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S³-A SPACECRAFT AND EXPERIMENT DESCRIPTION

G. W. LONGANECKER
R. A. HOFFMAN

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By

G. W. Longanecker

and

R. A. Hoffman

NASA-Goddard Space Flight Center
Greenbelt, Maryland 20771

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INTRODUCTION

The Small Scientific Satellite, S^3-A (Explorer 45) was launched on November 15, 1971, from the San Marco Equatorial Range, Kenya, Africa, into an elliptical, equatorial orbit by a four stage Scout rocket. The satellite is instrumented with a variety of charged particles and fields experiments to carry out definitive investigations of specific magnetospheric phenomena in the heart of the magnetosphere.

The S^3 program was established to provide experimenters with the opportunity of flying a well integrated set of detectors aimed at specific investigations. To accomplish this objective, the S^3 spacecraft was developed to be a small, flexible, general-purpose spacecraft, capable of being launched by the economical Scout rocket. It is unique in several aspects, especially in its data handling system, which is programmable from the ground.

This Letter will describe the scientific objectives of the first mission, define the orbital parameters, and provide a brief description of the spacecraft, a summary of the detector characteristics, and the capabilities of the data system. The Letters which follow basically contain the early results from the mission which were presented at the 1972 Spring meeting of the American Geophysical Union.

MISSION OBJECTIVES

The scientific objectives of the S^3-A mission are outlined in Table 1. The primary objective is the study of the ring current which causes the main phase of magnetic storms, with special emphasis on its development and source of energy. Closely associated with this objective is the determination of the relationship between magnetic storms, substorms, and the acceleration of charged particles in the magnetosphere.

A wide range of energies for both protons and electrons, as well as several energy channels for alpha particles, are being measured, all as a function of pitch angle. This will provide especially pertinent data for the analysis of both cross-L and pitch angle diffusion. These particle measurements, combined with both AC electric and magnetic field measurements, will allow particular studies of wave-particle interactions responsible for particle transport and loss in the inner magnetosphere.

ORBITAL PARAMETERS

The orbital parameters for the satellite were selected to fulfill the scientific requirements (Figure 1). The apogee had to be sufficiently high to measure the major portion of the storm-time ring current, yet the period sufficiently short to allow several traverses through the current region during a storm. Only at the magnetic equator can all trapped particles be measured, so a very low inclination was chosen. This dictated a San Marco launch if the Scout were to be used. With this particular orbit, the line of apsides moves around toward the sun at a rate of 12^{o} per month from its original position of about 21.8 hours local time. It was desirable to initially place apogee as close to midnight as shadow conditions, and therefore thermal conditions, would allow, in order to include sampling in the asymmetric region of the ring current and on substorm magnetic field lines.

The satellite is spin stabilized, with a 16 second spin period originally specified in order to acquire good counting statistics in pitch angle measurements from the particle detectors. However, thermal torques on the booms of the spacecraft produced a precession of the spin axis immediately after launch, so that a spin period of about 8.4 seconds was established to attain dynamic stability. An active spin control system has been used to modify the period during the course of the mission.

SPACECRAFT

A drawing of the spacecraft appears in Figure 2. It consists of a main body and five booms. The mid band of the spacecraft contains the electronics systems and particle detectors. All of the detectors except two are located perpendicular to the spin axis (the axis of symmetry), and therefore scan various pitch angles as the satellite spins. Since the spin axis was placed near the ecliptic plane, and therefore nearly perpendicular to the local magnetic field, particles in the pitch angle range from 90^{o} down to small pitch angles are measured.

A triaxial fluxgate magnetometer is contained in the rectangular box on the boom along the spin axis. Two search coil magnetometers, one parallel and one perpendicular to the spin axis, are held at the ends of the short booms. The two spheres mounted five meters apart on the long, insulated booms, serve as sensors for both DC and AC electric field measurements.

