Simulation of Mariner Mars 1971 Spacecraft

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In preparation for the Mariner Mars 1971 mission, operations personnel took part in an extensive training program during which the primary source of spacecraft data was a computer program simulating the spacecraft. The objectives of a simulation model for training purposes differ from objectives appropriate to a design or analysis model. Model subsystems were designed to provide realistic telemetry data reflecting changes due both to commands and environmental parameters affecting the spacecraft at various times during the mission.

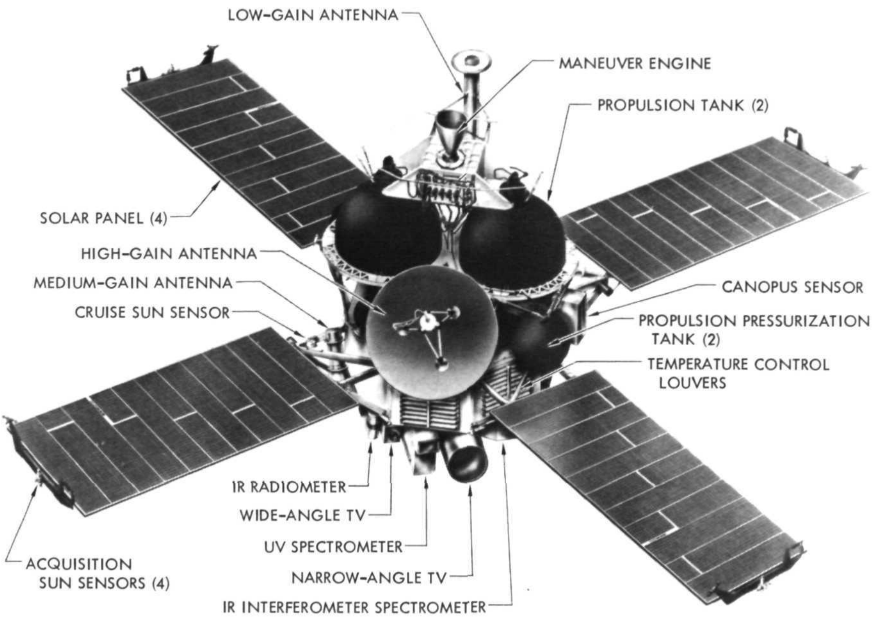
The spacecraft is modeled along two separate functional lines. Boolean operations are concentrated in the spacecraft logic model, which determines the spacecraft state or mode, while mathematical operations or algorithms are executed in computational subsystem models. Although logic parameters are interrogated as a part of each computational pass, actual logic model processing occurs only when a change-of-state input is generated by the operations organization. This article discusses the program design, some of the special characteristics of each of the modeled subsystems, and how the model was used in support of mission operations training.

Introduction

In the spring of 1971 the launch of two Mariner spacecraft (Figure 1) planned to orbit the planet Mars culminated nearly three years of preparation for Mariner Mars 1971 space flight operations at the Jet Propulsion Laboratory.

Just as the spacecraft and the launch vehicle must undergo a series of tests to verify readiness for launch, so must the Mission Operations Complex (MOC) be tested. Consisting of a Ground Data System, a Mission Operations Organization, and an Operations Plan, the MOC is required in the conduct of flight operations. Testing of the MOC is one of the last of the prelaunch preparatory activities directed by the Project. Basically, two classes of tests are involved:

(1) Ground Data System testing.



PROPULSION MODULE AND SCAN PLATFORM INSULATION BLANKETS NOT SHOWN

Figure 1. Mariner Mars 1971 spacecraft

(2) Organizational training.

Ground Data System testing verifies that the combination of hardware and software required to present spacecraft telemetry in a useful form and to generate commands which will control the spacecraft is, in fact, able to accomplish these functions. This class of test requires a data source capable of generating a known and relatively static input which can be compared against the output of the Ground Data System.

Organizational training presumes a checked out Ground Data System and verifies the ability of the organization to:

(1) Use the Ground Data System effectively.

(2) Understand the mission operations plan.

(3) Analyze spacecraft data properly and determine appropriate actions in nonstandard performance situations.

(4) Function efficiently as a team.

