, telemetry changes suggested that short-term healing of the anomaly may have occurred.

h. Standard mission (November 14, 1971, day 318, through April 1, 1972, day 092). The spacecraft was almost continuously in either real-time science 2 (RTS-2) or the playback data mode while being tracked by DSS-14. When in view of the 26-m stations, the spacecraft operated in the real-time science 1 (RTS-1) mode, which provided 50-bps science data. The high-rate science data were returned at 16.2 kbits/s (playback) and 8.1 kbits/s (RTS-2) until expected increasingly unfavorable antenna angles forced a reduction through the 8.1-, 4.05-, and 2.025-kbits/s data rates. Engineering telemetry was returned at 33½ bits/s throughout most of the prime science period.

As science SNR decreased, it was found that not only did the bit error rate increase (as expected) but also that large chunks of TV pictures and other science data were lost (which was not expected). The difficulty, caused by data synchronization requirements in DSS-14 and Space Flight Operations Facility (SFOF) processing equipment, was eliminated by reducing the originally programmed threshold SNR (by typing in a lower value) in the station TCP from 3 to 0 dB and by relaxing the requirements on PN errors in the mission and test computer (MTC) in the SFOF. After these changes were made, usable TV pictures were received at an SNR as low as 1 dB. The "usability" of a picture, always a subjective quantity, was strongly influenced by its detail and contrast. Figure 33 shows a TV picture, the top portion of which was received at 2.5 dB, while the station was in the listen-only configuration, and the bottom part at 0.5 dB, after the station had inserted the diplexer for two-way operation.

As engineering channel SNR decreased, it was found that the usability of the data was a function of the format as well as of the SNR. Alarm formats were particularly susceptible to bit errors and were unusable at SNRs below about 5-dB. On the other hand, the plot formats could be used down to about 2-dB SNR because the eye can integrate out bit errors. An example is shown in Fig. 34, which is a plot of the gyro channels received on the last day of DSS-62 tracking, when the ratio was 2 dB; upon handover to DSS-14, the ratio increased to 8 dB, and bit errors were virtually absent.

i. HGA switch to position 2 (January 17, 1972, day 017). The switch (made by a CC&S-controlled 8D event) was scheduled at a time when equal downlink power would be received from the HGA in either position. The switch was normal and was confirmed immediately by the appropriate counter events and by effects on the gyro channels.

However, it required a full week to ascertain definitely the effects of the switch on downlink AGC and in the

SNR. This time delay was characteristic of comparative telecommunications analysis throughout the flight mission because of the extraordinary resolution and accuracy required in the analysis. Day-to-day and pass-to-pass variability made long-term integration a necessity, both for analysis of ground station performance and for confirmation of spacecraft RF output.

After the antenna position switch, the science data rate remained at 16.2 kbits/s. The telecommunications performance, which had been decreasing up to this time, leveled out for about 3 weeks as expected. The continuously increasing distance to Mars was compensated for by the decreasing angle of the Earth to the HGA boresight.

j. Loss of 26-m station tracking capability (March 1972). Decreasing downlink telecommunications performance, caused by the increasing distance to Mars and increasing angle from Earth to the HGA boresight, resulted in loss of the RTS-1 capability at the smaller ground stations on March 14, 1972 (day 074); loss of the 33½-bit/s engineering mode capability on March 20 (day 080); and finally, loss of the 8½-bit/s engineering capability on March 31 (day 091). These stations still had a 1- to 2-dB performance margin for commanding, and they issued occasional commands through the summer of 1972. Thus, DSS-14 could remain in the listen-only mode, thereby increasing the data SNR at that station; and solar occultation sequences could be conducted later, when the station was not tracking.

k. Decrease in downlink capability at DSS-14 (March 1972). By March 31, 1972 (day 091), the Earth had moved so far from the HGA boresight that the effective gain of this antenna was no greater than that of the LGA. Accordingly, a switch was made to the LGA, and the spacecraft continued to use it for transmission. After the switch to LGA, DSS-14 was able to receive data only in the engineering mode. When in the listen-only configuration, at higher elevation angles, the station could receive 33½ bits/s; however, the data rate had to be reduced to 8½ bits/s whenever the station was in two-way configuration (diplexer in for transmitting) or at lower elevation angles.

4. Power subsystem. No battery energy was required to supplement the Mariner 9 solar array power output during the midcourse correction maneuver on June 4, 1971. At this stage in the mission, the spacecraft was close to the Sun, and the array output power capability was far in excess of the power requirement, even with the 44.7-

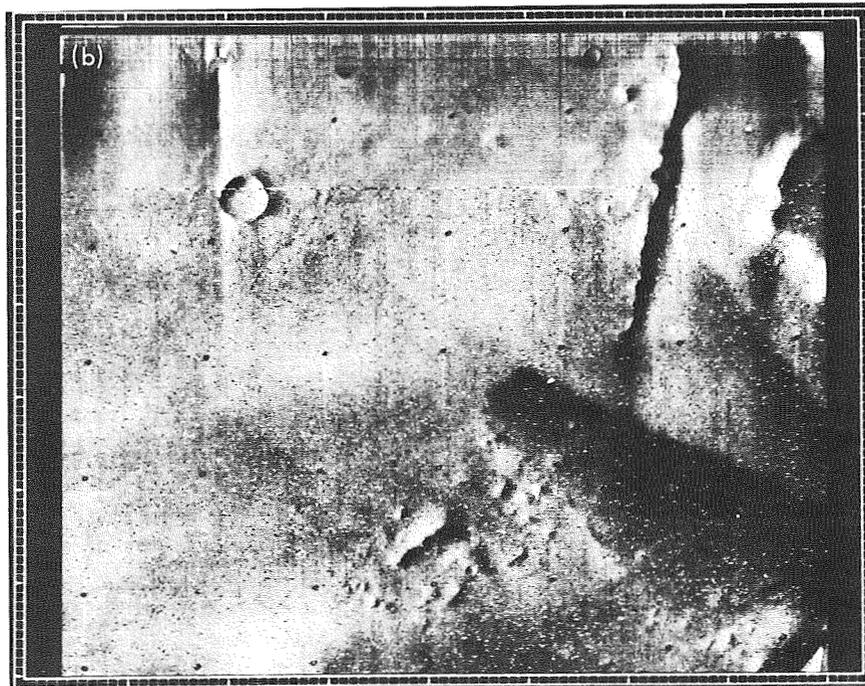
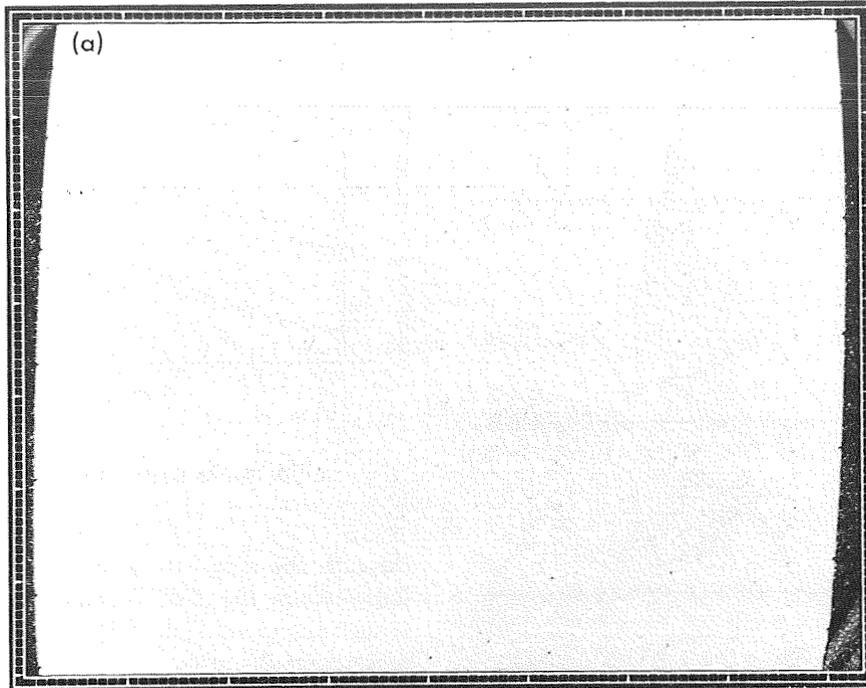


Fig. 33. Typical TV picture received at low signal-to-noise ratio after SNR and PN bit errors were less constrained (first 25% of picture was received at 2.5 dB SNR, last 75% at 0.5): (a) "Raw" picture before enhancement, (b) Enhanced picture

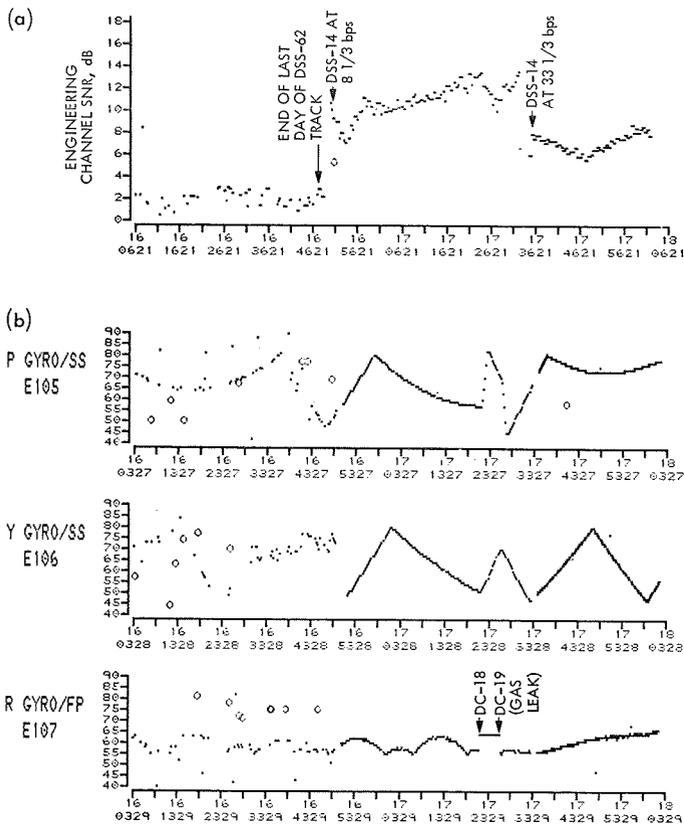


Fig. 34. Plot data quality as a function of engineering channel SNR: (a) SNR at DSS-62, handing over to DSS-14 (March 30, 1972), (b) Typical engineering telemetry channels resulting from above SNR

deg turn from the Sun required for the proper motor thrust vector. The spacecraft required 301 W at the array during the maneuver. The array maximum power on the day of the maneuver was estimated at 845 W with the solar array normal to the Sun. When the spacecraft was maneuvered from the Sun for the motor burn, the power was estimated at 632 W. This estimate included the effects of array shadowing by spacecraft structures.

Operational changes within the Mariner 9 power subsystem were of interest during the cruise to the planet. One change was the gradual potential increase on the dc power bus. With a constant spacecraft power profile, the array operating point gradually increased in potential as its temperature slowly declined because of the recession of the spacecraft from the Sun. The dc power bus potentials are plotted in Fig. 35, along with the Mariner 9 heliocentric distance. The two plots have a similar shape because of the relationship between the array operating point with a given load, the array temperature, and the heliocentric distance. An average potential curve is drawn

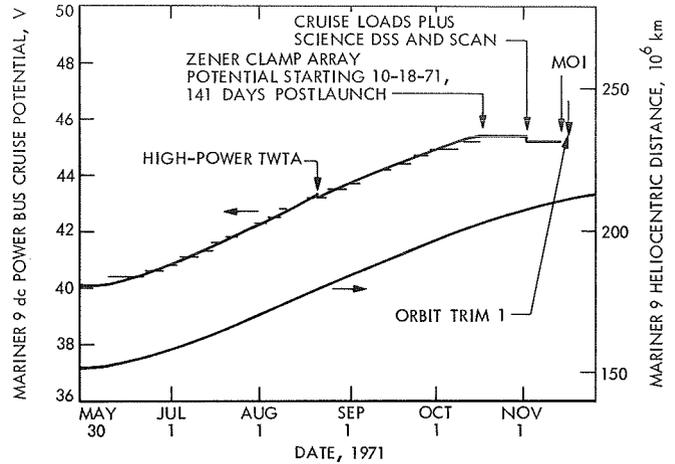


Fig. 35. Dc power bus potential during cruise

through the data points in the figure; this curve shifted down when the TWTA was commanded into its high-power mode, on August 21, 1971, to cause a 37-W power increase at the array. The bus potential continued to rise until October 18, 1971, when it was limited by the solar-array zeners, 141 days after launch, and 27 days before MOI. The Mariner 9 heliocentric distance at the time was 202.99×10^6 km, the Sun intensity 75.90 mW/cm^2 , the array temperature 3.3°C , the array load 303.1 W, and the dc power bus voltage 45.4 V. The voltage shifted downward again with the turn-on of precounter science loads, causing a 66-W increase at the array, in November 1971.

Battery operation also changed with the Mariner 9 trajectory to Mars. As the dc power bus potential increased, as shown in Fig. 36, the potential drop across the battery charger increased. After launch, the dc power bus potential was 2.8 V above the battery potential, the difference between the two being the battery charger potential drop. With this low potential drop, the battery low charge rate was 0.282 A. The full limiting low charge rate was 0.614 A, but that rate was attained only after the potential drop across the battery charger reached or exceeded 5.9 V. Figure 36 shows that the charger low rate gradually increased with the charger potential drop, and that it reached its 0.614-A limiting value in steady state on August 23, 1971, 85 days after launch and 83 days before Mars encounter. During cruise, the battery temperature followed the magnitude of the low charger rate. The Mariner 9 battery was generally in a planned overcharge mode during the mission, and the low charger rate provided its trickle charge requirements to replenish capacity lost because of self-discharge. However, most of the low-

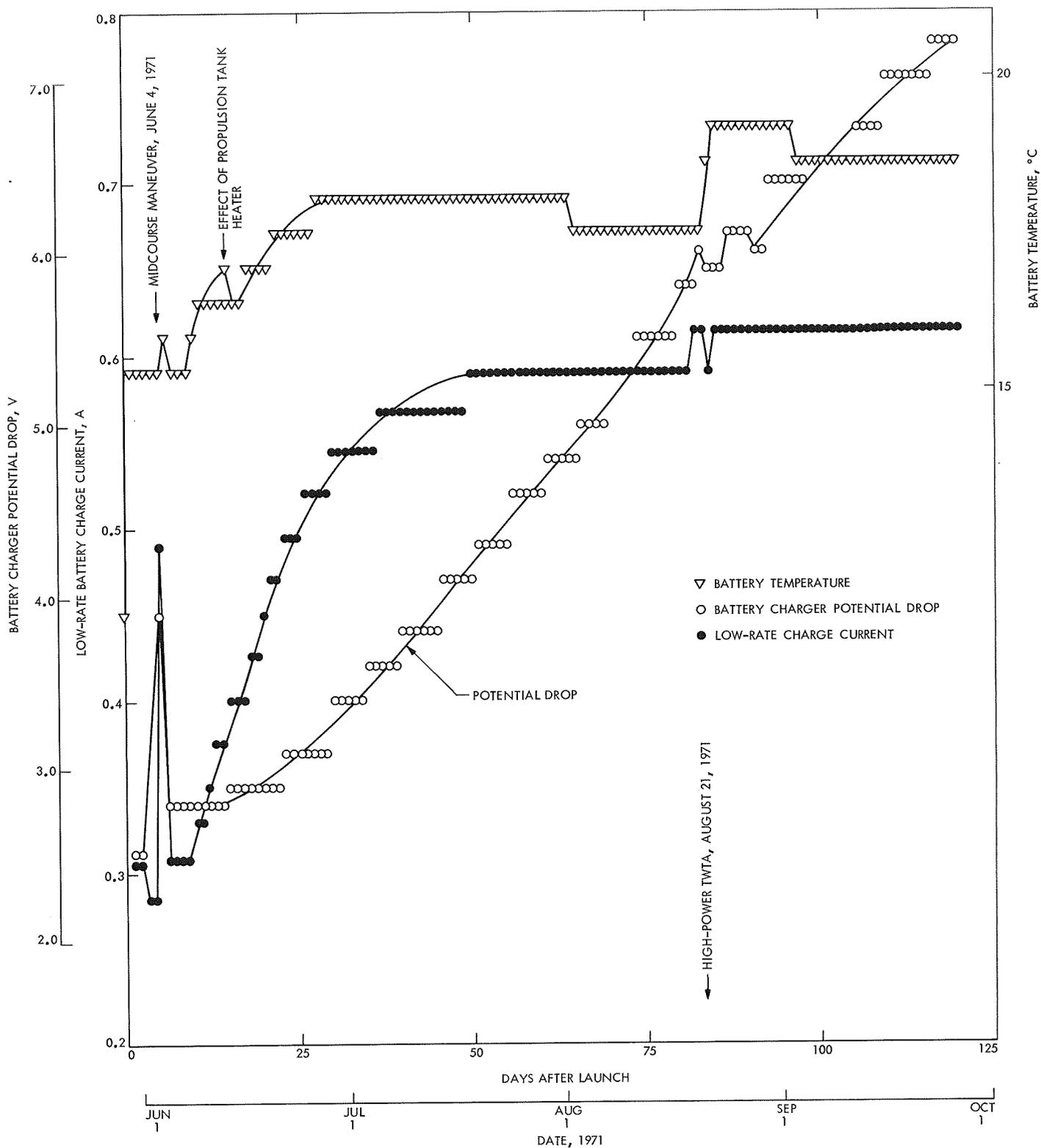


Fig. 36. Battery charge parameters during cruise

rate charge generated heat that was almost directly proportional to the charge rate level, until equilibrium temperature conditions were reached.

The trajectory correction maneuver caused operational changes in the battery, although it was not used during this mission phase. After reacquiring the Sun, the array was operating cold for a short time, causing an increased charger potential drop that increased the battery low charge rate. These effects are shown in Fig. 36. Also shown are battery temperature increases caused by the operation of the propulsion tank heater and the high TWTA mode. Charger operation was also affected by the high-power TWTA mode. Battery temperature equilibrium was reached 28 days after launch and lasted over a month. The spacecraft bus temperature then declined, because of increased Sun distance, and with it, the battery temperature decreased, starting 65 days after launch. The battery temperature is seen to decrease again for the same reason starting 97 days after launch, after the high TWTA power mode had shifted the temperature upward.

Another trajectory-related power subsystem change was that of the cruise electrical loads. Although the Mariner cruise power profile changed but once when the TWTA operating mode changed, the total array load increased with heliocentric distance (because of battery charger power requirements) until the charger reached its full limiting low-charge-rate magnitude, and (because of the increasing dc heater dissipation resulting from the increasing dc power bus voltage) until the array voltage became zener clamped. The array loads were 242.5 W soon after launch, when they were normalized to cruise power configuration with the TWTA in the low-power mode, and were 266 W just prior to the preencounter science sequences. The 23.5-W increase represents the influence of the spacecraft heliocentric distance during this interval on one spacecraft cruise power configuration.

