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SPACE SCIENCES DATA PROCESSING

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ORGANISATION EUROPÉENNE DE RECHERCHES SPATIALES
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A B S T R A C T

Spacecraft carrying large numbers of scientific instruments are presently transmitting data at the rate of approximately 150 million data points per day. These data must be converted from raw digital form into a conceptually meaningful form which the experimenters can analyze and from which they can draw valid conclusions about the phenomena being measured. The task of processing these data rapidly and accurately is a very large one, and is done in several steps. The first includes conversion of the raw data acquisition station tapes into computer tapes and includes signal clean-up, establishment of synchronization, and time decoding. In the newest processing lines this first step also includes a moderate amount of editing and quality-checking. The rest of the steps employ large-scale computers for further editing, establishment of accurate timing, computation of the spacecraft attitude, and sorting, to provide data tapes for the individual experimenters. The experimenters have the responsibility at present for the further reduction to more meaningful form. These operations include further sorting, storage, compilation, computation, and display. There is at present a great need for additional development of analysis and display programs, techniques, and equipment to assist in this work.

TABLE OF CONTENTS

LIST OF FIGURES

SPACE SCIENCES DATA PROCESSING *

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I. INTRODUCTION

This paper is concerned with the problems of data collection and data processing from space sciences satellites. Such satellites produce very large volumes of data over periods ranging from months to years which are subjected to systematic detailed analyses in order to ascertain the characteristics of phenomena in space. They are distinguished from the manned, lunar, planetary, meteorological and communications spacecraft, not discussed here, which have larger requirements for real-time and near-real-time processing, both for operational purposes, and because of the more volatile nature of their data.

In the pre-satellite era of the 1950's, experiments flown on sounding rockets and balloons produced from a few minutes to a few hours of data which were analyzed during the next several years by the experimenters and, at universities, by their groups of graduate students. Even the first satellites greatly expanded the data base by providing data for months of operating lifetime. Since then, the data rate has increased rapidly from a few bits per second to 64 000 bits per second in the case of the Orbiting Geophysical Observatory (OGO) series, and from operating lifetimes of a few weeks to several years. Figure 1 illustrates the manner in which the data volume has grown from 1961 to the present time. Only figures for the Explorer, Interplanetary Monitoring Platform (IMP), Orbiting Solar Observatory (OSO), OGO, Orbiting Astronomical Observatory (OAO), Applications Technological Satellites (ATS), and Biological Satellites (BIOS) series are included. Excluded are the international satellites (for which data processing services are normally

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provided by the experimenters' countries), NIMBUS satellites (which do, in fact, contain a number of scientific experiments), TIROS, Environmental Sciences Service Administration (ESSA), Department of Defense (DOD), and the University Satellite series. Although the distinction between spacecraft included and not included in this discussion may appear somewhat arbitrary, it does reflect the separation between projects whose data processing is performed within the large scale GSFC Central Processing Facility and those whose data processing is performed elsewhere.

II. THE INFORMATION SYSTEM

For the purposes of this paper, the "information system" refers to those portions of the electronic system that collect outputs from the experiment sensors on the spacecraft, process these data on the spacecraft, transfer them to the ground receiving stations, and prepare the information for the experimenters so that they may reach conclusions about the phenomena being measured[1].

A generalized information system for space experiments is illustrated in Figure 2. The sensors on the spacecraft are furnished by the individual experimenters and convert physical quantities such as temperature, charged particle energy, magnetic field intensity, etc. into electrical quantities. Signal-conditioning circuits aboard the spacecraft, such as amplifiers, feedback networks, charge integrators, etc. are frequently associated directly with the sensors to make the electrical quantities more easily processed and telemetered. These are often followed by additional processing circuits to count pulses, measure the amplitudes of pulses, measure the amplitudes of more slowly varying analog quantities and to measure time intervals in order to simplify the task of telemetering the data to the ground. This processing is indicated in Figure 2 by the elongated box on the left. The box is subdivided by dashed lines indicating that some of this additional processing may be done within individual experiment assemblies, while some of it may be done within a central data-processing subsystem. Additional processing of two basic types may also be done on the spacecraft within this same block. The first includes processing to reduce the amount of raw data without reducing the information content. It includes the elimination of redundant information, the elimination of meaningless zero readings, and the reformatting operations which involve simply the rearrangement of data. The second type of additional on-board processing is that which reduces the information content of the raw data, and which includes such processes as curve fitting, statistical analysis, spectral analysis, mathematical manipulation, etc.