Organizational training requires a data source which accurately reflects a realistic mission environment and correctly responds to commands which change the operation of the data source.

The Mariner Mars 1971 Simulation System was designed to satisfy all of the foregoing requirements. The spacecraft model, as a part of the Mariner Mars 1971 Simulation System, was developed expressly as a data source for organizational training. It is this phase of the Mariner Mars 1971 simulation effort which will receive the greatest emphasis in this article.

The Mariner Mars 1971 Simulation System will be discussed in general so that the role of the spacecraft model is understood in its proper context. The spacecraft model, specifically the logic model and the computational model and their integration, will be discussed in detail.

Simulation System

The Mariner Mars 1971 Simulation System uses current computer and electronic technology to generate a realistic mission environment. The Simulation System consists of two major elements: the multi-mission element provided by the Tracking and Data Acquisition System (TDS) and the mission-dependent element provided by the Mission Operations System (MOS). The TDS provides tracking (metric), station (command response and monitor), and telemetry (calibration) data types, while the MOS provides the command responsive spacecraft model which generates realistic spacecraft telemetry data. In combination, all data types used either for operations control or analytic purposes during a mission are generated by the Simulation System.

The various elements of the Simulation System are shown in Figure 2.

The Simulation System can operate in either a short-loop mode during which data is delivered directly to the Space Flight Operations Facility (SFOF) as though it had been processed by a Deep Space Station, or it can operate in a long-loop mode during which data is delivered to the Deep Space Station, such as Goldstone Tracking Station in the Mojave Desert, as though it had been generated by the spacecraft.

The Simulation System consists of one or more software programs for each data type to be generated. These programs operate in a combination of computers located in the Space Flight Operations Facility (Building 230) at Pasadena and at tracking stations around the world.

The SCF Univac 1108 computer is used in non-real time to prepare trajectory tapes and in real time to operate the spacecraft mathematical models. The SFOF IBM 360/75 computer is used to convert trajectory information into tracking station predicts. The Simulation Center Electro-Mechanical Research (EMR) 6050 computer is used for overall simulation system control, conversion of predicts into simulated tracking data, and the generation of tracking station command and status data. The DSIF Xerox Data System (XDS) 910 computer at the tracking station is used to convert