Mariner 9 required battery energy to supplement the solar array power during the MOI phase on November 13,

1971; orbit trim maneuver (OTM) 1 on November 15, 1971; and OTM 2 on December 30, 1971. The spacecraft data record for the MOI is good. However, data outages obscured the start and end of the battery discharge sequences for both OTMs. The outages resulted from RFS occult intervals caused by the planet celestial configuration and antenna misorientation during the maneuvers. Some battery parameters during these mission phases are shown in Table 16, with estimates wherever possible.

5. Scan platform control subsystem

a. Performance. The scan platform control subsystem met the mission requirements for pointing control and knowledge. The mission pointing accuracy requirements for the platform-mounted science instruments were 0.50 deg (3σ) for *a priori* pointing control accuracy and 0.25 deg (3σ) for *a posteriori* pointing knowledge. The pointing accuracies achieved were:

- (1) Cone pointing control: 0.378 deg (3σ).
- (2) Cross-cone pointing control: 0.486 deg (3σ).
- (3) Cone pointing knowledge: 0.096 deg (3σ).
- (4) Cross-cone pointing knowledge: 0.153 deg (3σ).

These accuracies were accomplished by ground and in-flight calibration.

The in-flight calibration was performed using the television imaging system in conjunction with scan control and attitude control subsystems. Forty-three days prior to encounter, an initial calibration was performed to determine large scan pointing offsets. Six days later, pointing over the entire range of the scan platform, the field of view (FOV) was calibrated. The calibration was performed by knowing the exact positions of the stars and the spacecraft attitude, taking TV pictures of stars, and then determining the offsets in star positions from the expected positions. In addition to pointing errors, the in-flight calibration revealed scan control feedback loop nonlinearities that had not been ground-calibrated.

Table 16. Battery parameters during maneuvers at Mars

Maneuver	Angle off Sun, deg	Time on battery, min	Average battery discharge current, A	Discharge capacity, A-h	Recharge at high charging rate		Maximum discharging temperature, °C (°F)	Minimum discharging temperature, °C (°F)
					Time, h	Capacity, A-h		
MOI	-124.90	40	9.5	6.34	6.4	5.4	20.3 (68.7)	12.5 (54.5)
OTM 1	-128.73	30 ^a	9.0 ^a	4.4 ^a	1.5 ^a	3.4 ^a	—	—
OTM 2	-118.26	25 ^a	9.4 ^a	3.9 ^a	1.4 ^a	3.1 ^a	—	—

^aEstimated.

In the course of the orbital mission, the scan control subsystem performed a total of 589,141 slew steps without error. This total included 208,458 steps performed during the first 50 days of orbit; 89,026 during Cycle I; 94,006 during Cycle II; 91,887 during Cycle III; 57,344 during the March Phase I and II; and the remaining 48,398 during the extended mission.

b. Problems. Some problems associated with the operation of the scan platform control subsystem were:

- (1) The scan cone actuator stepped one less step than expected on revolutions 16, 18, 20, and 22, and the scan clock actuator stepped one less step than expected on revolutions 17, 19, 21, and 23. The problem was traced to the fact that, in each anomaly, the CC&S had issued two scan step commands so close together that the scan stepper motor circuit could not respond to the succeeding step command, resulting in a slew step being missed.

Quantitative commands were transmitted as an immediate corrective action to return the scan platform to the correct position and to reduce the possibility of hitting the lower cone stop at the end of the sequence. In addition, the CC&S was reprogrammed to insure that the scan control requirement of at least 600-ms spacing between adjacent step commands from the CC&S would be met.

- (2) On November 28, 1971, GMT, the clock axis was off predict by 0.15 deg for picture 1 as a result of an imperfect modeling of the scan platform control loop nonlinearities in the scan platform operations program (SPOP). Although it was not needed to meet mission pointing requirements, a QC-3-1 was sent to optimize pointing for that picture. Because of the timing of the subsequent CC&S slew, a QC-4-1 could not be sent to delete the QC-3-1 until after slew 21, prior to picture 21. As a result, optimum pointing was not achieved in clock for many of the first 20 pictures of the sequence.

No immediate corrective action for this anomaly was needed or taken since all pictures were within the mission control accuracy requirement. The model of the scan control loop nonlinearities was improved as a result of the in-flight scan calibration.

- (3) On November 29, the scan platform was driven against a lower cone mechanical stop, causing the cone actuator clutch to slip, because of an anomalous command sequence triggered by a Deep Space

Network (DSN) operator error. No damage or degradation was observed in subsequent operation of the scan control subsystem. DSN procedures were modified to correct the problem.

- (4) On November 30, the slew program reached the lower alarm limit. No corrective action was necessary because the mechanical stop had not been violated.
- (5) On December 8, the CC&S failed to issue 21 cone step commands. The only corrective action needed was the sending of QCs to return the platform to the correct position.
- (6) On December 31, PST, a QC-1-15 was incorrectly transmitted in place of a QC-1-5. The only corrective action needed was to send QCs to correct the scan platform pointing.
- (7) On January 22, 1972, the scan platform upper clock operational limit was exceeded by one step. No real-time corrective action was taken because the mechanical stop was not violated. SPOP was modified to automatically check violations of the platform operational limits.
- (8) On January 22, the CC&S failed to issue 216 step commands because of a software error. Corrective action included QCs to correct the platform position.

6. Attitude control subsystem.

a. Performance. The attitude control subsystem met the mission requirements for spacecraft pointing and rate control during maneuvers and science-gathering periods despite problems which caused above normal gas usage. Prior to launch, 2.452 kg (5.4 lb) of N₂ gas was loaded, with 1.226 kg (2.7 lb) of N₂ contained in each one-half gas system. The 90-day orbital mission design required 0.817 kg (1.8 lb) of attitude control gas for the one-half gas system. Figure 37 shows the N₂ gas used during the standard mission (130 days in orbit). The gas usage rate was approximately 2.27 g (5 mlb) per day during transit cruise, excluding problems, and 6.81 g (15 mlb) per day during orbital cruise, including scan platform slewing. Approximately 0.227 kg (0.5 lb) of additional gas was used during transit because the Sun sensors were out of regulation, and another 0.014 kg (0.03 lb) during orbit to slew the scan platform while on roll inertial. The attitude control gas remaining at the end of the standard mission was 0.918 kg (2.023 lb).

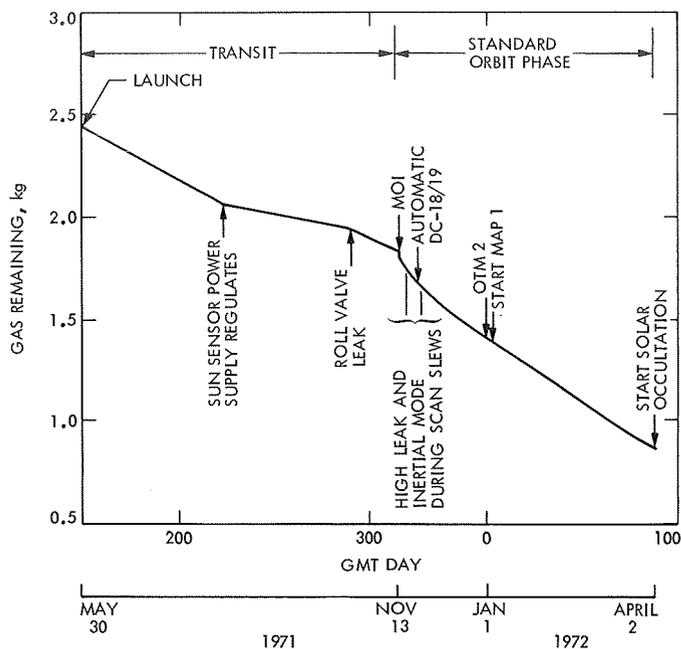


Fig. 37. Attitude control subsystem gas usage

Autopilot performance met the mission requirements for accuracy and control. The first trajectory correction maneuver was performed exactly as predicted, with a 5.1-s rocket engine burn resulting in a spacecraft velocity change of 6.7 m/s. The gimbal angles indicated no discernible displacement. The error in the desired velocity increment was 0.008 m/s. In the orbit insertion maneuver, the rocket engine burn duration was 915.4 s, resulting in a spacecraft velocity change of 1600.5 m/s. The engine gimbals registered a total angular movement during the burn of 2.75 deg in one axis and 0.3 deg in the other, caused by the spacecraft center-of-mass migration as propellants were being used. Limit-cycle analysis of the roll axis telemetry during the engine burn indicated a rocket engine swirl torque of the order of 202×10^{-6} N-m (149×10^{-6} ft-lb). The error in the desired velocity increment was 0.147 m/s. The orbit trim maneuvers also were performed as predicted. The rocket engine burn duration of the first orbit trim was 6.4 s, resulting in a spacecraft velocity change of 15.3 m/s, with an error in the desired velocity increment of 0.01 m/s. The engine burn duration of the second orbit trim was 17.3 s, resulting in a velocity change of 41.8 m/s, with an error in the desired velocity increment of 0.115 m/s.

Accurate predictions of Canopus star tracker stray light interference from Mars, Phobos, and Deimos were made once the exact orbits of Phobos, Deimos, and the spacecraft had been determined. Unless occulted by Mars,

Phobos interferences occurred alternately at 11-day and 4-day periods, beginning on day 325. There was no Deimos or Mars stray light interference during the standard mission. The spacecraft was commanded into the roll inertial control mode using the CC&S-7F/7F commands during periods of predicted stray light.

b. Problems. The problems associated with the attitude control subsystem were:

- (1) Following launch, the Mariner 9 spacecraft experienced an unexpected cross-coupling between axes and an abnormal Sun acquisition. In addition, from Sun acquisition on May 30, 1971, until approximately August 7, the spacecraft experienced excessive limit-cycle rates in both the pitch and the yaw axes, causing excessive gas consumption. This problem recurred during each orbit after MOI for a few minutes near periapsis. The problem was traced to incorrectly sized resistors in the Sun sensor voltage regulator. The resistors were too large to provide proper zener regulation of the acquisition and cruise Sun sensors when the composite Sun sensor resistance was below 3.1 k Ω , causing the Sun sensor voltage to be both low and unregulated. The low voltage created a low Sun sensor scale factor, resulting in a sluggish Sun acquisition. Unregulated voltage causes excessive pitch and yaw valve ON times (75 ms). Fortunately, the decrease in solar intensity and the effects of aging caused the Sun sensor resistance to increase above 3.1 k Ω , and the gas consumption returned to normal.

During the period between launch and day 225, approximately 0.227 kg (0.5 lb) of N₂ gas was expended in excess of that expected. When the problem recurred during orbit because of the increase in illumination from Mars, the excess gas consumption was small as a result of the short time the circuit was unregulated during each orbit.

- (2) On August 18, 1971, during the Canopus cone angle (CCA) update from position 4, the Canopus star tracker did a flyback and sweep, reacquiring Canopus in CCA 4. The problem was found to be generic, occurring on every other CCA update, 5 to 4, 3 to 2, 1 to 2, 3 to 4, etc. No corrective action was possible or required since performance was not affected.
- (3) Bright particles, probably dislodged from the spacecraft, crossed the Canopus star tracker FOV, causing erratic gas jet firing on September 9 and

December 12, 1971, and during a roll search when Canopus was lost on November 2, 1971.

No corrective action was required because the Canopus star tracker performed as designed. In cases in which a particle environment was expected, such as from spacecraft pyrotechnic activity, the stray light command, CC&S-7F, was issued to protect the spacecraft from loss of celestial reference.

- (4) Starting September 21, 1971, severe roll gas jet valve leaks, originating from the $-X/+Y$ reaction control assembly clockwise roll valve S/N 111, were observed. These leaks continued in a random fashion throughout the standard mission. An extensive investigation of the probable cause and cure was undertaken. Although no specific cause could be identified, the most probable failure mechanism was from particles, generated within the valve itself, being caught on the valve seat.

Corrective action was taken to clear the reaction control assembly valve leaks as they occurred by cycling the affected valve so that any foreign matter would be flushed out of the valve seat area. Because large valve leaks produced a disturbing torque on the spacecraft, which prevented a leaking valve from being cycled during normal limit-cycle operation, an external command action, which caused all roll axis valves to be cycled at least once, was implemented on November 24. DC-18/DC-19 pairs transmitted on 1-min centers were selected for this purpose and were successful in clearing leaks. The corrective action reduced the roll leakage consumption to less than 0.454 g (1 mlb) of gas per day. The total excess gas used between September 21 and November 23, 1971, was estimated to be between 0.068 and 0.113 kg (0.15 and 0.25 lb).

- (5) Roll gyro drift rate on November 13, 1971, during the initial warm-up for the orbit insertion maneuver, was approximately 0.12 deg/h rather than the expected 0.0005 ± 0.04 deg/h. The problem was traced to the fact that the gyro drift is temperature-sensitive and the 0.0005 deg/h prediction assumed a nominal operating temperature of 46°C (115°F).

No corrective action was taken or required since the gyro drift was below the maximum of +0.53 deg/h allowed by the inertial reference unit (IRU) specification. Data from Mariner 9 thermal vacuum test and Bay III temperatures measured during the flight indicated that gyro temperature is stabilized at approximately 41°C (105°F) after 4 to 6 h of full IRU operation.

- (6) On November 13 and 14 and December 28 and 29, 1971, disturbance torques similar to leakage were observed in the pitch and yaw axis. An analysis was undertaken to determine whether the torques were caused by gravity gradient or by yaw valve leakage. It was concluded that one of the two negative torques producing yaw gas jets was leaking.

Corrective action was taken such that, if the leak was severe enough to cause excess gas to be used beyond that used in the normal limit cycle, a DC-18/DC-19 pair would be transmitted to clear the leak. If the leak was not that severe, no action would be taken.

- (7) Predictions of Phobos interferences with the Canopus star tracker FOV were unreliable during the first month of orbit. The first Phobos interference, which occurred 8 days following MOI, was not predicted by CELREF (see Section II). On December 11, 1971, Phobos interference occurred, but for a much shorter period of time than predicted. On January 29, 1972, unpredicted Phobos interference was again observed. On February 28, Phobos interference was as predicted, but a roll search was performed because Canopus was lost when the Canopus star tracker high gate was violated. The five problems responsible for the above experiences and the corrective actions taken to solve them were:

- (a) The orbital elements of Phobos were not well enough known to predict its position accurately. Enough TV pictures were taken of Phobos and Deimos in the early orbits to eventually determine their orbital elements.
- (b) The save tapes used by CELREF to determine spacecraft position had computed position data once each hour of the orbital period so that interpolation between data points near periastris was inaccurate. The Navigation Team supplied save tapes with position data records every 10 min of the orbital period, starting on day 355 (December 21, 1971).
- (c) CELREF logic did not consider the possibility of eclipse or occultation of a body that might be in the Canopus star tracker field of view. CELREF was updated.
- (d) Outdated Phobos orbital elements were present in CELREF. CELREF was updated.
- (e) If Canopus was lost because of the Canopus star tracker high gate being violated, no flyback

and sweep was performed to reacquire Canopus in the DC-18 mode. The CC&S-7F/7F commands were substituted for the DC-18/19 commands for controlling the roll inertial mode during the expected times of interference.

After the five problems had been solved, all subsequent interferences were normal and as predicted for the remainder of the standard mission.

- (8) On December 21, 1971, and February 16 and 17, 1972, the pressure readings on the two attitude control gas bottles decreased unexpectedly, indicating an increase in N₂ gas usage. This problem was traced to the scan platform slew activity. The slew activity on December 21 was higher than normal by about 15 to 25%. On February 16 and 17, the scan platform slewing was performed while the spacecraft was on roll inertial control because of an expected Phobos interference. Analysis determined that slews performed while on inertial control use as much as twenty times the amount of attitude control gas as those performed while on celestial control. Corrective action minimized roll inertial time and precluded slewing in this mode.

7. Spacecraft structure and mechanical devices. The performance of the spacecraft structure and mechanical devices subsystems during the standard mission was normal. It can be inferred from the successful orbit insertion that necessary mechanical support, latching, and damping were provided at that time. The deployment of the high-gain antenna to the second position was performed as planned on January 17, 1972.

8. Temperature control subsystem

a. Performance. During the standard mission, the temperature control subsystem functioned as designed, with the exception of several anomalies. Table 17 lists the pre-launch temperature predictions and the actual spacecraft temperatures prior to science turn-on and orbit insertion. Table 18 presents the same comparison with science on. Good agreement of predicts and actuals exists, except in areas where the spacecraft power state differed from that expected.

The average bus temperature over the mission is shown in Fig. 38. The general trend with time was a decreasing temperature because of increasing heliocentric distance, with superimposed temperature increases caused by increases in power dissipation. These power changes are noted in the figure.

Table 17. Mars cruise temperatures with science off

Channel	Temperatures, °C (°F)		
	Prelaunch predicted	November 1, 1971, actuals	ΔT
VCO	21 (69)	18 (64)	-3 (-5)
Battery	15 (59)	16 (60)	1 (1)
Canopus sensor	12 (54)	12 (54)	0 (0)
Oxidizer tank	23 (73 ^a)	12 (54)	-11 (-19)
Fuel tank	24 (75 ^a)	13 (55)	-11 (-20)
IRR	-1 (31)	-1 (31)	0 (0)
Auxiliary oscillator 1	21 (69)	20 (68)	-1 (-1)
Bay I	17 (63)	18 (64)	1 (1)
Propulsion N ₂ tank	15 (59)	12 (54)	-3 (-5)
Bay III	17 (63)	17 (63)	0 (0)
Bay IV	18 (65)	16 (61)	-2 (-4)
Bay V	16 (60)	13 (56)	-2 (-4)
TWTA 2 base	41 (106)	38 (100)	-3 (-6)
Bay VII	12 (54)	11 (51)	-2 (-3)
Bay II	17 (63)	18 (64)	1 (1)
TV A-vidicon	13 (56)	14 (57)	1 (1)
TV B-vidicon	17 (63)	17 (63)	0 (0)
UVS detector	7 (45)	9 (48)	2 (3)
TV B-optics	13 (56)	14 (58)	1 (2)
Sun sensor	11 (52)	19 (67)	8 (15)
IRIS optics	-24 (-12)	-24 (-12)	0 (0)
TWTA 1 base	26 (78)	21 (70)	-4 (-8)
+X/-Y N ₂	14 (57)	12 (54)	-2 (-3)
+Y solar panel	-1 (31)	2 (35)	2 (4)
Engine injector	39 (103 ^a)	34 (93)	-6 (-10)
Engine valve	36 (97 ^a)	29 (85)	-7 (-12)
Engine thermal blanket	14 (58 ^b)	27 (80)	12 (22)

^aPredicted for propulsion module heater on; actual for heater off.
^bSolar degradation effects not included.

The scan platform temperatures during cruise storage were normal. The platform average temperature increased 6.5°C between Earth and Mars as the heater voltage from the solar panels increased.