Table 2 contains a weight breakdown of the satellite. With a total orbital weight of 108.2 lbs., a large fraction, almost 30%, is in the form of experiments. The on-board data processing system, which will be described later, consists of five trays of electronics, yet weights only 10.0 lbs. and consumes 6 watts of power. The power system delivered 34 watts after launch, of which 14 watts is used for spacecraft systems and 8 watts for a special purpose wide-band transmitter. The satellite contains two transmitters, one for the digital (PCM) data at 446 bits/second and the other for either digital data or wide-band analog data from the AC electric field and search coil sensors. The command system handles 80 commands for controlling the spacecraft and experiment functions as well as for flight program loads for the data processing system. The attitude determination system consists of a digital solar aspect sensor and one earth telescope for continuous aspect determination, and a scanning star sensor for aspect determination to better than 0.1^{o} during selected portions of the orbit.

Spin rate and attitude control is achieved through torques generated by the magnetic moment interaction of current-carrying coils with the earth's magnetic field. Control of the currents is provided by a separate magnetometer. Since launch a procedure has been developed to suppress the spin-axis precession angle through real-time ground control of the torquing currents.

An especially light weight structure was achieved through the use of a pop-rivet sheet metal construction technique. The structural weight is only 19% of the total satellite weight.

A considerably more detailed description of the satellite systems can be found in Williams et al, 1968.

DETECTOR CHARACTERISTICS

Table 3 contains the characteristics of the particle detectors. The channel multiplier detector system contains six detectors, two each to measure the energy spectra and pitch angle distributions of protons and electrons with two different geometric factors, and two fixed energy detectors mounted parallel to the spin axis. Each detector consists of a cylindrical electrostatic analyzer for particle species and energy selection and a channel electron multiplier as the sensor.

The solid state proton detector consists of two surface barrier solid state detector telescopes, each with two elements. The low energy range telescope is mounted behind a broom magnet to sweep out electrons with energies less than 300 kev. The heavy ion telescope measures fluxes of ions with $Z \geq 2$, and the back element makes proton measurements for energies greater than about 364 kev.

The solid state electron detector is a magnetic spectrometer with four surface barrier detectors. The energy windows established electronically are matched to the energy intervals from the magnetic dispersion of the beam by the magnet.

The properties of the fields detectors are described in Table 4. The three axis fluxgate magnetometer has two ranges controlled by ground command. The low resolution range saturates at about 2.5 R_E, and the high resolution range is commanded on each orbit at about 4.0 R_E. Besides the seven bandpass filters for each search coil magnetometer, the spin aligned magnetometer provides a 30 to 300 Hz wide-band signal and the perpendicular one a 30 to 3000 Hz wide-band signal.

The spheres at the ends of the long booms serve as sensors for both the DC and AC electric fields measurements. While the sensitivity of the DC fields measurement is about 0.2 mv/meter, the accuracy of the measurements depend upon the physical parameters of the plasma surrounding the satellite (Maynard, 1972). Included in the DC electric fields electronics are four bandpass filters for very low frequency waves. The AC electric fields electronics contains 15 bandpass filters plus a sixteenth broadband filter. A 100 Hz to 10 kHz broadband filter also provides an analog signal to the wide-band transmitter.

Both search coil magnetometers and the AC electric fields detectors have rapid wave form outputs in digital form which allow special high frequency sampling programs to be run.

While the electric field measurements are made only along one axis, two axis information is obtained because of the satellite spin.

DATA PROCESSING SYSTEM

The on-board data processing system is composed of four physically separate units (Figure 3):

a) A central processing unit provides the executive functions for the system, such as executing the stored program instructions, formatting data, addressing the memories, priority sensing and outputting the data to telemetry.

b) The program memory stores instructions that, when executed by the central processing unit, result in data acquisition, temporary data storage, data formatting, control, and other operations. This memory contains core locations for 256 instructions of 14 bits each. Within the memory, three independent programs can reside, one for acquiring data from sensor outputs and the buffer memory for telemetry formatting, one for acquiring data either asynchronous or synchronous with the spacecraft clock, but at rates different than the telemetry rate, and the third for priority interrupt data based upon test conditions within detectors.

c) The buffer memory provides for temporary storage of certain data types to allow for data acquisition at times other than at requests to fill the telemetry format. Examples are the occasional rapid collection of data at rates far exceeding the telemetry rate, collection of data asynchronous to the telemetry clock, and data called for by high priority interrupt lines. In addition, the buffer memory provides index registers and program address registers. The total capacity of the memory is 16,000 bits.

d) The input/output module is the interface between all detector and spacecraft systems and the data processing system. All data (analog, digital and random pulse data) enter the data processing system at this point by means of 64 addressable data channels and 128 non-addressable subcommutated channels.