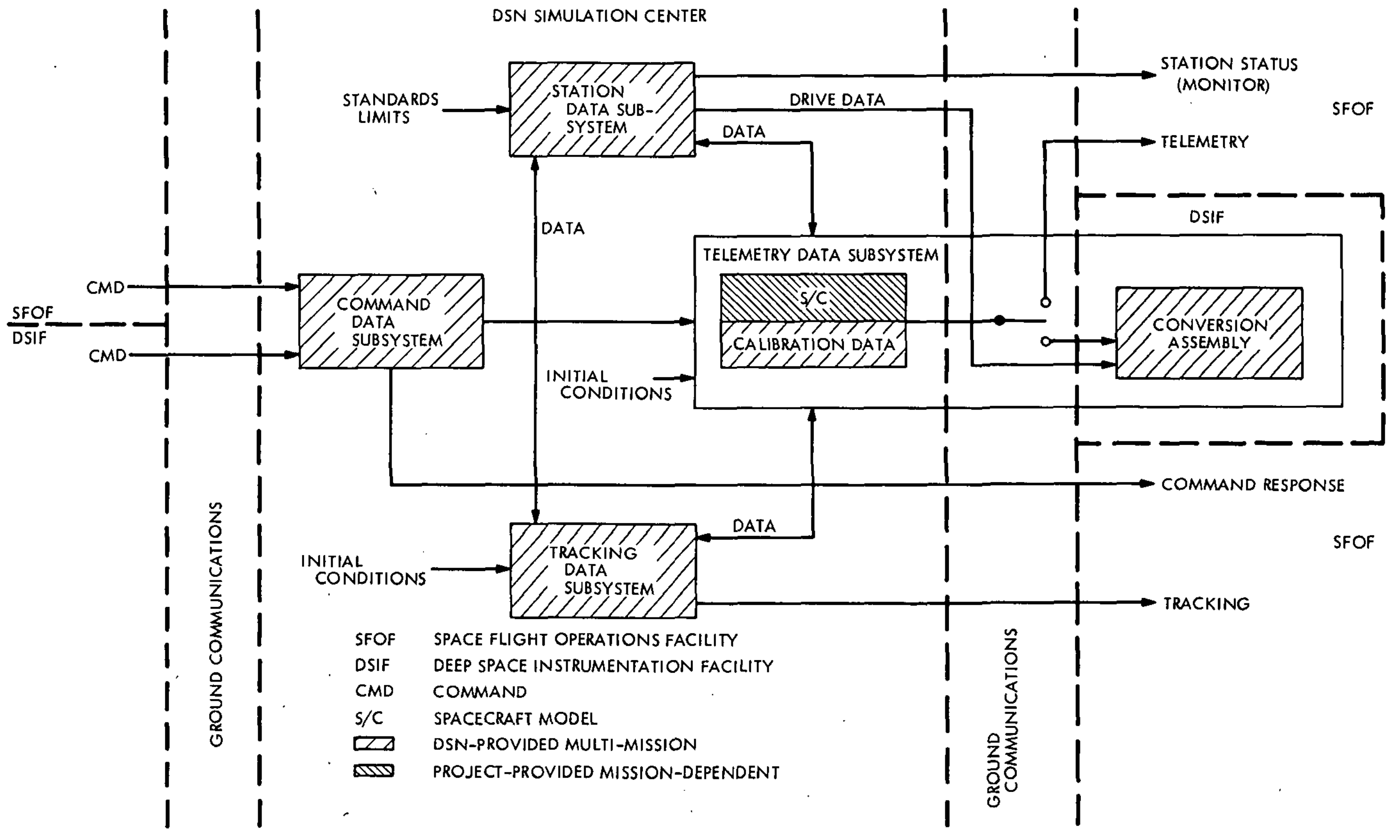


Figure 2. Simulation System

simulated telemetry data into a form appropriate for modulation on an RF carrier.

Elements of the Simulation System necessary to generate telemetry data are shown in Figure 3. Specifically, the telemetry subsystem is depicted as required to support long-loop training exercises.

Although it is important to understand the operations of the entire Simulation System, this article will concentrate on the spacecraft telemetry simulation.

The Spacecraft Model

The Mariner Mars 1971 spacecraft is modeled along two separate functional lines. All Boolean operations are performed in the spacecraft logic model which determines the spacecraft state or mode, while mathematical operations or algorithms are executed in a computational model. Although logic parameters are interrogated as an integral part of each computational pass, actual logic model processing occurs only when a change-of-state input is generated. There are several sources of change-of-state inputs, one of which is commands received and processed by the model in real time so that the telemetry stream reflects the changes in the spacecraft initiated by the operations organization. The logic and computational models will be discussed in subsequent paragraphs.

The Logic Model

Since the spacecraft state is essentially logically determined by relays and electronic switches, separating the logical program operations from the mathematical program operations within the model was a natural result of the spacecraft design.

The logical operation of each of the various spacecraft subsystems is described by a logic diagram. For example, the scan platform logic is portrayed in Figure 4. The diagram was developed from the spacecraft design specification for the scan platform subsystem which is a two-degree of freedom motorized platform for mounting and pointing the science instruments.

The motor, which can be turned on or off by command, is inhibited during launch. This is represented logically on the upper portion of Figure 4. The lower portion of the figure shows that the platform can be operated in three different modes:

(1) Fixed (both cone and clock are in stow position).

(2) Fixed cone (clock position is variable).