During orbital operations, all temperatures remained within the design temperature limits. Typical orbital temperatures for the VCO, auxiliary oscillator, solar panels, and Sun sensor are shown in Fig. 39 as a function of Earth

Table 18. Mars cruise temperatures with science on

Channel	Temperatures, °C (°F)		
	Prelaunch predicted	November 8, 1972, actuals	ΔT
VCO	24 (75)	23 (73)	-1 (-2)
Battery	18 (65)	19 (67)	1 (2)
Canopus sensor	16 (61)	16 (61)	0 (0)
Oxidizer tank	26 (79 ^a)	14 (58)	-12 (-21)
Fuel tank	27 (81 ^a)	14 (58)	-13 (-23)
IRR	1 (34)	-4 (25)	-5 (-9)
Auxiliary oscillator 1	24 (76)	24 (76)	0 (0)
Bay I	18 (65)	20 (68)	2 (3)
Propulsion N ₂ tank	17 (62)	16 (61)	-1 (-1)
Bay III	17 (63)	18 (65)	1 (2)
Bay IV	20 (68)	19 (67)	-1 (-1)
Bay V	18 (65)	17 (63)	-1 (-2)
TWTA 2 base	28 (82 ^b)	44 (111)	16 (29)
Bay VII	19 (67)	20 (68)	1 (1)
Bay II	19 (67)	21 (70)	2 (3)
TV A-vidicon	11 (52)	8 (46)	-3 (-6)
TV B-vidicon	13 (56)	11 (51)	-3 (-5)
UVS detector	10 (50)	11 (52)	1 (2)
TV B-optics	14 (58)	11 (52)	-3 (-6)
Sun sensor	11 (52)	19 (67)	8 (15)
IRIS optics	-24 (-12)	-24 (-12)	0 (0)
TWTA 1 base	47 (117 ^b)	27 (80)	-21 (-37)
+X/-Y N ₂	19 (67)	19 (67)	0 (0)
+Y solar panel	-1 (31)	-1 (31)	0 (0)
Engine injector	42 (107 ^a)	35 (95)	-7 (-12)
Engine valve	38 (101 ^a)	32 (89)	-7 (-12)
Engine thermal blanket	14 (58 ^c)	25 (77)	11 (19)

^aPredicted for propulsion module heater on; actual for heater off.
^bPredicted for TWTA 1 high power; actual for TWTA 2 high.
^cSolar degradation effects not included.

received time (ERT). The temperature change was caused by planetary heating. The TV vidicons and the IRR temperatures also showed this trend, whereas the UVS temperature remained the same or decreased (probably because of decreased instrument power dissipation resulting from decreased gain states). The IRIS optics remained at the same temperature, but the thermostatic heater decreased its on time to compensate for the planetary effects.

b. Anomalies. Although there were no spacecraft problems induced by thermal effects, there were a few unexpected anomalies, the most significant of which were:

- (1) The effect of the propulsion module heater on the propellant tank temperatures was 5°C (9°F) rather than the predicted 8°C (15°F). The probable cause was that thermal coupling between the propulsion module and the bus in flight increased over that obtained during unloaded prelaunch tests.
- (2) After science turn-on, the scan platform temperatures differed from prediction by the amounts shown in Table 19. The flight science instruments were not tested together during prelaunch system thermal tests, and instrument-to-instrument variations in power dissipation and thermal properties are the likely causes for the differences.
- (3) Following the MOI maneuver, the engine valve temperature peaked at 145°C (293°F), exceeding the allowable limit. This anomaly was caused by improper compensation in the predictions to account for nonflight conditions during testing. The primary test errors were believed to be gravity effects on oxidizer boiling and convective effects in the test chamber.

9. Flight telemetry subsystem. The flight telemetry subsystem (FTS) functioned well within all specifications over the standard mission. The only exception occurred over a 27-day period beginning July 8, 1971, when an anomaly was observed in the FTS engineering measurement numbers 410-414 and 416-419 (number 415 remained normal). The problem was manifested by a number of erratic measurements on deck 410. However, the anomaly progressively lessened and did not reappear. Most of the erroneous measurements were 0 DN, although at times some values between 0 and normal were observed. Loss of the 410 deck (temperature measurements) would not have affected the mission seriously because most of the measurements could have been derived or closely approximated from others.

As observed in the data, the problem was a shorted, or partially shorted, deck switch for engineering measurement number 415. Because the short was not permanent, the predominant failure model was a loose sliver of silicon (or other contaminant) within the field effect transistor (FET) can, which intermittently shorted two of the three FET terminals: source, drain, and gate. The contaminant, floating in free space, would be moved by movement of the spacecraft, such as in attitude control limit cycling.

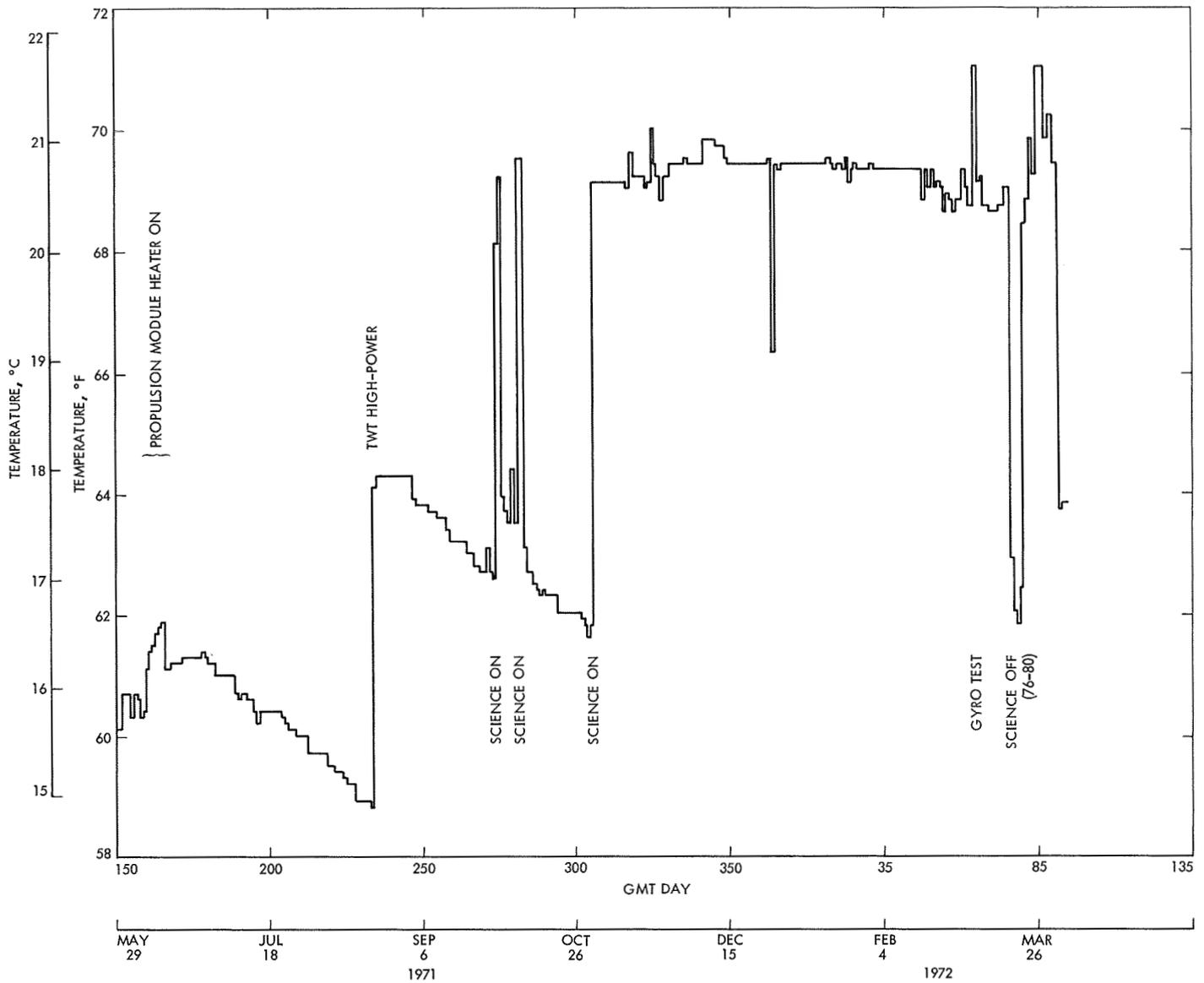


Fig. 38. Average bus temperature

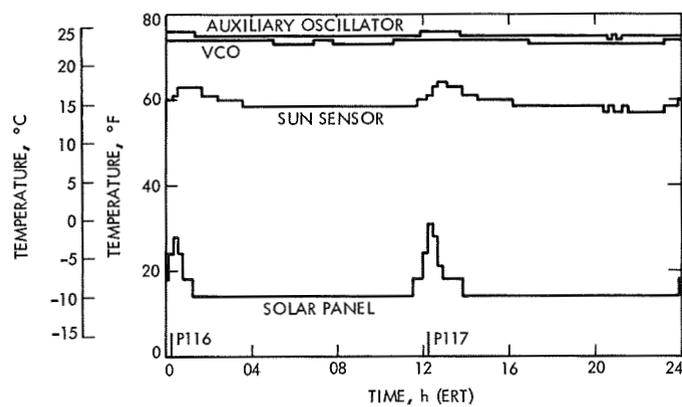


Fig. 39. Typical orbital transients

Table 19. Scan platform temperature changes after science turn-on

Channel	Temperature change, °C (°F)		
	Predicted	Actual	Actual - predicted change
IRR	2 (3)	-2 (-4)	-4 (-7)
TV A	-2 (-4)	-6 (-10)	-3 (-6)
TV B	-3 (-6)	-6 (-11)	-3 (-5)
UVS	3 (5)	3 (6)	1 (1)
TV B-optics	-2 (-3)	-3 (-6)	-2 (-3)
IRIS optics	0 (0)	1 (1)	1 (1)

Corrective action to eliminate the problem was not possible, or needed, because the problem disappeared.

One apparent anomaly occurred on July 24, 1971, when DSS-14 could not obtain lock on the downlink, high-rate (259.2-kHz) subcarrier during an RFS spectrum test. The FTS had been placed in the playback mode and the DSS turned off. This configuration removed the 16.2-kHz reference (supplied by the DSS during playback) to the FTS, resulting in an unmodulated downlink, high-rate subcarrier.

Removal of the DSS reference frequency allowed the FTS block coder phase-locked loop to run open-loop. The resulting downlink subcarrier drifted excessively to the point where the station could not obtain lock. Corrective action was not possible or necessary, because this was a nonstandard mode for the FTS and had no impact on the mission. Tests using the PTM spacecraft proved that the subcarrier drift in this configuration was an FTS design characteristic and not unique to Mariner 9. The FTS was not designed to operate without a frequency reference.

10. Central computer and sequencer. The CC&S functioned within specifications throughout the mission, with the following exceptions:

- (1) On December 7, 1971, during a scan platform stepping sequence, the CC&S failed once to issue all of the stepping commands programmed. Because all subsequent operation of the CC&S was normal, including the next day's checksum, this problem was written off as an electrical transient that interfered with a particular event sequence in the CC&S.
- (2) Four times on March 9 and 10, 1972, the DC-52 single B-picture routine operated improperly by issuing the first event of the sequence (20D-take picture pair) immediately after receipt of the command, instead of after the next B-frame pulse from

the data automation subsystem. The cause of this problem has not yet been identified.

- (3) The DC-84 after the U244 update on March 13, 1972, failed to result in a correct checksum event. Two additional attempts at a checksum also failed. A subsequent memory readout showed only a 1-bit error in the "sum" word, with no other errors in the memory. It is speculated that an electrical transient caused a 1-bit error in some word in the memory that was overlaid by program operation between the last checksum attempt and the readout. During this period, a zenith science sequence was executed correctly by the CC&S. Five words were overlaid during that sequence.
- (4) At the end of a DC-84-initiated checksum on March 16, 1972, the CC&S went into a continuous memory checkout. Switching the FTS to the readout mode and analyzing the readout data indicated that word 0 in the CC&S had been changed from NOP 0 1 to UNJ 144 24. This unconditional jump to word 24 caused the CC&S to be locked into the readout mode because processing of word 24 did not prevent the subsequent processing of word 25, which is the entry word for the readout routine. It was also verified by the readout data that normal processing of word 24 caused word 147 to change. Because the anomalous data in word 0 could not be identified with any program in the memory, it is assumed that word 0 was changed as the result of an electrical transient.

Some additional problems associated with the operation of the CC&S within the spacecraft system environment were:

- (1) A DC-52 command was transmitted to the CC&S to cause the single B-picture routine within the CC&S to start with the next B-frame from the data automation subsystem (DAS). However, it started immediately after receipt of the DC-52. This anomaly was traced to the fact that the arrival of the DC-52 at the CC&S just preceded the end of an automatic record sequence (16F). The net effect of terminating an automatic record sequence after receipt of DC-52 was that, as far as the DC-52 sequence was concerned (single B-picture), the program reacted as though a B-frame pulse had occurred. This was a normal response under the circumstances. The problem was avoided thereafter by timing the DC-52 to occur after termination of an automatic record sequence.

- (2) Twice the scan platform failed to respond to a CC&S platform step command. The problem was traced to the fact that the scan platform could not accept stepping commands closer than 600 ms. Because of the way in which the CC&S was originally programmed, if multiple events were required during any one CC&S memory scan, including a scan platform step, the platform step command was the last event to be issued. On the next second's scan in the CC&S, if the scan platform event was the only event to be generated, it typically would occur early in the scan, so that it would take place about 400 ms after the previous platform step command. This problem was corrected by changing the CC&S program so that any scan platform event occurred first in a CC&S scan, regardless of any other events.
- (3) On November 25, 1971, a DAS B-frame pulse occurred slightly before a CC&S 5C event, so that the B-frame pulse was not counted by the CC&S, and all subsequent CC&S science events referenced to B-frame starts were delayed one B-frame (84 s). This problem occurred because, at the time, the relative timing between the CC&S and DAS was not sufficiently well known. As a result, a B-frame pulse that was estimated to occur slightly after the 5C event actually occurred before it. Future occurrences of this problem were avoided by more conservative placement of the 5C event relative to a B-frame pulse, and later by use of the DAS pause mode to move B-frame pulses away from CC&S minute pulses.
- (4) On December 2, 1971, the CC&S "lost" a minute pulse when the CC&S scan, which was started 1 s before the lost minute pulse, lasted for longer than 1 s because of the generation of three separate events. This problem was also caused by the CC&S/DAS relative timing situation, as noted above. It was corrected by utilizing the DAS pause mode to move the B-frame pulses away from the CC&S minute pulse.

11. Data automation subsystem. During flight operations, two anomalies occurred that may have been caused by the DAS, but, as noted below, it is possible that the problems originated elsewhere.

- (1) During revolution 118, the TV subsystem filter wheel became permanently fixed at position 5 because of a mechanical problem in either the TV subsystem or the DAS. The exact cause of the

failure remains unknown; however, a similar failure in the Mariner Venus/Mercury spacecraft was caused by a failure in the TV subsystem filter stepping mechanism.

- (2) On two widely separated occasions (revolutions 130 and 224), incorrect B-camera shutter modes and shutter intervals were selected in response to CC20-09 commands. In both cases, a fixed shutter mode was requested, but the camera switched to the algorithm mode. During revolution 130, a CC20-09-0022 was sent to the spacecraft, but the DAS acknowledged receipt of a CC20-09-0011. This represents a 1-bit right shift; i.e.,

$$0022_s = 000\ 000\ 010\ 010$$

$$0011_s = 000\ 000\ 001\ 001$$

During revolution 224, a CC20-09-0024 was sent to the spacecraft, but the DAS acknowledged receipt of a CC20-09-0012. This also represents a 1-bit right shift. The detailed analysis of this problem did not provide conclusive results; consequently, the source of the anomaly (ground command system, FCS, or DAS) remains unknown.

12. Data storage subsystem. The data storage subsystem functioned well within specifications over the Mariner 9 standard mission. Apparent bit slippages did occur during the playback of scan calibration 2 data. Analysis of this problem indicated that it originated with the data storage subsystem. These dropouts were not totally unexpected.

Past experience has shown that the playback of recorded data will display occasional random errors caused by electrical or mechanical transients, or debris on the tape. Missing or extra bits are caused by a momentary loss of VCO lock because of erratic data, which causes the coherence detector in the playback logic to temporarily clamp the 32-stage data buffer to position 17. Data bits between the position of the buffer at the time of clamping and position 17 will, therefore, be lost or repeated, resulting in lost or extra bits in the data stream. If clamping occurs before the buffer has overflowed or emptied, there is no telemetry indication to substantiate the perturbation.

An incident surprise anomaly (ISA) was originated to document all cases of bit errors and missing or added bits attributed to the data storage subsystem so that bad tape spots and gradual degradation could be monitored. No degradation in data storage subsystem performance has been observed.

13. Propulsion subsystem. The Mariner 9 spacecraft was designed to use the basic spacecraft employed on previous Mariner (flyby) missions with the incorporation of a new and larger propulsion subsystem to accomplish in-transit trajectory corrections and to decelerate the spacecraft from a hyperbolic approach trajectory into an elliptical orbit about Mars. The schematic diagram of the pressure-fed, bipropellant subsystem is shown in Fig. 40. The hypergolic propellants, fuel (monomethylhydrazine) and oxidizer (nitrogen tetroxide), are carried in separate tanks, and each is contained within a Teflon expulsion bladder. A regulated supply of filtered nitrogen gas is used to force each propellant from its tank through a filter, a Teflon-lined flexible hose, and a bipropellant control valve to the rocket engine. The flexible hoses permit gimballing of the rocket engine to provide spacecraft pitch-yaw control. Positive isolation of the pressurant and propellants during long cruise periods is achieved with pyrotechnic-operated valves, which are actuated by ground commands.

Reference 35 describes the development and testing phases of the Mariner Mars 1971 propulsion subsystem. Flight performance results summarized in the following paragraphs are discussed in Ref. 36.

The propulsion subsystem successfully performed a trajectory correction maneuver, Mars orbit insertion, and two orbit-trim maneuvers during the Mariner 9 mission. Table 20 describes the propulsion sequence compared to a reference sequence used for propellant load determination and a modified plan in effect at launch after loss of the Mariner 8 spacecraft. A total velocity change (ΔV) of 1664 m/s was provided and an additional capability of 28 m/s was available at the end of the standard orbital mission. These values may be compared to a specified velocity requirement of 1650 m/s.