The addressable channels are interrogated at a rate and order determined by the stored program instructions. In this module the analog signals are digitized to 10 bits, with the 4, 8, or 10 most significant bits being telemetered for some data or the 4, 8, or 10 least significant bits for other data. Control is through program instructions. The random pulse data are accumulated and compressed in this module also. In addition the module contains circuitry allowing direct communication between the data processing system and detectors to command mode changes in the detectors at known points in the program.

A fifth unit, auxiliary to the data processing system, contains the data synchronized clock, which provides timing signals for acquisition of data synchronized to the roll of the satellite. The roll is defined either by sun sightings or a signal from the fluxgate magnetometer when the particle detectors are normal to the local magnetic field.

The reprogramming capabilities of the satellite have been utilized more extensively by the experimenters and spacecraft operations engineers than originally planned. To date over 90 reprogrammings have occurred, comprised of about 14 different programs, some general purpose for sampling all detectors on a fairly even basis, some special purpose with emphasis on a few detectors. For example, a special purpose program was written after the discovery of the anomalous pitch angle distributions discussed in Williams et al (1972) to obtain even higher resolution pitch angle distribution measurements during the development of the main phase of magnetic storms.

GROUND DATA HANDLING

The S^3-A program is also notable for its ground data handling procedures. The identification and data extraction schemes devised to identify all the telemetered data as to sensor source, time of acquisition, and word length, and the random extraction of desired data from the bit stream required new and unique software systems.

In keeping with the concept that the entire satellite comprises a single experiment in space is the precept that the satellite data is not separated at any stage of processing. The final output to all experimenters is identical data tapes that include all the data from the satellite. Several of the papers in this series would not have been possible without this form of data availability.

SUMMARY

The S^3-A spacecraft has provided the experimenters with a true scientific work bench in space. The single mission concept for a particular spacecraft has allowed the group of researchers the utilization of this entire bench for the solution of specific physical problems. All parameters affecting the mission, such as orbital parameters, orientation and control capabilities, aspect determination, all sensor properties, sensor sampling schemes, are under the control of the experimenters.

The value and success of these innovations instituted in the S^3 program have already become visible in the scientific returns reported in the series of papers presented at the Spring 1972 AGU meeting, only five months after launch, and in the Letters which follow.

ACKNOWLEDGMENTS

It is not possible to acknowledge all the persons who have and continue to make S^3-A a successful mission through their professional and enthusiastic services. With no slight intended towards anyone else, we wish to express particular appreciation to F. A. Carr, Assistant Project Manager, K. O. Sizemore, Project Coordinator, R. G. Martin, Electronic Systems Manager, X. W. Moyer, Mechanical Systems Manager, and V. L. Krueger, T. A. LaVigna, J. E. Oberright, E. J. Pyle, C. F. Fuechsel, T. W. Flately, M. J. Cuviello, and V. L. Cleveland, all of whom played principal rolls in various major engineering tasks. No less critical were the contributions in operations and software by S. R. Smith, Project Operations Director, Dr. Paul H. Smith, Scientific Software Coordinator, W. Crawford and M. D. Sweetin of the Satellite Control Center, J. T. Jackson and C. H. Freeman of the Information Processing Division, R. D. Werking of the Attitude Determination Office, L. Erlichman and C. Mills of Wolf R&D Corporation, and R. Finnin and L. Wilson of Computer Sciences Corporation.

We express special gratitude to the Italian launch team under the direction of Professor Luigi Broglio for a successful rocket launch.

We also thank all the experimenters for their active participation in the Project and for assisting us in the discussions of their instruments.