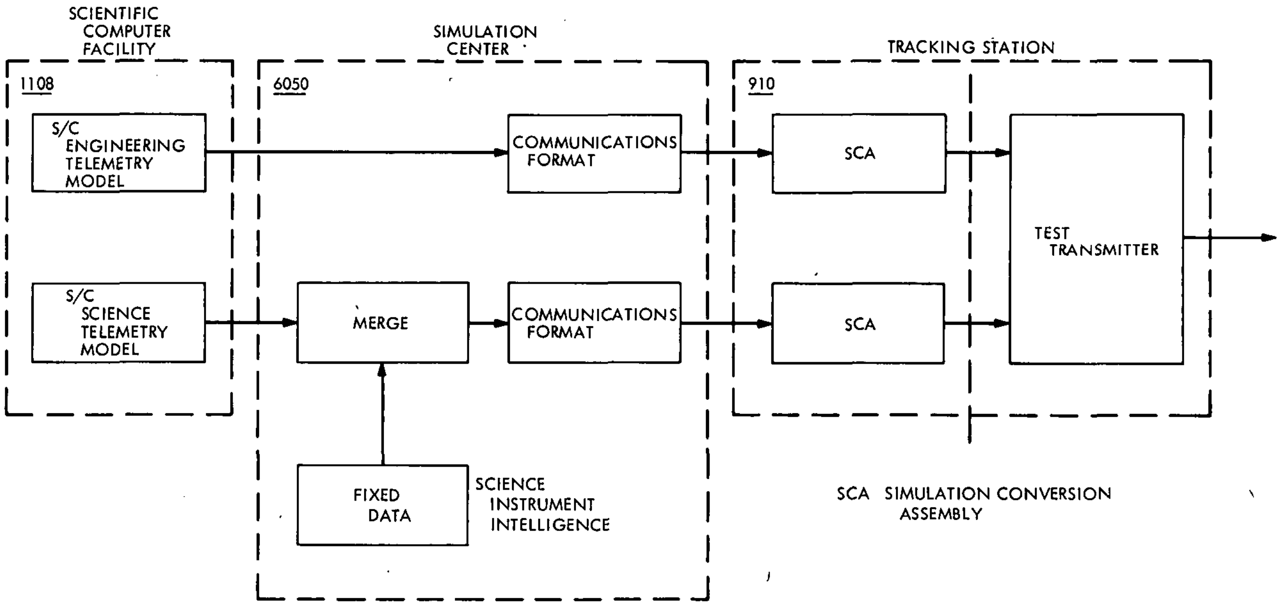


Figure 3. Simulation telemetry data subsystem (long-loop mode)

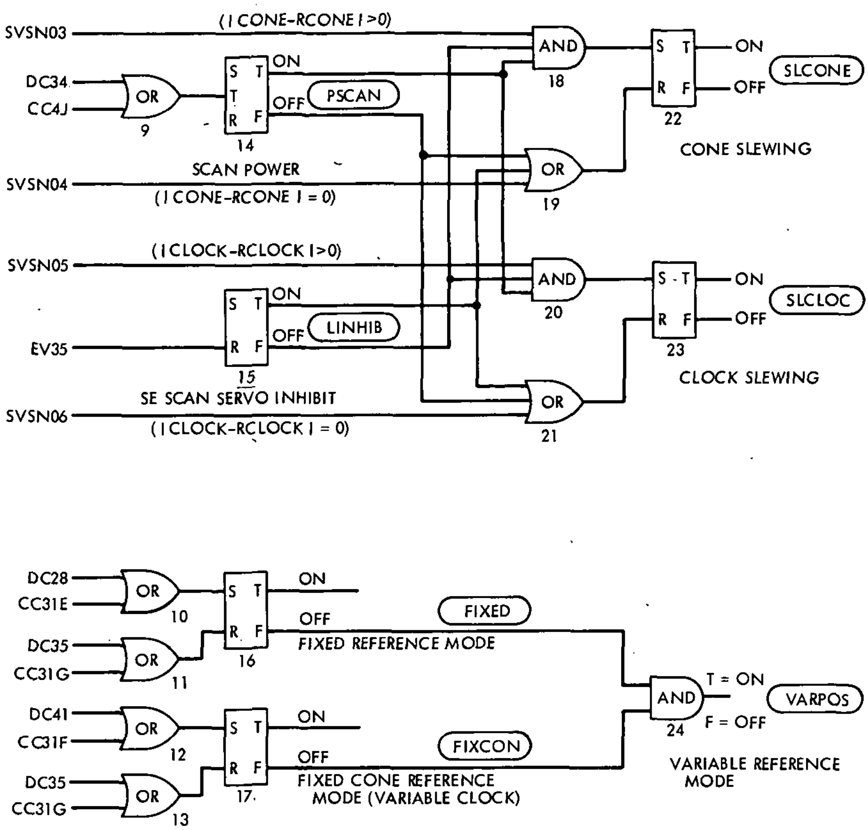


Figure 4. Scan logic

(3) Variable (both cone and clock positions are variable).