The propulsion sequence of maneuvers consisted of a single maneuver 5 days after launch, a 5-month cruise period, and three maneuvers at Mars. Pyrotechnic valves

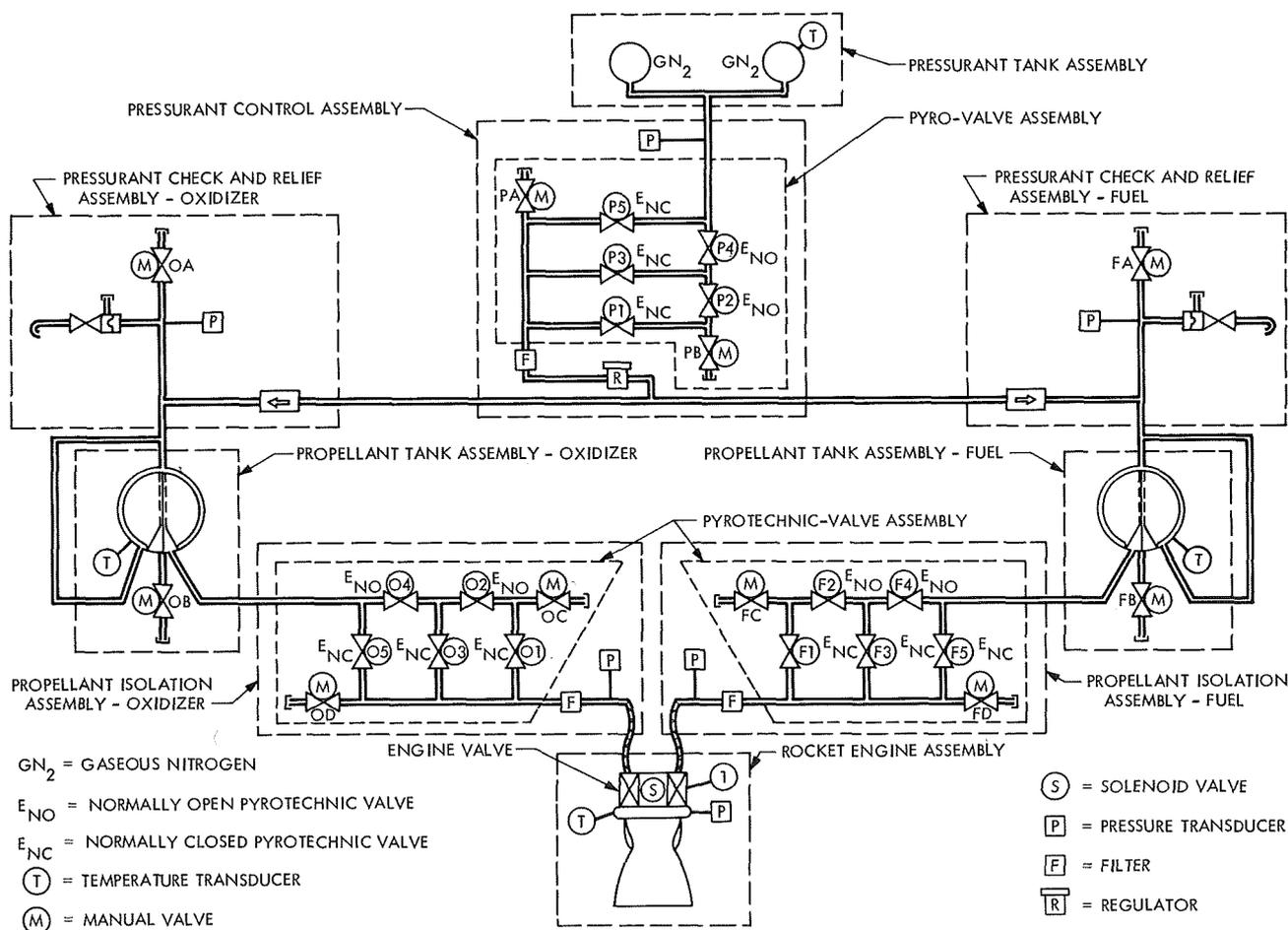


Fig. 40. Schematic of Mariner 9 propulsion subsystem

Table 20. Propulsion mission sequence compared to prelaunch reference sequences

Event	Time		Spacecraft ΔV , m/s			Burn time, s
	Reference	Actual	Reference allocation	Launch allocation	Actual	Actual
Launch (L)	May 7 to 22	May 30				
Open P1, O1, F1	L + 5d	L + 4d				
Midcourse 1	L + 6d	L + 5d	8	7	6.73	5.1
Close P2	L + 12d	L + 9d				
Close O2, F2	L + 12d	L + 15d				
Open O3, F3, P3	L + 167d	L + 155d				
Midcourse 2	L + 168d	—	2	3	—	
Orbit insertion (OI)	L + 188d	L + 167d	1450	1610	1600.50	915.4
Orbit trim 1	OI + 4d	OI + 2d	25	40	15.25	6.4
Orbit trim 2	OI + 4d	OI + 47d	5	—	41.80	17.3
Close P4	OI + 9d	OI + 4d				
Close O4, F4	OI + 9d	—				
Total ΔV planned or used			1490	1660	1664.28	
Mission margin			160	10	28	
Total ΔV committed			1650	1670	1692.28	
Total ΔV capability estimated			1673 ^a	1670	1692.28	

^aThis estimate is for spacecraft mass 2.27 kg (5 lbm) heavier than that used in subsequent calculations.

were used to isolate the pressurant and propellants during the cruise period. Propellant tank pressure decreases caused by nitrogen gas solution in the liquid propellants were compared to predictions made with a spherical permeation/diffusion computer model. The flight data allowed adjustment of the computer parameters to predict average saturation levels at orbit insertion. Excessive saturation of the propellants would cause a shift of engine mixture ratio compared to unsaturated conditions and would therefore impact total propulsion capability.

Although four propulsive maneuvers were accomplished, only the orbit insertion maneuver was long enough to provide sufficient data for a thorough comparison with preflight predictions. A propulsion subsystem operation and performance (PSOP) digital computer program was developed to support Mariner 9 flight analysis. PSOP is a low-frequency simulation model of the complete propulsion subsystem that predicts system pressures, temperatures, propellant and pressurant flow rates, thrust, spacecraft mass distribution, acceleration, total velocity change, and thrust pointing angles as functions of time. PSOP was used with empirical input data obtained from the Mariner 9 and similar propulsion subsystems to calculate the preorbital insertion predictions of Table 21. All parameters are average values for the burn period.

A review of the computer inputs after orbit insertion revealed a regulator-data input error, which is corrected in the second column of Table 21. A weighted least-

squares fit of the flight data and predictions resulted in the best-fit data list of Table 21. Also listed is the estimated 1- σ uncertainty of each parameter in the best-fit column. Burn time, chamber pressure, and engine mixture ratio are all within 0.5% of preburn predictions. The flight data were not sufficiently accurate compared to engine acceptance tests to improve knowledge of specific impulse, so little change was noted there. The increases in mixture ratio and burn time compared to the corrected prediction were attributed to a 0.8% increase in fuel resistance. However, the fuel resistance change required to provide a data match is less than the 1- σ uncertainty of that parameter.

Increased knowledge of the propulsion subsystem performance after orbit insertion allowed the increase in performance commitment previously shown in Table 20. Although little data were obtained from the three other maneuvers, prediction of burn time was of the same accuracy level as orbit insertion.

The near-perfect performance of the Mariner 9 propulsion subsystem during four maneuvers is a tribute to the design and development effort. The 1/2% agreement between observed performance during propulsion maneuvers and preflight predictions lends credence to the characterization of propulsion performance parameters obtained from development and qualification test programs. The demonstrated ability to match flight data by making small adjustments to independent variables in analytical models proved the validity of these models.

Table 21. Orbit insertion propulsion performance summary for velocity change of 1.6005 km/s^a

Parameter	Premaneuver predict	Corrected predict ^b	Best-fit data	1- σ uncertainty
Burn time, s	919.8	912.8	915.4	0.03
Regulator outlet pressure, N/m ² (lbf/in. ²)	1.74 × 10 ⁶ (252.2)	1.76 × 10 ⁶ (255.1)	1.75 × 10 ⁶ (254.5)	6.89 × 10 ³ (1)
Engine chamber pressure, N/m ² (lbf/in. ²)	7.93 × 10 ⁵ (115.0)	7.99 × 10 ⁵ (115.9)	7.97 × 10 ⁵ (115.6)	6.89 × 10 ³ (1)
Oxidizer (ox) resistance, N-s ² /m ⁵ -kg (lbf-s ² /in. ⁵ -lbfm)	1.632 × 10 ¹⁰ (17.6)	1.632 × 10 ¹⁰ (17.6)	1.632 × 10 ¹⁰ (17.6)	1.85 × 10 ⁸ (0.2)
Fuel resistance, N-s ² /m ⁵ -kg (lbf-s ² /in. ⁵ -lbfm)	2.429 × 10 ¹⁰ (26.2)	2.429 × 10 ¹⁰ (26.2)	2.447 × 10 ¹⁰ (26.4)	2.78 × 10 ⁸ (0.3)
Mixture ratio, kg (ox)/kg (fuel)	1.574	1.575	1.582	0.011
Specific impulse, N-s/kg (lbf-s/lbfm)	2817 (287.3)	2817 (287.3)	2816 (287.2)	6.8 (0.7)

^aBurn was controlled by on-board accelerometer to produce this change in velocity.

^bPostburn analysis revealed error in regulator data input to model.

These results should improve the predictability of similar propulsion subsystems used in future programs.

14. Pyrotechnic subsystem. The pyrotechnic subsystem supplies pyrotechnic devices to perform specific one-time mechanical tasks on the spacecraft that are suited to the high-energy, high-reliability characteristics of electroexplosive devices. It also provides a pyrotechnic switching assembly (PSA) that rectifies a 50-V, 2.4-kHz square-wave input, stores dc voltage on capacitor banks, and switches this energy upon command to fire the explosive squibs. This function was performed in the same manner as on the Mariners 6 and 7. A new function of the PSA on the Mariner 9 was to supply 30 Vdc to actuate the solenoid valve on the propulsion subsystem engine. Reference 37 describes design and development of the pyrotechnic subsystem.

The pyrotechnic subsystem successfully performed all functions commanded during the Mariner 9 mission. These included 10 of 13 pyrotechnic functions and 5 actuations of the rocket engine valve (1 vent and 4 burns). Accomplishment of these events was verified by various spacecraft telemetry measurements that exhibited predicted responses to the pyrotechnic functions.

Additional information on the pyrotechnic subsystem operation is available from stepping of event counters 1 and 4 generated by current output signals from PSA capacitor banks A and B, respectively. This information is clouded on some functions that use one dual-bridgewire squib. A time lead in the firing current to one bridgewire can cause the squib to fire before the second capacitor bank is discharged, thereby causing an open circuit that

prevents the second event counter from being advanced. Table 22 contains a listing of PSA timing characteristics based on prelaunch tests, a prediction of events, and a listing of observed events. The prelaunch predictions were based on the assumption that a lead of less than 0.5 ms would not cause loss of a channel. It was stated, however, that the receipt of only one event was a possible (and acceptable) condition for the reasons stated above, as long as that event corresponded to the lead module. Prelaunch testing with flight squibs was not performed (nor considered necessary) to more fully characterize this phenomenon.

Analysis of observed function counts shows that only one counter was advanced on all four functions that used one dual-bridgewire squib. Lead times varied from 0.3 to 0.6 ms. All functions with more than one squib generated both counter functions. One could conclude that the number of squibs fired, which determines the ratio of released energy to required energy, has an effect on the time required to fire the squibs. Sufficient data do not exist, however, to quantify this observation with respect to capacitor bank lead time.

The spacecraft roll gyro was turned on for the scan unlatch (8C), propulsion line opening (DC-65), and high-gain antenna update (8D) functions. These events resulted in appreciable mass movements on the spacecraft in addition to the pyrotechnic shock effect. All other propulsion line opening and closing functions were performed with the spacecraft in cruise mode. Some particles were observed by the Canopus tracker, but the tracker internal logic prevented loss of reference. Another pyrotechnic-shock phenomenon observed several times was the change

Table 22. Pyrotechnic subsystem event counter summary

Event	Number of dual bridgewire squibs	Lead module ^a	Lead time, ms	Predicted events		Observed events	
				1	4	1	4
Solar panel deploy ^b	NA ^c	NA	NA	X	X	X	X
Spacecraft scan unlatch	1	A	0.5	X	X	X	
Open P1, O1, F1	3	A	0.1	X	X	X	X
Close P2	1	B	0.3	X	X		X
Close O2, F2	2	B	0.3	X	X	X	X
Open O3, F3	2	B	0.3	X	X	X	X
Open P3	1	A	0.4	X	X	X	
Close P4	1	A	0.6	X		X	
HGA update ^b	NA	NA	NA	X	X	X	
Close O4, F4	2	A	0.8	X	X		
Open P5	1	A	0.5	X			
Open O5, F5	2	B	0.5	X	X		

^aModule A drives counter 1; B drives counter 4.

^bTiming variations have no effect on these functions, which use two single-bridgewire squibs per device.

^cNA = not applicable.

by 1 data number (DN) of one or more propulsion pressure transducers that should not have been affected. This was concluded to be a shock-induced hysteresis relaxation in the transducer.

15. Infrared interferometer spectrometer subsystem

a. Objective. The purpose of the IRIS subsystem was to provide information on the vertical structure, composition, and dynamics of the Martian atmosphere, and the emissive properties of the surface of Mars. The measurements of thermal emission in the region of 5 to 50 μm (200 to 2000 cm^{-1}) with an apodized spectral resolution of 2.4 cm^{-1} and a noise equivalent radiance of $0.5 \times 10^{-7} \text{ W cm}^{-2} \text{ Sr}^{-1}/\text{cm}^{-1}$ were intended to result in determining:

- (1) Vertical temperature profile.
- (2) Minor atmospheric constituents.
- (3) General atmospheric circulation.
- (4) Surface temperature, composition, and thermal properties.

These parameters were to be derived as a function of latitude and local time, for dark and light areas.

b. Performance. The IRIS instrument performed as designed during the Mariner 9 mission. No anomalies affected the validity of IRIS scientific data. Negligible amounts of scientific data were lost because of losses of phase lock or noise spikes.

Thermal. The IRIS optics heaters were thermostatically controlled throughout the entire standard mission, so that

the IRIS optics temperature remained constant, when the IRIS was in thermal control. Thermal control was established when the optics heaters were cycling and the instrument was being maintained at its specified operating temperature to within $\pm 0.5^\circ\text{C}$. Thermal control may be lost because of two conditions: (1) change of the thermal inputs to the IRIS to the extent that the heaters are no longer effective or, (2) decrease of the heater input voltage to a level where the heater dissipation can not overcome the heat lost by radiation. During flight operations, the IRIS remains in thermal control except when the spacecraft is operating in the battery share mode. The battery share mode is caused by loss of Sun acquisition after the standard mission, which results in an approximate 25% drop in the input voltage of the IRIS optics heaters.

During the standard mission, when thermal control was maintained, all IRIS temperatures were stable and within operational tolerances. Tables 23 and 24 list all of the IRIS temperature measurements from real-time science 1 (RTS-1), real-time science 2 (RTS-2), or tape recorder playback data. Included in the RTS-1 bilevel data is a single bit, which indicates whether or not the optics heaters are on or off; therefore, the heater duty cycle can be computed. Figure 41 depicts the optics heaters duty cycle for a typical 12-h Martian orbit. The decrease in the duty cycle at orbit periapsis is due to an added planetary heat input and is a function of orbit altitude.

Image motion compensation and calibration. The image-motion compensation was not commanded ON during the flight, so its performance was not verified. The calibration sequences occurred normally with no timing

Table 23. RTS-1, IRIS temperature, and power supply telemetry measurements^a

Telemetry channel	Flight specifications		Flight values		
	Min	Max	Min	Max	Avg
Warm black body temperature, K	295	301	295.7	296.8	296.4
Bay 2 electronic module temperature, K	273	323	293.2	299.5	297.5
Radiator surface temperature, K	247.5	252.5	247.5	248.3	247.8
Reference voltage, V	-2.46	-2.58	-2.46	-2.50	-2.50
IR detector temperature, K			248.1	253.0	252.7

^aThe flight data represent a time period when the spacecraft was in Martian orbit and Sun acquired. The time period was October 2, 1971, through February 29, 1972.

Table 24. RTS-2/tape recorder playback, IRIS temperature, power supply, and zero-volt telemetry measurements^a

Telemetry channel	Flight specifications		Flight values		
	Min	Max	Min	Max	Avg
Warm blackbody fine temperature, K	295.0	301.0	295.7	296.8	296.5
IR detector temperature, K			251.2	252.2	251.9
Beamsplitter temperature, K	247.5	252.5	248.2	248.7	248.4
Michelson drive assembly temperature, K	247.5	252.5	248.4	248.9	249.0
(+) reference voltage, V	3.475	4.310	3.890	3.890	3.890
IMCC drive temperature, K	247.5	252.5	250.2	251.3	250.8
Radiator surface temperature, K	247.5	252.5	247.5	248.0	247.6
Zero-volt calibrate 1, mV	-13.0	+13.0	-3.0	+3.0	-1.3
Temperature network current source, μ A	226.3	273.6	238.7	238.7	238.7
Warm blackbody coarse temperature, K	295.0	301.0	295.9	296.8	296.6
(-) reference voltage, V	-4173.0	-3651.0	-3930.0	-3930.0	-3930.0
Support base temperature, K	270.0	300.0	278.6	282.0	280.0
Zero-volt calibrate 2, mV	-13.0	+13.0	-3.0	+2.0	-1.5

^aThe flight data represent a time period when the spacecraft was in Martian orbit and Sun acquired. The time period was October 2, 1971, through February 29, 1972.

or mirror pointing anomalies observed. The maximum mirror pointing dispersion observed on the image motion compensator (IMCC) scan displacement channel, with the IMCC in the Mars position, was 0.52 deg; the maximum dispersion allowable was 1 deg.

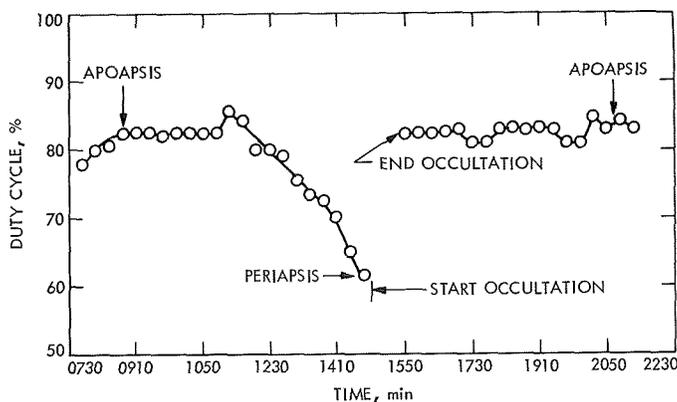


Fig. 41. IRIS heater duty cycle for day 321

Power supply monitors. One IRIS-regulated power supply monitor was contained in the RTS-1 data and two IRIS-regulated power supply monitors were contained in the RTS-2 data. All three regulated power supplies maintained stable outputs, which were within the tolerances for the duration of the mission, and they are summarized in Tables 23 and 24.

Zero-volt calibration. The zero-volt calibration is a monitor of the IRIS ground potential, which is measured between two ground locations within the IRIS instrument. The monitor was contained in the RTS-2 data. This parameter remained stable and within tolerance during the mission and is summarized in Table 24.

Neon delay line. The neon delay line, in the reference interferometer, has an automatic override capability. The neon delay line remained operational during the mission and the automatic override was not utilized.

Spectral range (200 to 2000 cm^{-1}). The excellent stability of the responsivity and noise equivalent radiance throughout the mission allowed the upper limit of the spectral range to be increased from 1600 to 2000 cm^{-1} .