The central collection and storage block in Figure 2 includes provisions for gathering the data from all of the individual sources, frequently by means of a time-division multiplexer and the equipment for bulk data storage, either for time-scale compression or expansion, or to permit reception of data for extended periods by the use of a few localized receiving stations. This is followed by the telemetry link, which includes the transmitter, receiver, antennas, space path, and encoding and decoding where employed[2].

For the spacecraft which contain command systems permitting modification of the operation of the experiments or spacecraft, the data are relayed in real time or near-real time to control centers at the Goddard Space Flight Center (GSFC) and are displayed for operational analysis. Decisions are made which result in the initiation of commands to the spacecraft through the command link to modify the spacecraft configuration.

After the data have reached the ground, a number of additional operations are performed before they can be used by the experimenters in their analyses. A number of these functions are performed within the Central Processing Facility (CPF) for the satellites under discussion, including the establishment of data synchronization, noise removal, time decoding, and quality determination. These steps result in the shipment to the experimenters and other users, of data tapes which contain the best estimations of the original data from each experiment output, along with the necessary status, performance, time, quality, command and validity information. It is also common practice to supply orbit and spacecraft attitude information necessary for the experimenter's analyses.

These operations are followed by a number of additional processing steps in which the data are edited, sorted, stored, and used in mathematical analyses and other manipulations and which result in the provision of the data in a form which can be readily interpreted. This function, too, is shown as one large block with dashed sub-divisions, again indicating that some portions of this function are performed by the individual experimenters and other portions are performed within the Central Processing Facility.

The final step is the analysis of the information received by the experimenters in order to ascertain some characteristics of the phenomena being investigated. This analysis leads to the presentation and publication of these results.

III. SEVERAL REPRESENTATIVE SYSTEMS

An example of an extremely simple space information system is shown in Figure 3. This is the Explorer I system[3], which was successfully launched on January 31, 1958, and led to the discovery of the Van Allen radiation belts surrounding the Earth. Pulses from a single Geiger-Müller (GM) counter were accumulated in a five-stage binary register capable of storing 32 counts. The state of the output stage was continuously transmitted. In addition, a number of temperatures and the continuities of a number of micrometeroid detection grids were also telemetered. Each signal source controlled a subcarrier oscillator so that the oscillator frequencies were proportional to the voltages from the sources. These oscillator signals were frequency-multiplexed by the addition of the outputs from the oscillators. The resulting composite signal modulated the transmitters directly, and the output of the receiver on the ground was, in turn, demultiplexed by passing the signals through a number of bandpass filters and frequency discriminators. At the output of the frequency discriminators on the ground, the signals (identical in form to the signals that modulated the subcarrier oscillators in the spacecraft but with noise added) produced strip chart recordings. These strip chart recordings were manually reduced by a number of data readers to provide tabulations of the GM counter pulse rates, temperatures, and the rates of breakage of the micrometeroid grids. This simple system employed very little on-board data processing and very little machine processing on the ground, and was used in the first satellites to give a high probability of success at a time when instrumentation on satellites was still an undeveloped science, and when large-volume data processing techniques on the ground were relatively unknown for this application.

Since that time, technology has advanced until quite complex electronics systems are now placed on spacecraft and operated reliably for a year or more. We now perform many more experiments that are individually much more complex than those on the early Explorers since, as we investigate various phenomena in more and more detail in order to study their detailed characteristics, we must make more and more discriminating measurements, which involve a higher order of data processing. To illustrate, on Explorer I only the omnidirectional intensity of all particles above a threshold energy determined by the thickness of the GM counter wall was measured. Now, in the continued investigation of cosmic rays and energetic trapped radiation, the directional characteristics, the types of particles, the intensity as a function of particle energy and type, and the temporal variations of these parameters must all be determined. Therefore, where one could once simply count the number of pulses, one must now perform a multiparametric pulse-height analysis of the outputs of rather complex detectors. These additional requirements impose a need for greatly increased capability of the entire information system.

The information system for a recent large spacecraft is illustrated in Figure 4. It is for the Orbiting Geophysical Observatory[4], a spacecraft in the 500-kg category, which was designed for a variety of orbits ranging from low, near-circular, polar orbits (Polar Orbiting Geophysical Observatory, POGO) to very highly eccentric orbits extending to approximately 24 earth radii at apogee (Eccentric Orbiting Geophysical Observatory, EGO). The first of these observatories, OGO-I, launched on 5 September 1964 into the eccentric orbit, carried 22 experiments from 17 institutions. Subsequently, OGO-II, a POGO and OGO-III, another EGO, were launched on October 14, 1965, and June 6, 1966, respectively.