Shown at the far left of the diagram is the complete set of commands and events that can affect the state of the scan platform subsystem. The circled parameters are subsystem outputs which are either telemetered to the ground or used internally to describe the current state of the subsystem. Similar logic diagrams were developed and programmed for every subsystem on the spacecraft.

The programming technique used to implement the logic model is illustrated in Figure 5. Algorithms were developed for three logic elements: *and* gates, *or* gates, and flip flops. All change-of-state inputs (external stimuli) were collected and cards prepared which rename the input in program language. Three classes of stimuli are shown on the left-hand side of Figure 5. Cards were prepared which establish the relationship between the logic elements for each input. Finally, the logic model outputs were collected and cards prepared which convert program language logic states to a readable form. A logic state as used here describes the operating condition of an element of spacecraft hardware. As coded, the logic model accepts stimuli changes and prints out the new model state. The resulting program can be operated either by itself to verify the spacecraft status during ground checkout or in conjunction with the computational model of the spacecraft.

The Computational Model

The spacecraft generates two telemetry streams: (1) science data, and (2) engineering data. Science data includes instrument housekeeping or status information in addition to instrument measurement data. Measurement data is defined as the actual science intelligence generated by the instrument. Science data simulation by computer model for Mariner Mars 1971 was limited to instrument status information. (Attempts to merge measurement data previously recorded on magnetic tape with the modeled instrument status data were abandoned, since the difficulty of developing this capability was not considered cost effective.) Fixed computer-generated measurement data was ultimately used instead. This data did not in any way approximate Mars data but was of use in testing and evaluating operational sequences. Science simulation is mentioned here only for the sake of completeness and will not be discussed further.

Engineering data includes all spacecraft state and housekeeping or status information. Spacecraft engineering data simulation was developed on a subsystem basis paralleling the organization and development of the flight spacecraft. In some cases, however, several spacecraft subsystems were combined. For example, the pyro, mechanical devices, and propulsion subsystems were combined in the model and designated as the propulsion model. The subsystem design approach was selected because it allows comparatively easy updating of the simulation model from project to project. The Mariner Venus-Mercury central computer and sequencer

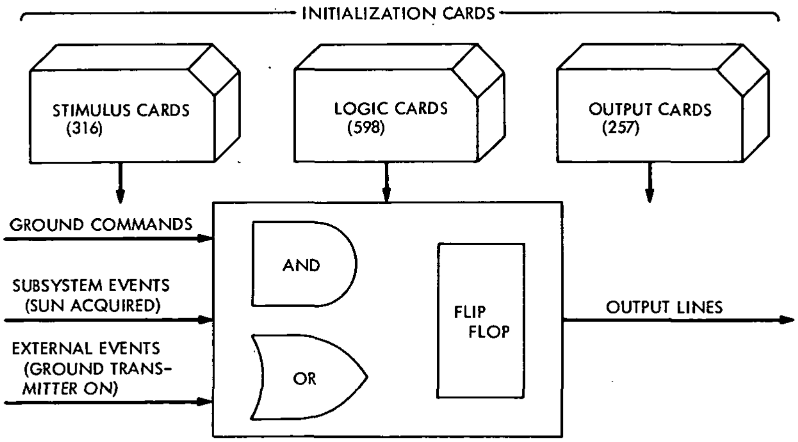


Figure 5. Logic program

(CC&S) is the same as the Mariner Mars 1971 CC&S. The Mariner Mars 1971 CC&S model will be usable in the Mariner Venus-Mercury 1973 model almost as is.

Information required to model each subsystem was provided by the engineers who were responsible for the design of the spacecraft. The simulation group translated the designer's knowledge into a software model that behaves in a manner similar to the actual spacecraft.

Subsystems modeled separately include the temperature (TMP), central computer and sequencer (CC&S), attitude control (AC), power (PWR), radio (RF), propulsion (PRP), data storage (DSS), scan platform (SCN), and flight telemetry (FLT). Each of these models will be described in subsequent paragraphs.