Responsivity. The performance of the IRIS can best be demonstrated by its responsivity stability over an extended time period. Figure 42 shows the results with the instrument in a thermal-vacuum chamber 3 months before liftoff on May 30, 1971, while in transit, and, finally, while in orbit around Mars. The detailed structure of the responsivity curve is determined primarily by the properties of the beamsplitter coatings, the transmission characteristic of the entrance window, and the spectral response of the thermistor bolometer. The constancy of the responsivity between prelaunch tests and orbital operation around Mars is a good indication that optical alignment did not suffer during transit to Mars and that the *CsI* beamsplitter maintained its flatness. The curves in Figs. 42 and 43 have been displaced vertically to facilitate comparison.

Noise equivalent radiance (NER). The NER for the same periods as the responsivity is shown in Fig. 43. A NER of $0.5 \times 10^{-7} \text{ W cm}^{-2} \text{ Sr}^{-1} / \text{cm}^{-1}$ was achieved over most of the spectral range; this is very close to the calculated theoretical value. The smoothness of the plots is

improved with the increased number of cold and warm calibration pairs used in the NER computation.

Spectral resolution. The IRIS spectral resolution met the experiment objective of 2.4 cm^{-1} in the apodized mode of data reduction as demonstrated by the calibrated spectrum shown in Fig. 44. This was recorded at midlatitude from a single interferogram in March 1972, after most of the mineral dust had settled.

c. IRIS problems/anomalies

Reference interferometer neon amplitudes. An integral part of the IRIS was the neon reference interferometer that generated a 675-Hz sine wave, which was used to phase-lock the Michelson motor and to provide equal distance sampling of the IR data relative to the Michelson motor position. The neon amplitudes are measurements of the envelope of the 675-Hz sine waves peak-to-peak signals, which were sampled at ten points during each 21-s IRIS interferogram. Figure 45 is a plot of neon sample number 5, which occurs near the center of each interferogram. The decay of the neon 5 amplitude occurred at a similar rate in the other nine neon samples and was caused by darkening within the neon bulb, which was the light source for the reference interferometer. The darkening was caused by a metallic migration from the electrodes in the bulb to the inner side of the bulb's glass

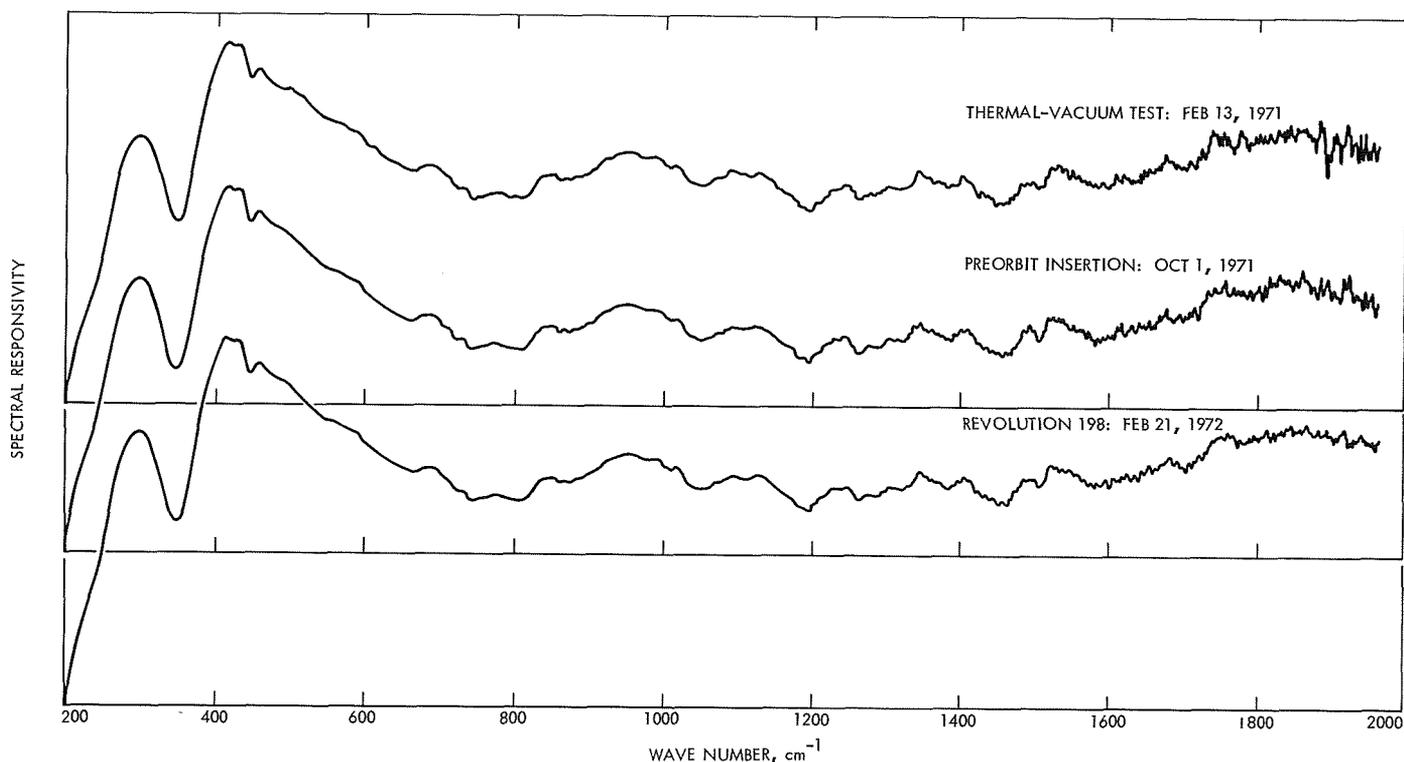


Fig. 42. IRIS spectral responsivity vs wave number

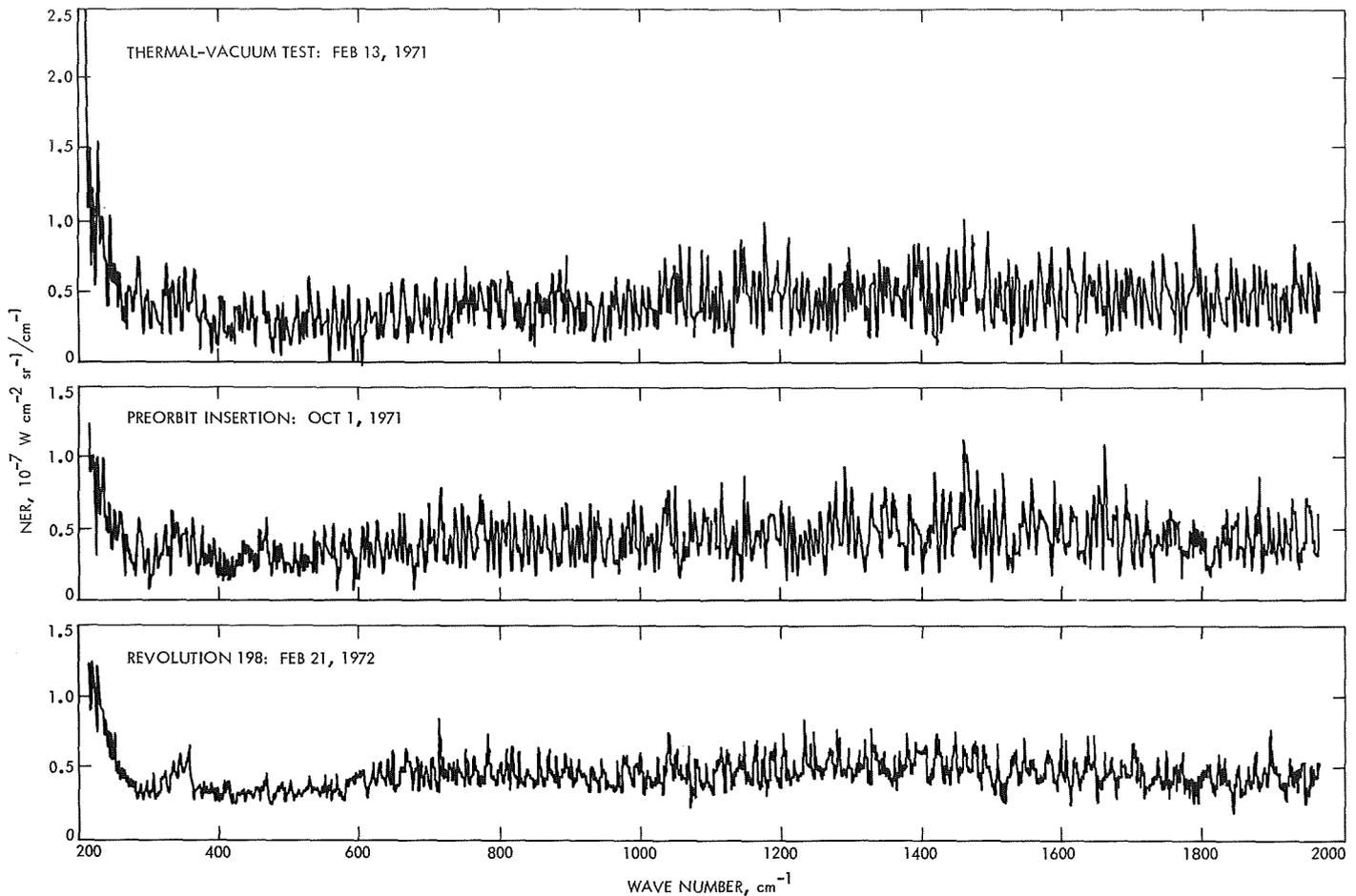


Fig. 43. IRIS NER vs wave number

envelope. The loss of neon intensity is theoretically expressed by: $I = I_0 e^{-kt}$ where I is the intensity at any time, I_0 is the initial neon intensity, t is the time of operation, and k is a constant. The decay of the neon amplitude did not cause any degradation or loss of IRIS scientific data since a large amplitude margin was provided initially.

Phase lock. The phase-locked loop (PLL) locks the Michelson motor drive to the reference spacecraft 675-Hz clock signal. The neon signal is phase-compared to the stable spacecraft clock and, if excessive phase error is detected, a loss of phase lock is indicated by a bilevel status bit that is present in both the RTS-1 and RTS-2 data formats. Figure 46 is a plot that depicts the number of RTS-2 phase-lock losses, where each data point was normalized by converting the number of phase-lock losses observed each day into phase-lock losses per hour. The increasing number of phase-lock loss incidents that occurred as the mission progressed can not be linked to a specific cause. However, the most probable cause was the gradual shift in the Michelson motor start position,

which was detected by observing that the position of the interferograms central peak was shifting to higher interferogram word numbers. The central peak shift is considered to be caused by an increase in motor drive current that most likely resulted from an electronic component value shift in the Michelson motor drive electronics.

The interferograms that indicated loss of phase lock were not used. The IRIS scientific yield was not materially affected since the percentage of interferograms lost because of the phase-lock losses was approximately 0.3%.

Noise spikes in interferograms. Noise spikes were expected to occur at random locations in a small number of IRIS interferograms because of occasional bit errors. Analysis of IRIS interferogram data showed that noise spikes were more apt to occur at IRIS interferogram word 3945 than at random word locations. These noise spikes were generally of negative polarity and were located only in interferograms in which an infrared radiometer (IRR) reset event occurred. The data automation

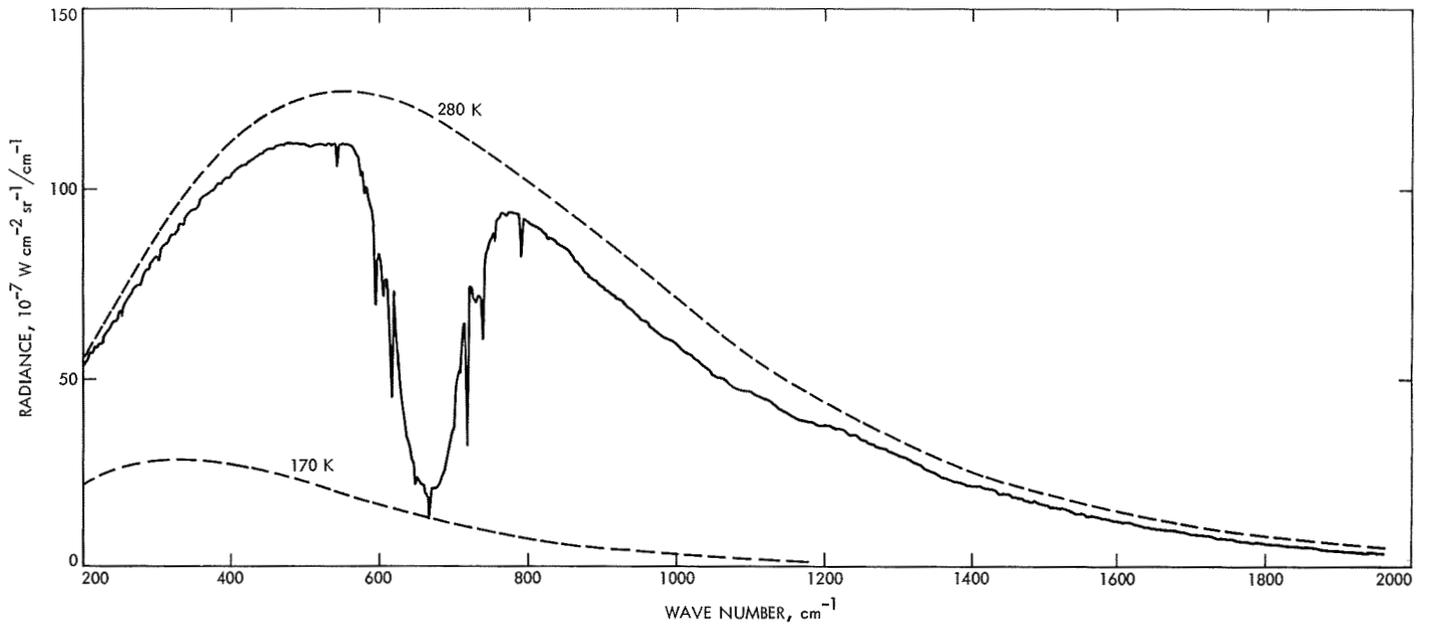


Fig. 44. IRIS spectral resolution

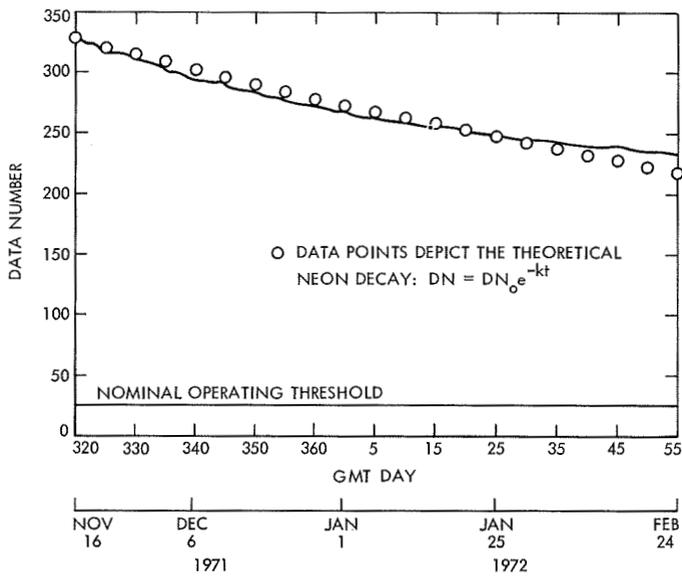


Fig. 45. Neon sample 5, DN vs days

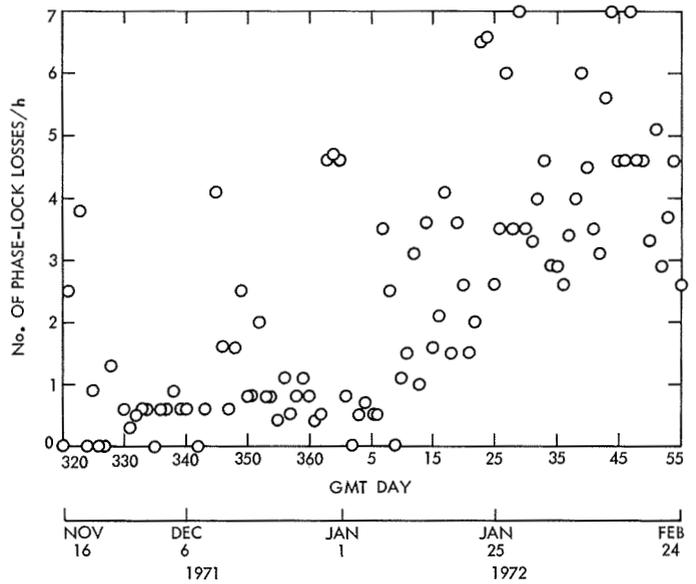


Fig. 46. RTS-2 phase-lock losses

subsystem generated an IRR reset pulse during every other IRIS interferogram at word 3924. The time interval between interferogram words 3924 and 3945 was 93 ms. The time interval between the data automation subsystem/IRR reset pulse and the IRR motor reset event was approximately 30 ms, and the variable amplitude noise spikes did not occur for every IRR reset pulse. A mechanism by which the data automation subsystem/IRR reset pulses could be coupled into the IRIS data is unknown. Computer processing routinely removed the spikes from the majority of interferograms through the use of interpolation techniques. No scientific data was lost because of the occurrence of noise spikes at IRIS interferogram word 3945.

16. Infrared radiometer subsystem

a. Objective. The objective of the IRR subsystem was to measure the surface temperature of the solid surface of Mars by detecting the thermal energy emitted in two wavelength bands (8 to 12 μm and 18 to 25 μm) covering the temperature range from 140 to 325 K (-207 to 125°F).

Absolute temperature measurements as a function of local time were correlated with the terrain features viewed by the TV experiment, thus providing a means for mapping the planet's surface. IRR data received from the orbiting Mariner 9 spacecraft vastly improved and extended the surface coverage obtained from earlier flights and provided further information regarding: (1) polar cap temperatures for establishing whether or not the caps are formed from H_2O ice or from CO_2 (dry) ice or a mixture of both, (2) large-scale distribution of the thermal inertia of the surface materials, (3) occurrence of irregularities of the cooling curve, and (4) existence of "hot spots" that may indicate sources of internal heat.

b. Functional design of instrument. The IRR weighed 3.8 kg (7.5 lb), had dimensions of $22.9 \times 15.2 \times 8.1$ cm ($9.0 \times 6.0 \times 3.2$ in.), and contained two detector packages, each with its own optical imaging and signal processing system.

The detectors were thin-film thermopiles each having 13 antimony-bismuth junctions, an increase of 8 over those used on Mariners 6 and 7. The lenses and filters through which the radiation must pass were of different materials so that one detector system (Channel 1) responded to radiation in the 8- to 12- μm wavelength band and the other detector system (Channel 2) responded to radiation in the 18- to 25- μm band. Respective optic systems provided detector 1 with a 0.53×0.53 -deg FOV and detector 2 with a 0.7×0.7 -deg FOV.