Finally, we wish to acknowledge the major contributions to the Project by two former Project Scientists, Mr. Leo R. Davis, under whose guidance the project originated, and Dr. D. J. Williams, who held the position during the majority of the hardware phase of the project.

REFERENCES

Maynard, N. C., Electric fields in the magnetosphere and ionosphere, in Magnetosphere-Ionosphere Interactions, Ed. K. Folkestad, Univ. Press, Oslo, Norway, 1972.

Williams, D. J., R. A. Hoffman and G. W. Longanecker, The small scientific satellite (S^3) program and its first payload, Goddard Space Flight Center Preprint, X-612-68-418, 1968.

Williams, D. J., T. A. Fritz and A. Konradi, Observations of proton spectra ($1.0 \leq Ep \leq 300$ keV) and pitch angle distributions at the plasmapause, NOAA Technical Memorandum, ERL SEL-21, June 1972, (submitted to J. Geophys. Res.).

FIGURE CAPTIONS

Figure 1. Orbital parameters for S^3-A.

Figure 2. A drawing of the S^3-A satellite showing the configuration of the detectors mounted on booms and in the main body.

Figure 3. A block diagram of the S^3-A on-board data processing system showing the four principal modules and the types of interface signals.

SCIENTIFIC OBJECTIVES

- RING CURRENT AND DEVELOPMENT OF THE MAIN PHASE
- RELATIONSHIP BETWEEN MAGNETIC STORMS, MAGNETIC SUBSTORMS, AND THE ACCELERATION OF CHARGED PARTICLES
- DIFFUSION MECHANISMS
- WAVE-PARTICLE INTERACTION MECHANISMS

TABLE 1

WEIGHT CONFIGURATION

	WEIGHT (LBS.)				
EXPERIMENTS					
PARTICLE DETECTORS (3)	11.6				
MAGNETIC FIELDS (2)	11.8				
ELECTRIC FIELDS (2)	7.3				
		30.7			
SPACECRAFT SYSTEMS					
DATA HANDLING	10.0				
POWER	24.7				
TELEMETRY AND COMMAND	7.5				
PROGRAMMERS	2.8				
ATTITUDE DETERMINATION	4.4				
ATTITUDE AND SPIN CONTROL	2.1				
WIRING HARNESS AND TURN-ON CARD	5.0				
STRUCTURE AND THERMAL CONTROL	21.0				
		77.5			
TOTAL WEIGHT, ORBITAL CONFIGURATION			108.2		
DESPIN WEIGHTS AND CABLES			.4		
TOTAL WEIGHT, LAUNCH CONFIGURATION				108.6	
LAUNCH VEHICLE ATTACH FITTING				4.8	
TOTAL WEIGHT ABOVE VEHICLE 4th STAGE					113.4

TABLE 2

PARTICLE DETECTORS

- CHANNEL MULTIPLIERS

PROTONS	800 eV TO 25 KeV IN 16 STEPS
ELECTRONS	800 eV TO 25 KeV IN 16 STEPS

- SOLID STATE PROTON DETECTOR

PROTONS	24 KeV TO 300 KeV IN 6 INTERVALS
	364 KeV TO 1.5 MeV IN 7 INTERVALS
	5 INTEGRAL MEASUREMENTS TO > 3.8 MeV
ALPHAS	0.6 MeV TO 4 MeV, 4 INTERVALS
IONS	(Li, Be, B), (C, N, O), $Z \geqslant 9$, 5 INTERVALS

- SOLID STATE ELECTRON DETECTOR

ELECTRONS	35 - 70 KeV
	70 -140 KeV
	140 - 250 KeV
	250 - 400 KeV

TABLE 3

FIELD DETECTORS

- FLUXGATE MAGNETOMETERS (3-AXIS)

RANGE	RESOLUTION
$\pm 3{,}000\,\gamma$	$6\,\gamma$
$\pm 300\,\gamma$	$0.6\,\gamma$