TMP. The temperature model computes all telemetered spacecraft engineering temperatures (28), including propulsion tank temperatures, electronic bay temperatures, solar panel temperatures, and science instrument temperatures. Twenty-seven other temperature calculations are computed for use by other subsystem models. Temperatures generally vary exponentially as a result of logic state or environmental changes. The environmental changes most affecting spacecraft temperatures are Sun and Mars radiation effects.

CC&S. The central computer is a general purpose, internally stored program digital computer with a 512-word memory. It is also a serial computer in that each memory access time (417 μs) obtains only one bit of the addressed memory location. A fixed sequencer is used to provide redundancy to the central computer during maneuvers.

The CC&S model provides a complete and exact map of the computer memory, issues 86 computer commands and 5 sequencer commands used by the other subsystem models, and generates data for 3 separate telemetry channels. In addition all CC&S maneuver states (tandem, parallel, computer, and sequencer) are modeled. Modeling of a serial computer on a parallel computer required the reversing of all computer words since the least significant bit of each CC&S word is located at the left end of each word. The computer clock is controllable so that it can be synchronized to simulation time. The CC&S model can be fast stepped either to speed up the check out of other mathematical model subsystems or to skip over programmed sequences not required during a particular test profile.

AC. The attitude control model provides dynamic simulation of the star (Canopus) sensor, Sun sensors, gyros, switching amplifiers, gas jets, autopilot, gimballed engine, spacecraft orientation, internal power consumption, and telemetry channel switching. A total of 17 telemetry measurements are simulated by the AC model in addition to event counter inputs.

The AC model computes the spacecraft orientation relative to the Sun–Canopus coordinate system using one of two separate star tables. The model automatically turns on the roll gyro if the reference star is lost and reacquires an appropriate reference star as does the actual spacecraft. The spacecraft Sun angle is calculated and used by the temperature and power models. Limit cycling about the celestial reference is also simulated.

Overall, attitude control was probably the most complex model to simulate since it was three dimensional and quite dynamic. Simplification, commensurate with the objective of accurately simulating telemetry data, was introduced where possible.

PWR. The spacecraft operates with energy from four solar panels backed up by a nickel–cadmium battery. The power model provides a total of 20 telemetered measurements. In addition to the solar panels and the battery, the PWR model simulates the battery charger, boost regulator, and inverter input/output. The model calculates the total spacecraft power load using information provided by other subsystem models and then determines the power source simulating either panel only, battery only, or shared modes of operations.

The Sun angle calculated by the AC model is used by the PWR model to determine the solar panel shadowing effect during maneuver.

RF. The radio frequency model computes 10 telemetry measurements, including high- and low-gain antenna drive and spacecraft receiver automatic gain control (AGC) and static phase error (SPE). In addition the model calculates the RF power radiated toward Earth, a function of antenna drive, spacecraft attitude, and ranging modulation. This calculation allows the accurate simulation of ground receiver AGC from launch through Mars orbit.

PRP. The propulsion model combines the functions of three spacecraft subsystems: propulsion, pyrotechnic, and mechanical devices subsystems. Propulsion subsystem pressures are computed as a function of temperature. During a motor burn, the spacecraft PRP model computes nitrogen pressure decay, engine mixture ratio, chamber pressure, and spacecraft acceleration. Propellant tank pressure decreases due to nitrogen gas/propellant saturation are also modeled. A total of nine telemetry measurements in addition to event counter inputs are calculated by the PRP model.

DSS. The tape recorder aboard the spacecraft records science data for subsequent playback when the spacecraft is being tracked by the Goldstone Tracking Station. The DSS model computes tape recorder start up and shut down characteristics, tape position, tape mode, and buffer loading. Power loads for each of the various modes are computed and sent to the PWR model. In addition to event counter inputs, three telemetry measurements are computed by the DSS model.

SCN. The scan model simulates the platform upon which the science instruments are mounted. The reference positions of the scan platform are updated by ground command. When the scan platform is enabled, the model will move to the newly commanded position. Four telemetry measurements are calculated by the SCN model.