The IRR FOV was boresighted within the TV-B camera small-angle field to insure that the temperature measurements could be correlated with terrain features appearing in the TV pictures of the Martian surface.

Each detector produced an output voltage that increased with the incident infrared radiation. To facilitate amplification, this low-level dc voltage was converted into ac by an electronic chopper. This signal was amplified, reconverted to dc by a half-wave synchronous demodulator, filtered, and then fed to a commutator. The chopper and demodulator of each channel were driven by a common 200-Hz multivibrator, the output of which was derived from 2.4-kHz power frequency dividers. The outputs of the two data channels, the reference surface temperature monitor, and a power supply monitor were combined in a single data output by the commutator, which was controlled by signals from the spacecraft data automation subsystem.

A scanning mirror, actuated by a digital stepping motor, enabled the IRR to direct its field of view to any one of three positions: planet, space, or reference. When viewing space at 90 deg from the planet direction, the voltage output of the system was held in a memory circuit for analog subtraction from subsequent planet and reference readings. Thus, the output of the system was proportional to the difference in radiance between space and the planet surface. With the mirror in the reference position, which was 90 deg on the other side of the planet direction, the detectors viewed a serrated thermal plate that provided data for inflight calibration. The temperature of the thermal plate was independently monitored by a thermistor. The mirror was retained in its respective viewing position by a mechanical detent attached to the scan motor shaft.

To enhance the life of the detent mechanism, the mirror was stowed in the reference position during intervals of the orbit when the IRR was not gathering data or when the spacecraft was required to perform special maneuvers. This also precluded the possibility of having the detectors exposed to the Sun at any time throughout the mission.

During data gathering intervals, when the mirror was unstowed, a scan cycle was completed every 42 s as follows: Starting from the reference position, a "step scan" pulse from the data automation system switched the mirror to the planet position for a period of 19.2 s, then the mirror was switched to space for 2.4 s, back to planet for 18 s, then to the reference position for 2.4 s, after which

a new cycle was initiated. Data words (Channels 1 and 2 measurements) were produced in data pairs at 1.2-s intervals.

c. Parameters used for analysis. During each 42-s scan sequence, a total of 35 readings or data words (10 bits/word) were provided in each IRR channel and displayed in DN values on the 50-bit/s orbital science format. Of the 35 readings, 31 were planet measurements, two were reference calibration readings, one was a space measurement, and one was a temperature and voltage engineering measurement (temperature taken from the thermistor attached to the reference calibration plate was displayed in the Channel 1 format; the voltage monitor was displayed in the Channel 2 format).

d. Performance. The initial IRR turn-on occurred on September 30, 1971 at 00:17:51 GMT (ERT) day 274. The mirror was in the unstowed condition at time of turn-on and remained in the stepping sequence for a period of 20 min and 28 s. The mirror was then stowed. During this time, all IRR data readings were normal except for a period of 121 s between 00:32:04 and 00:34:05, when anomalous IRR Channel 1 planet and thermal reference readings were observed. At this stage of the mission, 43 days prior to orbit insertion, readings of approximately -420 DN were expected, indicating deep space. However, for this short period of time and for reasons presently unknown, the actual planet data readings ranged from -442 to -271 DN, a maximum deviation from normal of +150 DN. The maximum deviation on the thermal reference reading was -20 DN.

On October 2, 1971, the IRR was unstowed for 30 min during which time all data readings were normal with no indications of Channel 1 anomalies. The second science turn-on occurred on October 5 with the IRR again being commanded on in the unstowed condition. This stepping sequence lasted for 33 min during which time the observed data was as expected, that of space temperature.

The IRR was off from October 9, 1971, until November 1, 1971. On November 1, the IRR was turned on in the stowed condition and on November 2 was unstowed for 26 min during Saturn calibration.

The first indication of Mars as observed by the IRR occurred between the times of 23:16:19, November 8, 1971, and 02:13:26, November 9 during the Mars calibration exercise. Planet data observed during this 3-h stepping sequence showed an increase of approximately 8 DN for Channel 1 and 24 DN for Channel 2, indicating temperatures warmer than space. At 4 days prior to orbit

insertion, this small increase in the planet position measurements was expected, and indicated that Mars was quite small in the IRR field of view. More importantly, this was a fair indication that the IRR alignment within the TV B-camera FOV had not changed during launch.

As the spacecraft approached Mars, the planet readings increased and on November 14, 1971, day 318, during orbit 1, the maximum planet measurements (as referenced from space) were 190 DN for Channel 1 and 453 DN for Channel 2.

Data received throughout the mission was generally as expected. Large quantities of diurnal and nocturnal surface temperatures were obtained over a large portion of the planet. The maximum planet response observed during the mission occurred in orbit 236 on March 10, 1972, when the planet data reading was 444 DN and the thermal reference reading was 715 DN.

During orbit 25, two occurrences of unexpected planet and thermal reference readings were observed in the data from both IRR channels. The readings showed significant negative offsets lasting for exactly 2 frames during the first occurrence and exactly 3 frames during the second occurrence, approximately 35 min later. These readings were later found to be normal and were the direct result of Mars being viewed by the IRR through the spaceport. As Mars was being detected through the spaceport, the associated memory circuit subtracted this value from subsequent planet and thermal reference readings, which produced the negative offsets. These offsets were observed several times throughout the mission in varying degrees of amplitude depending on the scan platform slew positions and were indicative of proper IRR performance.

The IRR remained well within its operating temperature limits and responded to all mirror "stow and unstow" commands without incident.

The total on-time of the instrument from launch on May 30, 1971 through March 30, 1972 (science turn-off for solar occultation) was 3548 h. In a total 802-h mirror scanning time, approximately 275,000 mechanical detent actuations were completed.

e. Problems. There were no major problems associated with the IRR during the mission. On three occasions, however, for relatively short periods of time, anomalous IRR Channel 1 planet and thermal reference readings were observed. The first anomaly, as previously stated, occurred during cruise on October 1, 1971, approximately

15 min after initial science turn-on. Similar Channel 1 planet and thermal reference readings were observed during orbits 17 and 19 (November 22 and 23, 1971) for a period of approximately 2 h in each orbit and occurring at unpredictable intervals.

Possible areas, external to the IRR, having any relevance to the cause of these anomalies, such as spacecraft events, mechanical ringing, the spacecraft data system, and ground data processing were thoroughly considered. However, information obtained in each area failed to establish any meaningful correlation.

In assuming that the anomaly was caused by a malfunction within the IRR, the fault would have had to originate within the preamplifier/amplifier chain between the detector and multiplexer. The stepping mirror, power supply, and analog-to-pulsewidth converter are not candidates, since they serve both channels and only Channel 1 was affected. The establishment of a specific cause within the Channel 1 preamplifier/amplifier chain was precluded by the difficulty in arriving at any definite conclusions because of the lack of sufficient information contained in the data. Since orbit 19, over 700 h of anomaly-free science data has been gathered by the IRR.

17. Television subsystem. On September 30, 1971, the Mariner 9 Test Video System (TVS) was turned on for the first time after launch. Prior to turn-on, the only TVS data available was the camera-head and Bay VII electronics temperatures. Cruise values were within specifications. The TVS engineering telemetry was activated with turn-on and indicated that the TVS was operating as expected based on preflight data. All of the standard mission data confirmed that the TVS operated as designed with only one major exception: the A-camera filter wheel failed to step following revolution 118.

The operating performance of the cameras was evaluated through a series of in-flight calibration sequences and compared with preflight data. Table 25 identifies those in-flight calibrations and the performance characteristics that were obtained.

Analysis of the in-flight calibrations permitted assessment of TVS performance. The absolute photometric accuracy has not been determined to date. The geometric characteristics of the cameras were essentially the same as prelaunch after the correction for the Earth's magnetic influence was made. The modulation transfer functions (MTF) of the cameras have not been evaluated in detail, but an expected degradation in the B-camera MTF at

Table 25. TVS in-flight calibrations

Calibration sequences	Date performed (GMT)	Data obtained
Scan calibration I	10/1/71	B camera: Pointing accuracy, geometric distortion, point source response, noise analysis, residual image A camera: Not applicable
Scan calibration II	10/8/71	B camera: Pointing accuracy, point source response, residual image A camera: Not applicable
Saturn calibration	11/3/71	B camera: Light transfer, residual image, shading A camera: Not applicable
Revolution 7	11/17/71	B camera: Point source response A camera: Exposure intervals for filter positions 1, 2, 3, 7, and 8
Revolution 76	12/22/71	A camera: Light transfer in filter position 2 B camera: Not applicable
Revolution 225	3/5/72	A camera: Light transfer in filter position 5 B camera: Light transfer

highlight levels appears to be the same as was observed prior to launch. Table 26 contains TVS data. The TV imaging evaluation is being published in Ref. 38.

The general performance of the TVS was monitored daily using the real-time engineering telemetry data. The electrical and temperature characteristics, such as average video level (both scene and dark current levels),

Table 26. TVS performance data

Parameter								Total
Total pictures taken through March 23, 1972, GMT (revolution 262) ^a								10,364
Filter position	1	2	3	4	5	6	7 8	
A pictures received	11	1,158	24	109	1,588	95	18 359	3,362
B pictures received								3,486
Total pictures received in flight								6,848
Shutter operations (including false shutters)								13,186
Filter wheel operations								1,400
TVS on time, h								3,533
Beam on time, h								651

^aIncludes prelaunch and cruise calibration tests.

cathode current, A and B vidicon temperatures, and TV B-camera optics temperature, were observed and noted. Small changes in the dark current levels, and the camera head and optics temperatures have been used in support of decalibration of the video data received. The decrease in cathode current did not cause any degradation in the performance of the subsystem. The electrical and temperature characteristics that were monitored are tabulated in Table 27.

Of the two problems encountered during the mission, one was determined to have been present prior to launch. This was the microphonic noise induced by the mechanical vibrations inherent in the ultraviolet spectrometer (UVS) instrument. The other problem was the failure of the A-camera filter wheel to respond to stepping commands. It was determined after the failure that the filter wheel was in position 5. In position 5, a polarizing filter with a spectral response approximately equivalent to SCHOTT glass, type GG-495, is used. Prior to the failure, the filter wheel stepped 1,400 times as commanded. Other than the noise induced by the UVS instrument, analysis determined that the inherent noise in the TVS had not changed significantly since preflight testing.

The use of computer techniques enabled the observation of such low-level and low-contrast features as dust on the vidicon faceplate and the UVS and IRR noise. Further analysis confirmed that these properties existed prior to launch and were not acquired after launch.

The TVS exceeded expectations in successfully performing its designed role in support of the Mariner Mars 1971 mission.

18. Ultraviolet spectrometer subsystem

a. Objectives. The scientific objectives for the UVS subsystem are divided into two categories: (1) ultraviolet cartography, the mapping of the surface and lower atmosphere in the ultraviolet spectral region, and (2) ultraviolet aeronomy, the study of the composition and structure of the upper atmosphere using the techniques of ultraviolet spectroscopy (Ref. 39).

The ultraviolet cartography objectives are to:

- (1) Measure the local atmospheric pressure over the major portion of the planet and provide topographic maps.

Table 27. TVS engineering characteristics

Parameter	Prelaunch, 5/7/71	Cruise, 9/1/71	Turn-on, 10/30/71	Revolution 168, 2/5/72	Turn-off, revolution 276, 3/30/72
A cathode current					
Read, μ A	7.3	NA	7.3	5.95	5.6
Erase, μ A	14.45	NA	14.45	11.95	11.45
B cathode current					
Read, μ A	9.1	NA	9.4	9.0	7.4
Erase, μ A	17.9	NA	18.4	17.6	13.6
A G ₂ , V	616.0	NA	611.0	613.0	611.0
B G ₂ , V	615.0	NA	611.0	612.0	611.0
A-B focus, mA	76.0	NA	75.9	75.9	76.0
Event ladder, V	1.463	NA	1.474	3.463 ^a	3.474 ^a
Input power current, A	0.65	NA	0.65	0.65	0.66
+4 V	4.12	NA	4.12	4.12	4.17
A average video (dark), V	0.186	NA	0.186	0.186	0.126
B average video (dark), V	0.126	NA	0.126	0.126	0.090
A vidicon temperature, °C	NA	11	7	7	7
B vidicon temperature, °C	NA	14	9	11	10
B optics temperature, °C	NA	NA	10	9	6
B optics temperature (front), °C	NA	12	11	10	11
Bay VII temperature, °C	NA	12	20	21	21

^aHigher value indicates A-camera cover deployed.

- (2) Measure the local ozone concentration.
- (3) Measure the variability of the surface features in the ultraviolet.
- (4) Search for evidence of biological activity by measuring local variations in the oxygen-ozone abundances.
- (5) Measure the scattering properties of cloud and haze layers.
- (6) Determine the photometric properties of the atmospheric dust, the surface, the polar caps and the moons of Mars.

The ultraviolet aeronomy objectives are to:

- (1) Measure the composition and structure of the upper atmosphere as a function of latitude, longitude, altitude and time.
- (2) Measure the variability of the ionospheric composition.
- (3) Measure the variability of the rate of escape of atomic hydrogen from the exosphere.
- (4) Measure the distribution and variability of the ultraviolet aurora and determine the induced planetary magnetic field.
- (5) Determine the correlation of airglow emissions with solar activity.

b. Parameters monitored. Each of the two UVS channels contains spectral data as well as engineering data in repetitive 3-s scans with each UVS channel containing 600 data words per scan. The data from the APW converter are encoded in binary most significant bit (MSB) first with 255 DN representing a 6-V, UVS analog output.

The engineering data extracted from the "high rate" (RTS-2) spectral data stream were processed and displayed at SFOF in real time by the mission and test computer (MTC). The real-time engineering data, as well as the spacecraft recorded data, were available on digital TV in several formats and in line print. The nonreal-time processing consisted primarily of tabulating the data in the form of a histogram, full-scan digital prints, and sample-by-sample averaging. In addition, the MTC provided a real-time analog output converting the digital data to analog data, which drove a strip chart recorder.

In the low-rate data mode (RTS-1), none of the UVS engineering functions are available. However, the data automation subsystem integrates a small portion of the

UVS Channel 1 data in the spectral region of the Lyman alpha 1216-Å atomic hydrogen resonance line. This region of the UVS scan is sampled by the automation system four times per frame. MTC channels 0-010, 0-024, 0-047, and 0-064 are assigned to the Lyman alpha and are used to derive channel 0-500, which contains the latest available Lyman alpha data. Only a very minimum performance evaluation can be made in this mode.

c. Performance. UVS performance is described from the scan calibration exercises through the preorbital science sequence and orbital operations up to spacecraft solar occultation. Table 28 shows the power on/off sequences undergone by the UVS during the above periods. The 3569 h of operation represent 4.3×10^6 UVS scans and 1.9×10^9 revolutions on the motor.

In addition to accomplishing all of the prescribed scientific objectives by measuring the ultraviolet emissions from the sunlit surface and atmosphere of Mars, and from Phobos, the UVS demonstrated a significant capability for stellar observations. Strong UV signals were observed from Delta Cetus, Epsilon Persus, and Alpha Lyra; low-level signals were observed from 29 other stars.

Evaluation of the spectral data includes only those times when the instrument was pointing into dark space. This represents the dark current or background levels in the spectral region of the scan. The scientific data evaluation was performed by the University of Colorado.

The first power application to the UVS, subsequent to launch and the 124-day transit to the planet Mars,

Table 28. UVS power on/off sequences

Date	GMT	Duration, h	Spacecraft command	Function
10/1/71	00:10	44:19	DC 77	Power on
10/2/71	20:29		DC 77	Power off
10/7/71	22:27	43:33	CC Trip. 4D	Power on
10/9/71	18:00		DC 77	Power off
11/1/71	19:30	284:59	DC 77	Power on
11/13/71	16:29		CC Trip. 4D	Power off
11/14/71	09:13	31:36	DC 77	Power on
11/15/71	16:49		DC 77	Power off
11/16/71	09:04	1059:00	DC 77	Power on
12/30/71	12:04		DC 77	Power off
12/31/71	00:55	1874:25	DC 77	Power on
3/17/72	03:20		DC 77	Power off
3/21/72	04:00	231:20	DC 77	Power on
3/30/72	19:20		DC 77	Power off
		Total 3569:12		

occurred on October 1, 1971. For the initial 20-h period, only low-rate RTS-1 data were available; hence, a very minimum performance evaluation could be made. The Lyman alpha data observed from the RTS-1 data stream in a serial sequence were 17, 18, 18, 17, 18, 18, 15, 25, 14, 14, 16, 15, 15, 19, 13, 13, . . . and represented the predicted pattern of A BB C DD E F GG H II J KK . . . A histogram of the MTC Channel 0-500 UVS-1 Lyman alpha showed a distribution value of about 15 DN, representing the 8 most significant bits of the sum of 20 samples of the baseline noise (5 to 8 DN) on the G-Channel in the Lyman alpha spectral region plus the Galactic Lyman alpha background.

The fact that these numbers were changing each 3-s period verified that the UVS scan drive mechanism was operating and providing the data automation subsystem with a fiducial pulse used to sample the UVS-1 Lyman alpha data.

On October 1, 1971, the spacecraft was in the RTS-2 data mode for approximately 2 h; hence, data products were available providing information for a complete performance analysis that led to the positive results that launch and the 124-day transit had not degraded the instrument performance in any way. The observed DN values of each UVS engineering measurement are shown in Table 29.

Random signals were observed in the spectral region of UVS 2 (F-Channel), whose frequency and magnitude were not characteristic of those observed during pre-launch tests. It is the consensus of the investigators that the increase in frequency and magnitude of the random signals was the result of cosmic radiation (Refs. 40 and 41). Recent experiments at the University of Colorado using a radioactive source in the proximity of the Mariner Mars 1971 engineering model UVS verified that γ rays, for example, will cause an increase in frequency and magnitude of random signals. A comparison of these data with the Mariner 9 far-encounter data, showed that the frequency and magnitude of the spikes were greater than were observed on the Mariner 9 N-Channel. This difference is explained by the fact that the gain on the Mariner Mars 1971 photomultiplier tube (PMT) in state 7 is greater by a factor of 10.

The effect of random cosmic radiation and noise spikes on data recovery can be greatly reduced by averaging the UVS scan, sample-by-sample. Figure 47 shows an example of a sample-by-sample average for 239 successive scans of background noise and radiation. The area under

Table 29. UVS orbital engineering measurements

UVS function	MTC channel	DN values observed	
		Preorbit	Orbit
UVS-1 zero check	U 500	7-9	5-10
UVS-1 gain calibration	U 502	194-196	192-197
UVS-1 T ₁	U 504	165-166	161-166
UVS-1 +15 V	U 506	205-206	204-207
UVS-1 high voltage	U 508	177-179	178-180
UVS-2 zero check	U 501	4-5	2-5
UVS-2 gain calibration	U 503	185-186	181-186
UVS-2 T ₂	U 505	166-167	164-170
UVS-2 gain state	U 507	—	29-31
		—	57-60
		—	84-85
		—	110-111
		—	135-136
		162-163	162-163
		188-189	187-188
		214-215	216-217
UVS-2 high voltage state	U 509	—	69-71
		—	79-81
		—	92-93
		—	104-105
		—	119-120
		135	134-135
		153	152-153
		176-202	175-202
FTS temperature monitor	E 416	7.8-10.6°C	6-10.6°C

the average baseline is approximately equal to the area under the noise and random spikes for any individual scan.