Instrumentation for OGO experiments ranges from extremely simple generators of analog signals corresponding to, for example, currents in ion collectors, to extremely complex digital data processing subsystems involving digitization and manipulation of pulse heights from a number of detectors. Each of the two digital data handling subsystems on the spacecraft consists of a main time-division multiplexer with 128 data inputs, and three slower sub-multiplexers with 128 inputs each. In addition, each has a flexible format time multiplexer that can be set at any one of 32 different input data formats by ground command. The latter multiplexer is intended for use with extremely high information bandwidth experiments for relatively short periods. Two large-capacity tape recorders are included on the spacecraft. They can record at 1000 bits/sec for 24 hours for EGO missions or 4000 bits/sec for 8 hours for POGO missions. These rates correspond to approximately one and four main multiplexer measurements per channel per second for the two cases. In addition, digital information can be telemetered directly without the tape recorder at bit rates up to 64 000 bits/sec, corresponding to 55 measurements per input channel per second.

Data processing in the Central Processing Facility on the ground involves four major steps. The recordings containing the raw outputs of the receiver detectors are first passed through a set of equipment which estimates the values of original data bits, establishes bit, word and frame synchronization, and decodes the times recorded on the tapes at the ground receiving stations. The equipment produces a computer buffer tape. The second major step involves editing this computer tape to ascertain that there were no errors in its production and to determine data quality. The third step involves establishment of the relationship between data as recorded on the spacecraft and Universal Time (U.T.). The fourth step is the decommutation (sorting) of buffer-tape data and the generation of individual experimenter's data tapes and status and performance data tapes used for subsystem analysis. These data tapes, along with orbit/attitude tapes, are forwarded to the experimenters for additional processing.

IV. AN EXPERIMENTER'S TIMETABLE

Each experimenter invests a considerable effort in conducting a specific space experiment. The timetable shown in Figure 5 is representative of the Explorer, IMP, and Observatory missions. It indicates that a specific experiment may require from seven to nine years for its completion, including the time from the beginning of the actual building of the experiment hardware to completion of work on the data. Even before the experiment selection, the experimenter may have invested a considerable effort in the development of new detector techniques; therefore, the time scale may, in fact, be one to two years longer than indicated. Preparations for the data-processing activities sometimes begin as early as two to three years before launch. However, it must be kept in mind that the experimenters are frequently not able to predict the detailed characteristics of their expected data accurately enough to permit them to write the final processing programs before launch. It is often necessary that they study the actual flight data before deciding the exact manner in which they will process the data and display them for analysis. Thus, although experimenters can sometimes present preliminary results a few months after launch by the use of interim processing systems, it is common for them to require from six months to a year after launch for the preparation of the final processing programs. Their detailed reduction and analysis then takes place over a period of from two to five years.

This long time-scale produces problems for the experimenters. They are especially severe for the university experimenters, since the time scale is so long that it is impossible for graduate students to complete any single experiment from instrument design through data reduction. For many reasons, including this one, a very strong effort is being made at the Goddard Space Flight Center to reduce the processing backlog in the Central Processing Facility and to maintain the processing on a current status. It is believed that some further progress in shortening the experimenter's time scale can be made by additional work on on-board processing equipment and techniques and by the development of improved programming and display techniques for the experimenter's ground data reduction. The remainder of this paper will discuss these three activities in more detail.

V. ON-BOARD DATA PROCESSING

In the earlier programs, data processing on the spacecraft was kept relatively simple in order to obtain high equipment reliability and high confidence in our ability to interpret the results after flight. However, some steps have already been made towards increasing the amount of data processing on the spacecraft. A very simple example is the inclusion of floating point counters on several spacecraft which count pulses in a non-linear manner in order to provide a very large dynamic range and a fixed accuracy with a minimum amount of circuitry. Processing in many current experiments is considerably more complex, involving, for example, the accurate digitization of a number of photomultiplier and solid-state detector pulse heights from cosmic rays when a given logic condition is met. Specialized computers for the computation of an autocorrelation function and for performing statistical analyses are being built for some of the IMP-F experiments.