FLT. The flight telemetry model simulates analog-to-digital conversion of spacecraft data, telemetry commutation, digital data conditioning, and command decoding. This model also converts the engineering units computed by each of the subsystem models into data numbers which are the integer equivalents of the binary bit stream telemetered to the ground stations.

System Integration

The logic model was programmed and checked out first. The separate subsystem models discussed above were programmed as separate entities and then checked out in conjunction with the logic model. As each subsystem model was delivered, it was integrated with the logic model and its subsystem predecessors to ensure the compatibility of data transferred between the subsystem models. The last model to be integrated was the AC model. Once the model integration was complete, system integration was accomplished. This building block technique of development and integration proved very effective, thus, minimizing integration problems.

The model can be operated in either a stand-alone mode (this is the way in which the program was originally checked out) or in a real-time operation mode as illustrated in Figure 6. Dual spacecraft simulation is achieved by time-sharing the model with all calculations based upon a spacecraft-peculiar set of constants. Thus, it is possible, for example, to simulate one spacecraft in a cruise state and another in a launch state.

The model resides in the Univac 1108. Stand-alone input is via demand terminal or cards. Real-time input is via an interface with the EMR 6050 computer which formats input instructions. The model uses approximately sixty thousand 36-bit words of the 1108 core and approximately 5% of the 1108 computing time for each simulated spacecraft. Other programs may operate at the same time in a time-sharing mode.

Concluding Remarks

Thus far the Mariner Mars 1971 spacecraft model has been used a total of 330 h in support of organizational training. The data generated by the spacecraft model compares favorably with the actual data streams generated by the flight spacecraft. Although problems with the Simulation System, primarily the EMR 6050, have detracted from the effectiveness of the training, it is apparent that the elements of the mission operations

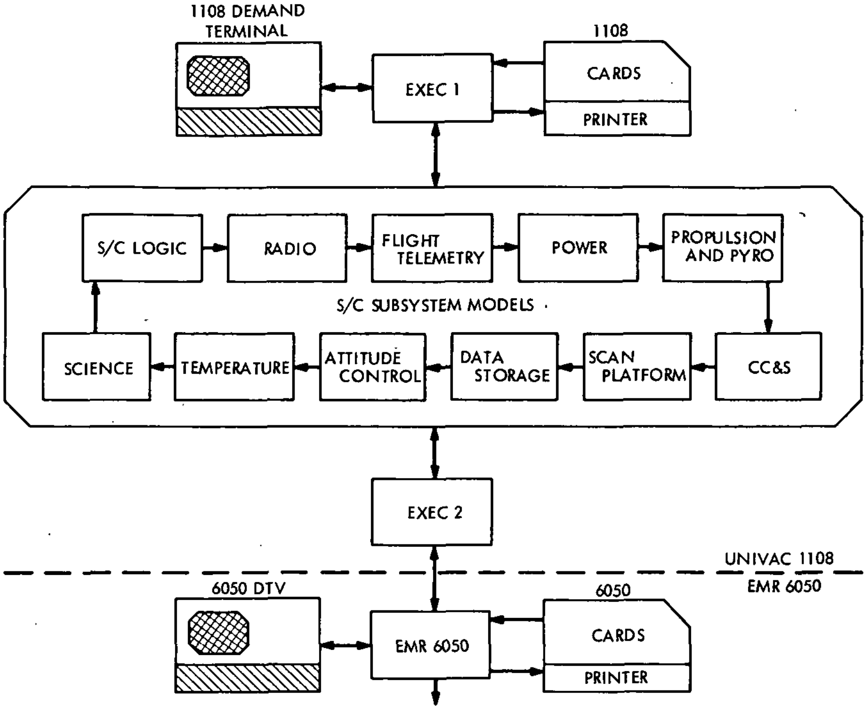


Figure 6. Spacecraft model processing

organization benefited significantly from the test program. The heart of this program was the ability to generate a realistic mission environment and to respond correctly to changes in that environment caused by the trainees. Such a response is only possible with a precision, operationally simple, software model. The Mariner Mars 1971 spacecraft model with its modular design is being used to support orbital training and in the future will be revised as necessary to meet the requirements of the Mariner Venus-Mercury Project.