The engineering measurement from the high-voltage monitor showed that the voltage was 26 DN above normal about 10% of the time. It was concluded that this high DN is related to the full scale random spikes caused by cosmic radiation. These spikes draw current of about 10^{-4} A through the PMT dynode string, thus causing the high-voltage regulator to react and to increase high voltage at its maximum value, momentarily corresponding to 202 DN on the monitor. This will be observed only when a cosmic particle impinges on the PMT during the time the high voltage is being sampled, which is four times out of 600 samples in a UVS scan. To observe the occurrence of a spike on the PMT during the four samples of high voltage readings 10% of the time, it is expected that 13 full scale events, 2 to 4 samples in width, will be observed in the spectral region.

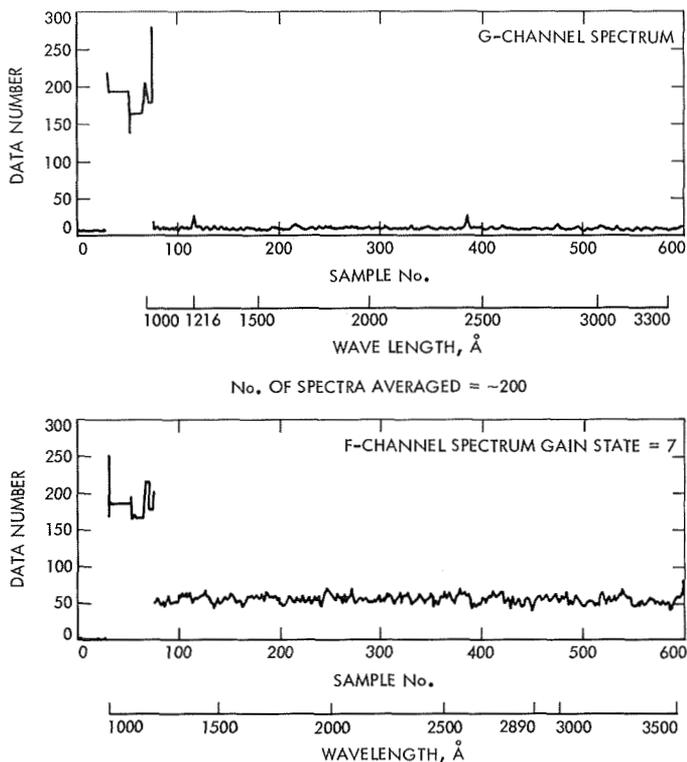


Fig. 47. Dark current average

Reliability is not affected when the high voltage swings to its maximum value because it does this by design during the sequencing of the engineering pedestal data every 3 s. During the zero check and the gain calibration, the high voltage is reduced to a low value, representing a negligible gain on the PMT. Between the gain calibrate monitor and the temperature monitor, the high voltage is returned to its operating value. As it returns, it swings to its maximum value within the time constant of the regulator.

The science instruments were secured from the pre-orbital sequences on November 13, 1971, in preparation for the orbital insertion maneuver. On November 14, 1971, the spacecraft was successfully orbiting the planet Mars, and science power was resumed. The performance characteristics of the UVS had not changed, indicating that the insertion maneuver had no adverse effects on the instrument.

During the initial orbital sequence, the automatic gain control was operated over its full range for the first time after launch. It continued to function throughout the entire orbital operation, providing the appropriate dynamic range for the UV science measurements.

In general, the performance characteristics of the instrument remained unchanged throughout the orbital sequence with one exception: the baseline of the F-Channel above gain state 5 increased during several orbits before recovering its normal level. Table 29 shows the range of values for each of the 10 UVS engineering measurements observed during orbital operations.

The increase of the F-Channel baseline in the spectral region was systematically plotted as a function of the orbit shown in Fig. 48 by averaging the UVS scans sample-by-sample for a 10-min period each day when the UVS field of view was pointed away from the planet and the spacecraft was in the RTS-2 data mode. The baseline or average galactic background of 50 to 55 DN represents the normal level for gain state 7.

With all engineering functions operating as expected, it was concluded that the increase in baseline current was produced by the F PMT.

An increase in PMT dark current is characteristic of an F type of PMT that has been overexposed to intense UV light in a high-gain state. Considerable effort was spent to quantitatively correlate this phenomenon, with slewing the scan platform from dark space across the bright limb of the planet at a rate much greater than the time constant of the automatic gain control. The phenomenon, however, requires further investigation. Another conjecture is that the UVS was viewing an unknown radiation source during this period.

During the spacecraft solar occultation period, the science power remained off with replacement heater power only for thermal control. The UVS temperatures remained well within the specified range; hence, the post occultation performance is expected to remain unchanged.

19. Reliability assurance

a. Introduction. This section includes summaries of Mariner 9 reliability assurance functions, problem failure reports (PFRs), and ISAs. PFRs were used for documenting spacecraft problems and failures in the same manner as for previous JPL flight projects. Two weeks before MOI, the ISA system was expanded from a spacecraft team/command team reporting system to a system that covered an almost infinite variety of MOS anomalies, involving all MOS organizations. Previously, many of these anomalies were not documented, monitored, or solved. Each of the reliability assurance functions contributed to efficient anomaly solution, minimizing spacecraft risk, and maximizing science data return.

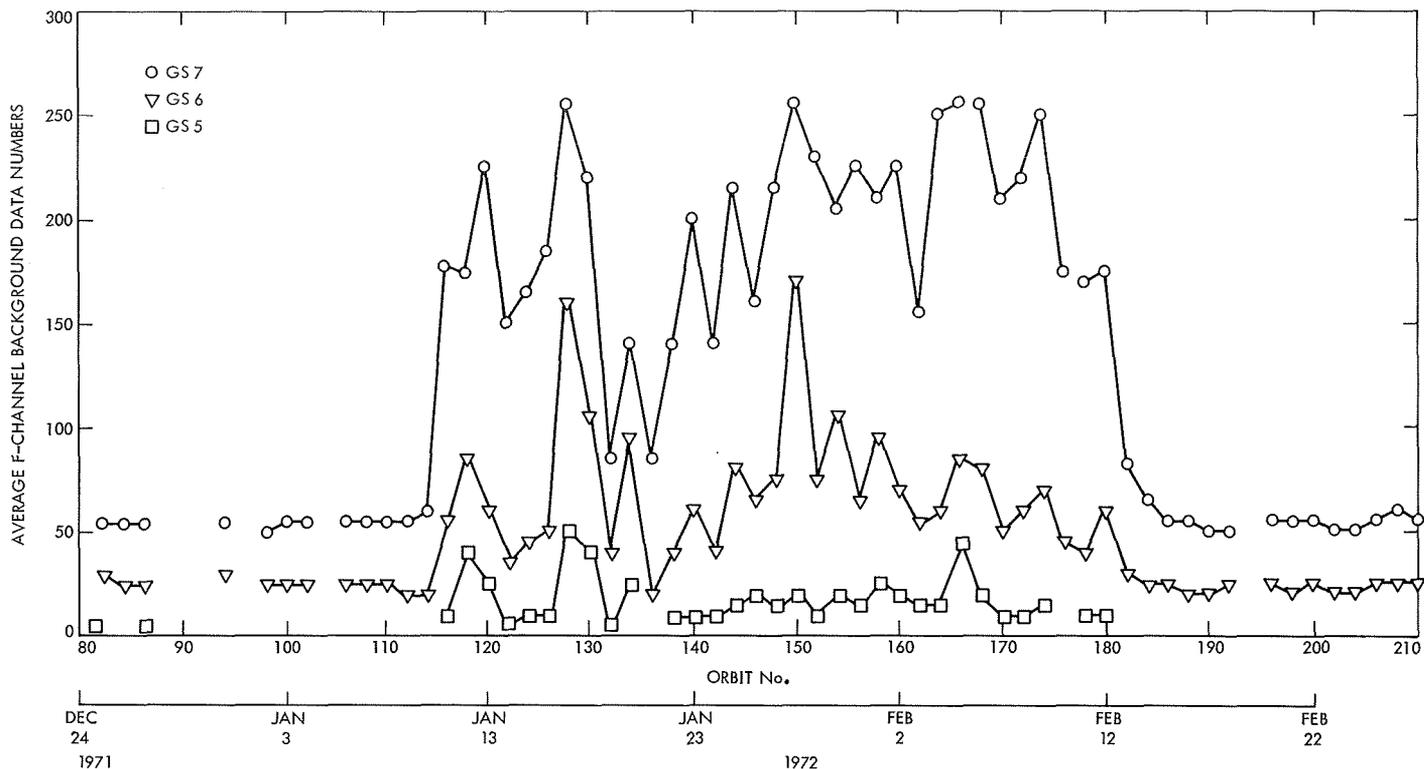


Fig. 48. Average F-channel background

b. *MOS reliability assurance functions.* MOS reliability assurance functions include the following:

- (1) Ensuring that PFRs are written for all appropriate spacecraft anomalies, are investigated promptly, and closed out completely in a timely manner.
- (2) Participating with the spacecraft team in real time analysis of spacecraft anomalies. Primary tools for this effort included:
 - (a) Familiarity with prelaunch PFRs.
 - (b) Complete sets of all Mariner Mars 1971 PFRs and all Mariner Mars 1969 mission PFRs available in the spacecraft team area of the SFOF.
 - (c) Several types of PFR computer summaries, which provide rapid access to PFR data.
- (3) Participating with the spacecraft team in risk assessment, particularly in planning new sequences, spacecraft operation in untested modes, contingency planning, and consideration of constraint violation.
- (4) Managing the ISA system.

c. *Problem/failure reporting.* After launch of Mariner 9, PFRs were required for the following types of anomalies:

- (1) All spacecraft subsystem failures.
- (2) Subsystem performance degradation.
- (3) Significant actual or potential spacecraft operational problems.
- (4) Spacecraft problems that had an actual or potential effect on achieving mission goals.
- (5) Unexpected spacecraft or subsystem performance that could not be explained within a few hours.
- (6) Problems and failures during proof test model (PTM) spacecraft testing in the JPL spacecraft assembly facility.

Table 30 includes a summary of Mariner 9 and PTM PFRs by subsystem.

A comparison of the number of prelaunch PFRs with the number of postlaunch PFRs for the spacecraft system and the ten spacecraft subsystems with the most prelaunch PFRs (Table 31) shows that subsystems with the most prelaunch PFRs generally also had the most postlaunch PFRs. The percentage of system PFRs is larger

Table 30. Postlaunch PFR summary

Name	Spacecraft Mariner 9	PTM
System	13	0
Radio frequency (RFS)	5	1 (proto)
RFS support equipment (SE)	NA	0
Flight command (FCS)	4	0
FCS SE	NA	7
Power	2 (1 coassigned)	0
Power SE	NA	0
CC&S	5	0
CC&S SE	NA	0
Flight telemetry (FTS)	1	0
FTS SE	NA	0
Attitude control (A/C)	8	1
A/C SE	NA	0
Pyrotechnic	0	0
Pyrotechnic SE	NA	0
Cabling	0	0
Cabling SE	NA	0
Propulsion	1	0
Propulsion SE	NA	0
Temperature control	2 (1 co-assigned)	
Mechanical devices	0	0
DSS	0	0
Antennas	0	0
DAS	0 (see PFR 105503) ^a	0
SCAN	0 (see PFR 105495) ^a	0
UVS	1	0
TVS	3	1
IRR	2	2
IRIS	1	0

^aSystem PFRs involving but not assigned to these subsystems.

Table 31. Comparison of pre- and postlaunch PFRs^a

Subsystem	Prelaunch		Postlaunch	
	Number of PFRs	Rank	Number of PFRs	Rank
RFS	440	1	5	3 tie
A/C	357	2	8	2
Propulsion	213	3	1	2nd from last
CC&S	165	4	5	3 tie
IRIS	146	5	1	2nd from last
FCS	124	6	4	4
DSS	120	7	0	last
FTS	116	8	1	2nd from last
TV	111	9	3	5
Power	71	10	2	6 tie
System	68	11	13	1

^aThe 10 subsystems listed above are those with the most pre-launch PFRs.

for postlaunch than for prelaunch because telemetry limitations after launch make it more difficult to determine the subsystem causing an anomaly. The infrared interferometer spectrometer (IRIS) had only one postlaunch PFR, which documented subsystem degradation. The degradation had no effect on performance, i.e., the quality or quantity of science data retrieved. Figure 49 shows a curve of cumulative Mariner 9 PFRs versus time. The average rate of PFR initiation was about one per week. However, 11 PFRs were written during November 1971, a busy month when several preorbit science sequences, MOI, orbit trim, and initial orbital science sequences in a new environment were performed.

Table 32 contains a summary of the most significant Mariner 9 problems and failures from launch through beginning of solar occultation. This summary is intended to provide an accurate relative perspective for these PFRs by categorizing them and describing probable causes and effect on the mission.

PFRs were considered significant if they met one of the following criteria:

- (1) An actual electronic or electromechanical failure could be confirmed through analysis of available telemetry data.

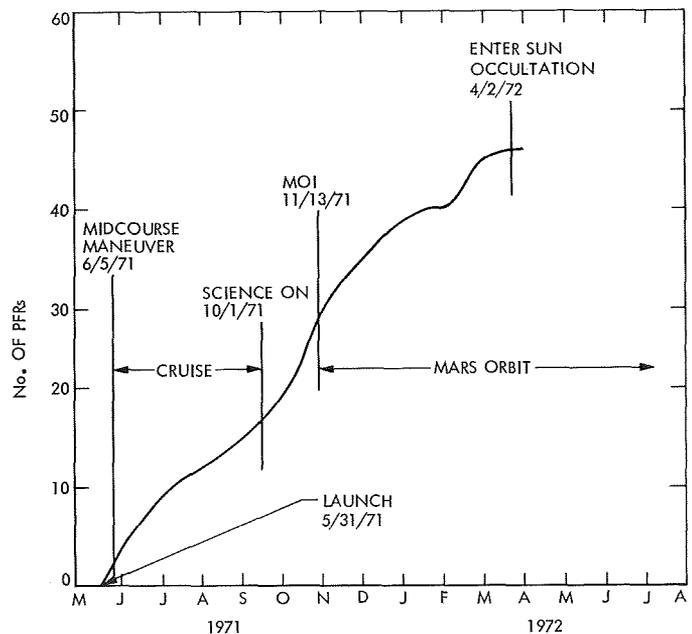


Fig. 49. Mariner 9 postlaunch PFRs vs time

- (2) A spacecraft subsystem performance degradation had a significant mission effect.
- (3) Possible indications or causes of performance degradation would have a significant mission effect.
- (4) Intermittent anomalies repeated more than once could have serious consequences if they persisted continuously.

- (5) Intermittent anomalies that occurred only once could have serious consequences if they persisted.

d. Incident surprise anomalies (ISAs). The expanded ISA system is considered a project-oriented anomaly reporting system that provides a cost effective means of identifying, communicating, monitoring, and correcting a wide variety of problems that do not require the formal documentation and processing requirements of the PFR

Table 32. Significant postlaunch failures

PFR No. and date	Description	Probable cause	Mission effect
A. Probable electronic/electromechanical failures			
105489 11/17/71	RFS receiver anomaly	Failure of one of ≈ 30 electronic parts in one stage of limiter input to AGC loop; highest probability is a solid tantalum capacitor short	(1) RFS receiver best lock frequency has shifted ≈ 10 kHz (2) RFS receiver tracking rate capability decreased (3) Degraded ranging performance, unless procedural compensation was made
105497 12/7/71	RFS TWT failure	Most likely cause: TWT 2, tube cathode moving; possible cause: short between collector and ground in TWT or in power supply	(1) Switched to TWT 1 (2) Established a mission constraint not to switch back to TWT 2 unless TWT 1 shows more anomalous behavior (excessive power drain, or rapidly rising temperatures) than TWT 2; a switch to low power mode would be required prior to switching back to TWT 2
105503 1/11/72	TVA filter wheel stuck in position 5	Failure possible in DAS of one of following: (1) Any one of 7 integrated circuits (ICs) in logic (all gates) (2) Interface circuit (one each IC gate, diode, capacitor, and transformer) (3) Shorts or opens along signal path. Failure possible in TV on one of following: (1) Open gate in a Signetics M1480Q IC (2) No start pulses from DAS (see DAS failures) (3) High-frequency noise on stop line (4) Stop pulses arriving sooner than 14 ms after start pulse	Mission constraint was established not to step filter wheel because of possibility of being stuck in a less desirable or unknown filter position
B. Performance degradation			
105469 6/2/71 105478 8/21/71	RFS exciter 2 output decrease	Decrease in gain of two overstressed transistors in X30 module	(1) Lost more than 2 db in exciter output (2) Rate of decrease about 0.1 dB per month before switch (3) Necessitated exciter switch on 5/30/72 to return IRIS data and double picture playback capability. Exciter 1 did not show this degradation

Table 32 (contd)

PFR No. and date	Description	Probable cause	Mission effect
105471	Excess gas usage because of error	Resistors in the attitude control's ± 12 -V supply caused unregulated sun sensor voltage, which, in turn, caused excessive limit cycle velocity	(1) Gas usage was about 4 times normal from launch through about 8/13/71, causing loss of about 227 mg (0.5 lb) of N ₂ more than expected (2) Shorter mission duration
105481 9/21/71 105486 10/24/71	Roll gas valve leakage	Contamination, probably generated within the leaking valve; possibly because of wear caused by a hard particle, wedged between push rod and sleeve, working back and forth with valve motion; wear particles collecting on valve seat probably cause leakage	(1) Caused usage of an extra 1135 mg (0.25 lb) of N ₂ (2) Use of DC-18/DC-19 commands reduced leakage to normal rates of less than 0.908 mg (0.002 lb)/day (3) Gas usage was an important factor in sequence planning (4) Shorter mission duration
C. Possible indications or causes of degradation			
105491	UVS photomultiplier tube saturation	Slewing UVS FOV across Mars bright limb	(1) Saturation occurred several times before constraint was established not to slew UVS FOV across planet bright limb (2) Effects could be seen for up to 2 weeks in high-gain states (3) Possible degradation of F photomultiplier tube
105495 11/29/71	Cone actuator slipped 64 min	Scan platform driven into stops because of DSN operator error	(1) DSN modified procedures and implemented a software change to prevent recurrence (2) Contingency plan set up to use DC-34 (scan power on/off) (3) Possible slip clutch degradation
105513 3/21/72	Lower TVB cathode current	Possible degradation of TVB vidicon	(1) No effect since performance margin existed (2) Cathode current was monitored after each on-off cycle
D. Intermittent anomalies (repeated)			
105473 7/8/71	TLM 410 Deck Temperature Channels outputting ODN intermittently (many occurrences for about 15 days)	(1) Loose sliver of silicon in FET can (2) Diode CR6 open	Anomaly continued for 15 days intermittently and did not recur; loss of all 410-deck temperature measurants was not considered serious at this time because complete temperature history had been obtained.
105508 1/18/72 3/4/72	Extra zero inserted in CC-20-09 command (two occurrences)	(1) Noise transient on FCS-DAS synchronization interface could have caused extra synchronization pulses (2) Transients may have caused internal DAS logic to be set giving extra shift pulses	Pictures recorded with nonoptimum exposures; extra zero inserted in other commands could be more serious
105509 3/9/71	DC-52 erroneously set Flag 4; 4 recurrences on same day	Bit error in bit 15, word 8 of CC&S memory Cause could not be verified because DC-52s were not attempted again	Constraint imposed to prevent use of DC-52 (computer flag interrupt) Single A pictures can be taken with alternate CC-1/2 pair instead of DC-52; however, the CC-1/2 approach requires additional constraints

Table 32 (contd)

PFR No. and date	Description	Probable cause	Mission effect
E. Intermittent anomalies (nonrepeats)			
105498 12/7/71	CC&S did not issue a programmed series of 21 scan steps (31 Ds)	Possibly a "glitch" caused a memory bit change that halted slew routine	None; missing steps were in "safe" direction. QC commands were sent to correct missing steps
105510 3/13/72	CC&S U244 DC-84 checksum failed in two attempts (see PFR 105511 for similar problem)	A memory error, probably caused by a "glitch" before or during the initial checksum while the CC&S was processing memory data; also, possibly caused by bit error mentioned under PFR 105509	Resulted in cancellation of 4 of 5 planned high-gain antenna maneuvers prior to solar occultation to allow trouble shooting; caused extensive contingency planning and analysis
105511 3/16/72	CC&S went into continuous readout routine when it should have terminated checksum routine initiated by DC-84. (PFR 105510 shows a similar problem)	Probable noise glitch while CC&S was locked up in checksum routine; also possibly caused by bit error mentioned under PFR 105509	(Same comment as for PFR 105510 above)
105512 3/23/72	Spacecraft FCS out of lock during high-gain antenna maneuver	Possible DSS-62 power or frequency transient, which may have occurred within 5-s measurement sampling interval	Loss of 3-1/2 TV pictures; caused extensive contingency analysis and planning

system. Essentially, the ISA system serves as a project management tool for ensuring that anomalies involving interface between MOS organizations are explained and corrected on a cost/risk effectivity basis.