- SEARCH COIL MAGNETOMETERS (2-AXIS)
  7 BANDPASS FILTERS, 1 Hz TO 3,000 Hz
- DC ELECTRIC FIELDS
  SPHERE SEPARATION 5 METERS
  SENSITIVITY ~ 0.2 MV/METER
  BANDPASS FILTERS
  - 0.3 - 1.0 Hz
  - 1 - 3 Hz
  - 3 - 10 Hz
  - 10 - 30 Hz
- AC ELECTRIC FIELDS
  15 BANDPASS FILTERS
  35 Hz TO 100 kHz

TABLE 4

ORBITAL PARAMETERS

APOGEE:	5.24 R_E
PERIGEE:	222 km
INCLINATION:	3.6°
PERIOD:	7 HRS. 49 MIN.
SPIN PERIOD:	8.4 SEC.
INITIAL APOGEE DIRECTION:	21.8 HOURS LOCAL TIME

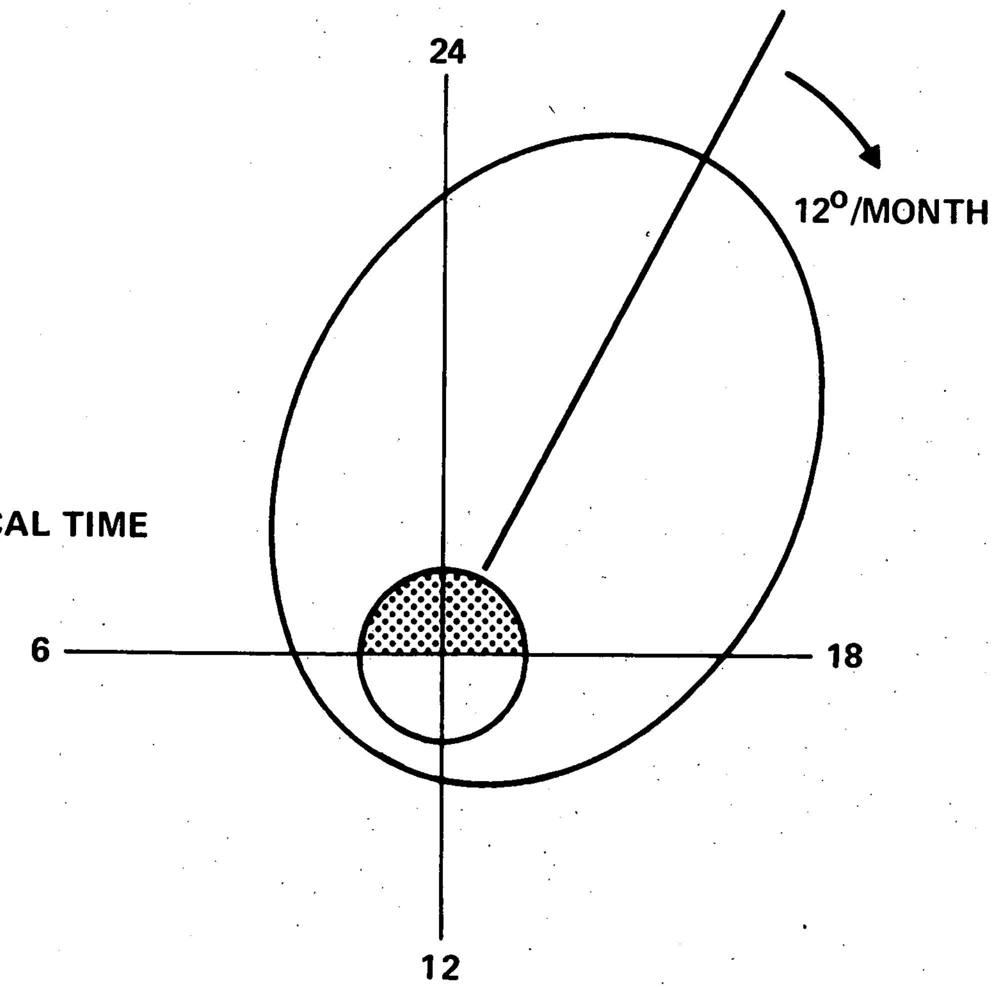

FIGURE 1