The ISA system was expanded into this integration role about November 1, 1971. Thereafter, ISAs were written for all of the following types of anomalies:

- (1) Nonreal time reporting of science data anomalies by Experimenters and experiment representatives. Science data anomalies were also reported from several members of the Spacecraft, Science Data, and Science Recommendation Teams, and from the image processing laboratory. These ISAs from other sources are included in other categories below.
- (2) Documenting of spacecraft trend observations (such as tape recorder bit errors).
- (3) Unexpected spacecraft performance (not documented by PFRs).
- (4) Deviations from planned command sequences (used for experiment and master data records).
- (5) Spacecraft Team internal and interface software and procedural problems.

- (6) Immediate interim documentation of anomalies that could not be definitely assigned to a specific MOS organization.
- (7) MTC software problems.
- (8) Flagging significant discrepancy reports (DRs) for Project attention.
- (9) Providing a system for economically providing real time documentation of data that was efficiently coordinated with other MOS organizations and used for closeout of PFRs, DRs, and MTC failure reports (FRs).

The quantities and percentage of ISAs in these nine categories are summarized in Table 33.

The most significant ISAs written (excluding those resulting in PFRs) prior to solar occultation, April 2, 1972, are listed in Table 34.

C. Data Processing System

1. SFOF System problems. The fundamental problem of the Mariner Mars 1971 Data Processing System was the late delivery of scheduled software functions and the poor reliability of the operating system in the IBM 360/75. This problem can be attributed to the selection of IBM 360/75 hardware too late in the course of project develop-

Table 33. ISAs by category

Category	Quantity	Percentage
NRT science data anomalies	9	2.5
Spacecraft trend observations	5	1.4
Unexpected spacecraft performance	49	13.6
Deviations from planned command sequences	59	16.4
Spacecraft Team internal and interface software and procedural problems	63	17.5
Anomalies not assigned to specific MOS organization	5	1.4
MTC software problems	55	15.3
Flagging significant DRs	20	5.6
The quantity of ISAs used for close-out of PFRs, DRs, and MTC FRs:		
PFRS	33	
DRs	21	
MTC FRs	3	
Subtotal	57	15.8
Not accounted for:	38	10.6
Total quantity	360	

ment. In less than a year, a real-time operating system had to be developed and implemented in parallel with the development of the tracking, telemetry, command and analysis programs, which were selected to operate in the real-time environment. An existing real-time operating system was acquired with the hardware, but it required major modifications.

Parallel development, integration, and testing resulted in late deliveries of system and user capabilities, which caused development milestones to slip. The slip resulted in stretching the already critical resources of manpower and computer time.

Having to share critically thin development resources between development, integration, testing, and operational support activities affected the total job in that some confusion on priorities resulted. At times, this resulted in actions that were uneconomical, although they may have been the most expedient from the standpoint of criticality. Development schedules began to slip because resources were being used to solve problems that occurred in integration and testing. Delivery to the operational data base also began to slip as the integration and test activities slipped because of late development delivery. Therefore, the next set of deliveries was late because development resources were being used to support system integration and testing of the previous model or version.

Table 34. Significant ISA

ISA	Date	Description
015	11/4/71	During loss of Canopus lock (PFR 105487), receivers were out of lock because of lower than expected AGC, followed by AGC variations; the cause was determined to be the LGA/HGA interferometer effect; this was later confirmed in the orbit trim maneuver
018	11/4/71	This ISA, written during Saturn calibration playback, was held open for the remainder of the mission to record all missing bits in Mariner 9 playbacks as a way of monitoring tape recorder performance
30	11/15/71	Three dark spots were observed in all A-camera stretched pictures; it was confirmed that spots were dust particles on the vidicon, which had been present but unnoticed prior to launch
31	11/16/71	TLM and RF carrier thresholds were different than predictions because the LGA/MGA patterns were not smooth between antennas and thus caused ± 30 -s time variation between predictions and actuals; this anomaly occurred during the yaw turn from the LGA to MGA
46	11/22/71	Phobos entered Canopus tracker FOV for 45 min; this also occurred when Phobos, Diemos, or Mars limb entered the FOV of the Canopus Tracker, IRR space port, or UVS and caused considerable operational difficulties (also recorded by ISAs 95, 126, 187, 200, 224, 228, 234, 238)
68	12/1/71	First of several ISAs concerning considerable TV picture data loss during 2-kbit/s overseas playbacks caused by a noise source the DSN could not isolate (recorded by ISAs 113, 115, 122, 123, 142, and 179)
72	12/1/71	Message intended for DSS-62 was sent to DSS-41 (discrepancy report 056). This was second occurrence of problem, which caused the cone actuator clutch slip (PFR 105495)
78	12/5/71	AGC (Channel 115) changed signature; this was the first of several ISAs to document observations related to the RFS receiver anomaly (PFR 105489); also, ISAs 161, 181, 240, 253, and 352 documented related observations
130	12/21/71	Gas usage higher than expected because of slew activity (other ISAs related to gas use are 151, 156, 270)

Table 34 (contd)

ISA	Date	Description
145	12/28/71	Snowstorm at DSS-14 caused loss of playback data on December 28 and 29, 1971
164	12/31/71	First chamber pressure reading during Trim 2 motor burn was higher than expected; the most likely cause is that the N ₂ saturation gradient in the oxidizer tank outlet was not accounted for in the preburn prediction
343	3/23/72	FTS did not respond to 6A command when at 8½ bit/s TLM rate because of FTS idiosyncrasy

Operational support was inadequate and often not time-responsive because the designated personnel were too busy on development and integration of the next set of capabilities to be delivered. Lack of adequate computer time was a further contributor to slipping schedules. Since there was not sufficient computer time for development, integration, testing, and flight support activities, the first three were penalized. Often regression testing to determine if the capabilities of the last system version were still functioning had to be passed over lightly. Thus, discrepancies that had previously been solved and corrected on the prior mission system version, were encountered during flight operations.

During the early part of the mission, the software system supporting the Mariner Mars 1971 flight project failed approximately every five hours. Although the failure rate decreased to approximately one failure every 20 hours subsequent to orbital operations, the running times of analysis programs and the operation of certain elements were somewhat erratic. The high failure rate of the software system is the result of many factors in a number of different areas.

The operating system supporting the launch and cruise phase of the Mariner Mars 1971 mission had a number of errors that resulted in system failures. These errors were not found until actual mission operation because of the abbreviated time period between the development of a given capability and its actual use for mission support; these errors had a definite effect on the failure rate.

As these errors were located and corrected, system and program development continued to add processing loads to the system. A continued high failure rate resulted primarily because of a weakness in system design, referred to as "main memory allocation contention." As processing

activity increased, main memory resources were used more extensively, and the operating system was unable to cope with the increasing load, which led to variable, sometimes excessive, running times for analysis programs and to system failures.

The original plan for software development was a four-stage process, wherein each stage, referred to as a model, would incorporate additional capabilities. Because of the schedule slips that occurred, a fifth model was added to complete the essential processing requirements. Various versions of each model were then created as corrections became available.

The project requirement for telemetry master data record, and experimenter data record, processing in the IBM 360/75 was removed as a result of the development problems discussed above. This requirement was successfully met by the MTC system. All telemetry master and experiment data record production was accomplished by the MTC, but the delivery schedule of these records was late because of the load of real-time activities placed on the system.

Implementation of the science telemetry processor in the IBM 360/75 was not successfully completed in accordance with the project requirements. A processor for low-rate science data, O 420 at 50 bits/s, was brought into operational status, but insufficient special processing was available to provide a useful output for analyses by the Science Data Team. Processors of the high-rate science, visual and spectral data, were developed but not fully tested and accepted. The completion of this capability was deemphasized because the MTC delivered a similar capability and the development resources were more urgently needed to support other required IBM 360/75 capabilities (see Subsection II-B-6-a).

Table 35 lists the model and version changes made in the IBM 360/75 system during the mission.

2. DSS System problems. The TCP program performed satisfactorily during the mission. There was a deficiency in the TCP command modulator assembly (CMA) interface, which resulted in occasional command aborts caused by bit-verify failure. The fault was isolated to a timing problem between the TCP and the CMA, and a TCP correction was generated. There was not time for testing the correction before launch. No aborts were encountered because of the minimal commanding required during these phases. Subsequently, the correction was implemented.

Table 35. Model and version changes in the IBM 360/75

First used for flight support	Model	Version
May 3, 1971	M-2	V 26.7
June 8, 1971	M-2	V 27.2
August 9, 1971	M-3	V 20.3
September 3, 1971	M-4	V 6.1
September 29, 1971	M-4	V 10.8
October 20, 1971	M-4	V 11.3
December 1, 1971	M-4	V 12.5
December 16, 1971	M-4	V 12.7
January 18, 1972	M-5	V 21.3
January 27, 1972	M-5	V 24.0
February 7, 1972	M-5	V 24.2
February 14, 1972	M-5	V 27.2
March 9, 1972	M-5	V 27.3
March 24, 1972	M-5	V 27.4

It should be noted that the TCP hardware resources were completely absorbed by the TCP program, and in fact, considerable effort was required to improve the efficiency of the coding so that the required functions could be performed. The major limitation is memory space, but the required rate of flow from input to output (throughput) is nearly to the limit of capacity.

3. System performance. Despite the problems and shortcomings encountered in the development and operation of the Data Processing System, the overall work performed by the system was obviously sufficient to accomplish the mission successfully. Some statistics are presented here to summarize the support from the various facilities of the data processing system.

- (1) IBM 360/75: Actual up-time versus scheduled up-time was about 97%; the mean time between failures, 7¼ to 8 h; and the mean time to recovery, 11 to 14 min. There were 626 outages over a period of 5000 h.
- (2) MTC: Actual up-time versus scheduled up-time was 99%.
- (3) DSS: Actual up-time versus scheduled up-time was 97% average.
- (4) 360-DSS System: Average percent of down-time is shown below on a system basis for each DSS. The system consists of an IBM 360/75, and a DSS.

DSS	12	14	41	42	62
Down-time	3.9%	3.9%	3.2%	2.4%	4.0%

4. Tracking System. A total of 90 occultations were supported. Of these, 85 occultations consisted of an entrance and an exit occultation pair, and 5 occultations were grazing occultations, without a distinct break in radio transmission. In all, some data were lost in 5 separate occultations. In all cases, the failure to acquire all the data was basically due to procedural error.

5. Telemetry System. Approximately 96% of all data telemetered from Mariner 9 was processed through the telemetry system in real time and logged on the system data record (SDR). Additional data detected and logged at the DSS were lost at various points in the system. This quantity is estimated to average 1% of the total telemetered by the spacecraft. On a daily basis, these losses were as high as 8% on several occasions.

These data were played back postpass as recalls from the DSS, and then processed and merged into the SDR. There were a total of 994 such recalls due to a variety of telemetry system failures. Over half of these recalls covered data gaps of less than 7 min. The largest failure category, 45%, was high-speed data line (HSDL) errors. The table below summarizes the number of recalls versus the reason for recall.

No. of recalls	Reason for recall
454	HSDL problems
204	Miscellaneous problems
157	Wideband data line problems
151	MTC problems
28	TCP—symbol synchronizer assembly (SSA)

Data gaps impacted the master data record/experiment data record (MDR/EDR) production process because many gaps were not detected previously. Acceptance of MDR and EDR packages was then delayed to recover and merge the missing data into the data records. Of a total of 225 MDR/EDR packages processed, 44 had to have additional data recalled after the MDR had been run.

6. Command System. From launch until April 2, 1972, a total of 37,554 commands were processed and radiated successfully to the spacecraft. In the same interval, 22 attempts were aborted, six of which were caused by procedural errors. The remaining aborts were caused by software and hardware problems. See Table 15 for a summary of command aborts.

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Appendix

Project and System Milestones From Mariner 9 Trajectory Correction Maneuver to Start of Solar Occultation

Date completed	Milestone	Date completed	Milestone
7/1/71	Laboratory test equipment released	9/14/71	MOS training test; MOI maneuver test completed (24 h)
7/1	SET 2 support equipment released (except radio)	9/22-24	MOS operational demonstration test; MOI maneuver and central computer and sequences (CC&S) update completed (65 h)
7/23	Tracking and data system (TDS) hardware, software development, and performance demonstration completed (Model 3)	9/27	TDS hardware and software development and performance demonstrations completed (Model 4)
7/25	Approximate lineup of Earth-spacecraft-Mars	10/1	Scan and television geometric calibrations completed
8/2	Mission operations system (MOS) and TDS integration, system test, and performance demonstration completed (Model 3)	10/4	MOS training test; Orbit trim maneuver (OTM) completed (24 h)
8/5	Approximate lineup of Mars-spacecraft-Sun	10/5	MOS training test; OTM completed (24 h)
8/5-6	Orbital operations review held	10/8	Scan and television geometric calibrations completed
8/10	Approximate lineup of Sun-Earth-Mars (opposition inferior conjunction)	10/11-14	MOS operational demonstration test; MOI and OTM completed
8/16	MOS intrateam training (orbit) started	10/15	Mission profile studies through orbit insertion completed
8/16	MOS intrateam internal tests started	10/15-16	MOS operational demonstration test; orbit operations completed
8/17	Postlaunch analysis of compliance with Committee on Space Research (COSPAR) recommendations (PD 610-18, Part IV) issued	10/20-21	Operational readiness test completed
8/26	MOS-science data flow tests completed (10 h)	10/25	Midcourse maneuver policy (PD 610-34, Part III) issued as an interoffice memorandum
8/26	MOS and TDS training (orbit) started	10/27-28	Operational readiness test completed
9/2	MOS and TDS flow tests completed (10 h)	10/28	MOS and TDS integration, system test, and performance demonstration completed (Model 4)
9/8	MOS training test; Mars orbit insertion (MOI) maneuver test completed (24 h)	10/29	NASA preorbit press briefing held in Washington
9/8	MOS intrateam training completed (orbit)	11/2	TV photometric calibration completed (Saturn)
9/9	MOS and TDS flow tests completed (16 h)	11/3	MOS operations training and readiness tests completed (orbit)
9/13	MOS intrateam internal tests completed		

Appendix (contd)

Date completed	Milestone	Date completed	Milestone
11/3/71	MOS and TDS training and readiness tests completed (orbit)	1/26/72	Mission status review completed
11/3	Science recommendation team (SRT) training test completed	1/31	Map 3 cycle plan completed
11/7	Deep Space Network (DSN) configuration verification tests completed (orbit)	2/1	Science results presented to Dr. Fletcher and Dr. Naugle at NASA headquarters
11/8	Space flight operations plan (SFOP) (610-29, Volume II B, Mission A) issued	2/2	Science results press briefing held in Washington
11/8	Mars television calibration 1	2/7	Project format report, Volume II, and preliminary science report issued
11/9	Mars television calibration 2	2/10	Map 2 cycle completed (revolution 177)
11/10	JPL preencounter press briefing held	2/10	Map 3 cycle started (revolution 178)
11/10-13	Preorbit science sequence completed	2/12	Standard mission orbit operations completed (90 days in orbit)
11/13	MOI completed (16:39 PST)	2/12	Extended mission started
11/14	JPL postencounter press briefing held	2/16	Map postcycle 3, Part I, plan completed
11/15	JPL preliminary science results (Infrared Interferometer Spectrometer, Infrared Radiometer, and Ultraviolet Spectrometer) press briefing held	2/29	Proof test model (PTM) spacecraft released
11/19	JPL preliminary science results (all experiments) press briefing held	2/29	SET 1 support equipment released
12/3	JPL TV experiment results press briefing	2/29	Map 3 cycle completed (revolution 216)
12/15	Subsystem technical reports submitted for publication	3/1	Map postcycle 3, Part I, started (revolution 217)
12/17	Extended mission Support Instrumentation Requirements document (PD 610-41, Revision 2A) issued	3/6	Map postcycle 3, Part II (high-gain antenna maneuvers), plan completed
12/20-21	Project mission planning conference held	3/14	Map postcycle 3, Part I, completed (revolution 243)
12/30	Second OTM completed	3/14	Map postcycle 3, Part II (high-gain antenna maneuvers), started (revolution 244)
1/2/72	Map I cycle started (revolution 100)	3/21-24	American Astronomical Society meeting of Planetary Science Division held in Hawaii
1/6	Standard mission plan (90 days) presented to NASA headquarters	3/23	Map postcycle 3, Part II (high-gain antenna maneuvers), completed (revolution 262)
1/13	Map II cycle plan completed	3/24	Map postcycle 3, Part III (spacecraft team test for solar occultation), started (revolution 263)
1/19	Mars mapping coordination meeting held	3/24	Map postcycle 3, Part III (spacecraft team test for solar occultation), started (revolution 263)
1/21	Map 1 cycle completed (revolution 138)	3/28	Solar occultation operations plan issued
1/22	Map 2 cycle started (revolution 139)		