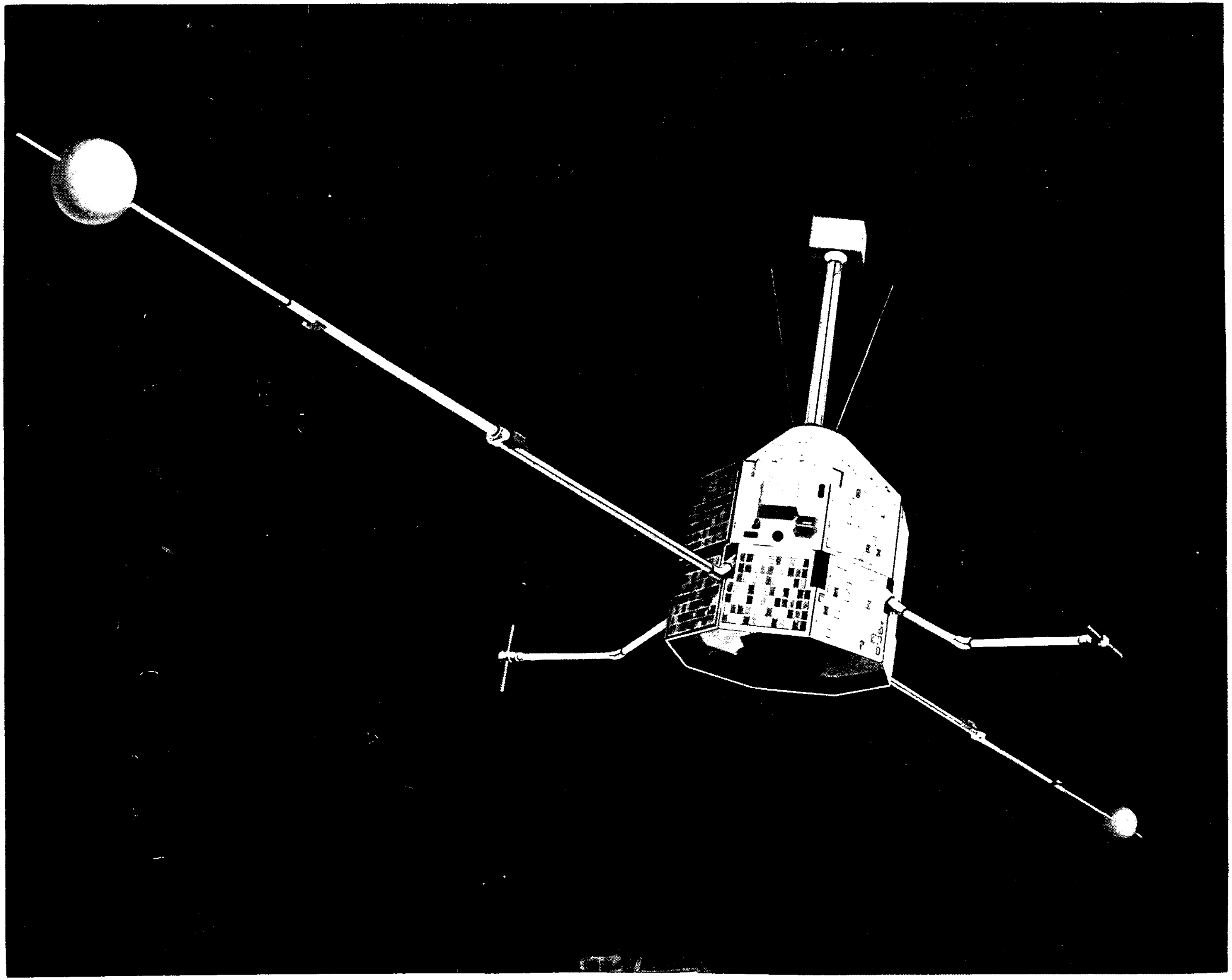

FIGURE 2

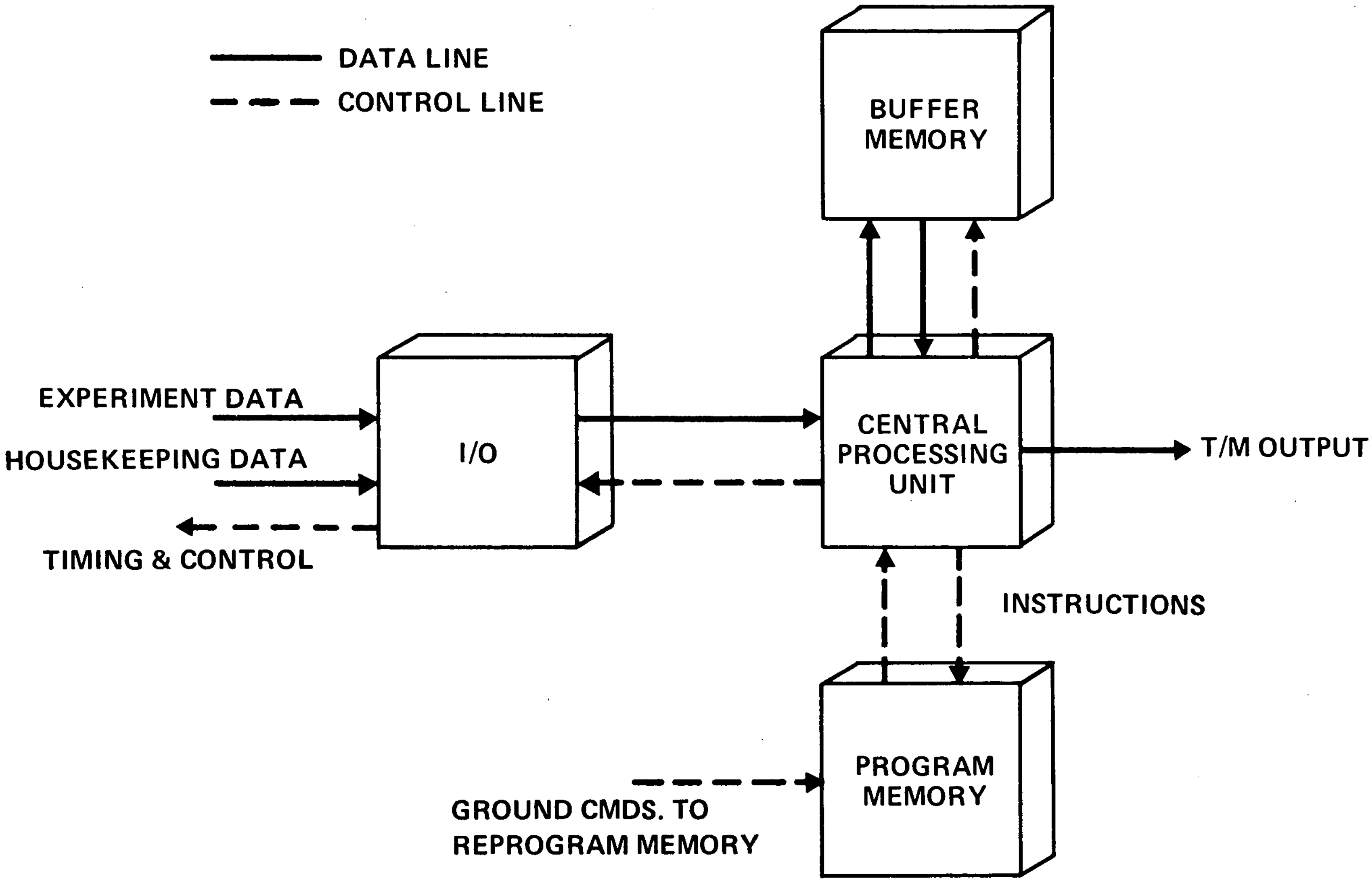
DATA LINE
CONTROL LINE
BUFFER MEMORY
EXPERIMENT DATA
HOUSEKEEPING DATA
TIMING & CONTROL
I/O
CENTRAL PROCESSING UNIT
T/M OUTPUT
INSTRUCTIONS
PROGRAM MEMORY
GROUND CMDS. TO REPROGRAM MEMORY

FIGURE 3