There are a number of arguments for developing more extensive on-board processing techniques. A major argument is that the volume of data being returned from the satellites is becoming extremely large, and the task of processing the data on the ground both in the central facility and by the individual experimenters is expensive and time consuming. On-board processing may check the present high rate of growth of data volume by reducing the volume of unused data. Another strong argument is that on-board computers may make it possible to obtain information that might not otherwise be recoverable because of telemetry link bandwidth limitations.

A system designed for significant on-board data processing should be designed so that any degree of processing from essentially zero to a large amount can be performed by reprogramming from the ground after the spacecraft has been launched. Thus, the spacecraft can be launched with a very simple data processing program and then, as the characteristics of the phenomena and the behavior of the instruments are ascertained in orbit, additional degrees of data processing can be added. An on-board processing system of this type should also be designed so that it can, at any time, be reprogrammed for very simple processing to verify the proper operation of the experiments and data-handling equipment. This is necessary to provide a high level of confidence in the data, particularly if anomalous effects are seen.

On-board computers with stored but replaceable programs are now being developed by several groups. Some of these computers may also have the ability to control the calibration of experiments, the computation of spacecraft attitude relative to the Sun or magnetic field (with resulting control of experiment sampling times and programs), and may interface with the spacecraft attitude control, power and thermal control subsystems.

The computer project underway within the Information Processing Division at the GSFC is illustrative. This on-board computer, illustrated in Figure 6, employs a data bus with a variable number of memory modules (1 to 8) and central processing units (CPU's) (1 to 3) to provide a multi-mission capability. The input/output (I/O) provisions are also modular to adapt the basic computer to a large variety of experiments and spacecraft. The memory modules are woven, plated wire, random accessed, and true non-destructive readout. Each module will provide 8192 eighteen-bit words of storage with a 2-microsecond cycle time. The CPU employs a full parallel adder and parallel transfer at register and I/O interfaces. It uses automatic scaling for binary point bookkeeping and hardware multiply/divide. Add and multiply times will be about 6 and 45 microseconds, respectively, including operand fetch. An alternative CPU employing serial arithmetic is also planned for those missions which do not require the speed of the parallel system. The I/O equipment will be customized for each mission but will have an over-all capability exceeding the requirements of any single application. It has a cycle-steal capability for rapid direct exchange of data with the memory, priority interrupt for entry of data by external control, and external request scanning for entry of data by programmed control. The computer can be used as a multi-processor and digital tape decks may be added when they become available. The single memory module, single parallel CPU, average I/O version of this computer is expected to weigh approximately 12 pounds and have a volume of about 0.25 cubic foot. It will consume from 3 watts (idling) to 13 watts (400 000 word per second memory exchange rate). It will be ready for missions in the 1969-1970 era.

It is important to recognize that the use of general purpose on-board computers will have an important effect on the manner in which the data processing is performed on the ground. The early spacecraft which had no command capability depended on the ground network and the Central Processing Facility to gather the data as transmitted and to make them available at some later time for analysis by the experimenters. There was very little requirement for real-time and near-real-time processing since there was no possibility of modifying the operation of the spacecraft or experiments. As the spacecraft systems have become more complex and extensive command capabilities have been added, it is now necessary to perform a large amount of processing within the various Mission Control Centers (MCC's) in order to ascertain the performance of the spacecraft and to control its operation. When general purpose on-board computers are used, even greater reliance on real-time and near-real-time processing will be necessary in order that the programs for the on-board processing can be most effective. Thus, we can expect a shift towards more real-time and near-real-time processing in the Mission Control Centers and Central Processing Facility. Although it is not yet known how far this will proceed, it is entirely possible that, for spacecraft employing the general purpose on-board computers, most of the data processing will be done immediately by the use of data transmission links from the data acquisition stations to the Goddard Space Flight Center and by the use of additional data transmission links directly to the experimenters' laboratories. One of the eventual functions of the Data Reduction Laboratory, which is described in a later section of this paper, will be to ascertain the desirability and practicability of this type of operation.

VI. GROUND DATA PROCESSING IN THE CENTRAL PROCESSING FACILITY

After the satellite telemetry data are recorded on tape recorders at the twelve data acquisition stations, the tapes are forwarded to the Goddard Space Flight Center for processing. The initial processing is performed in the Central Processing Facility, which includes the necessary production control, tape inventory, quality control, and library provisions, in addition to the processing lines and computer equipment. As was mentioned earlier, the output of this facility is a set of tapes for each experimenter containing the data from his experiment, plus the necessary auxiliary information and the spacecraft orbit and attitude. The functions performed by this Central Processing Facility are illustrated in Figure 7. One tape from each shipment from each data acquisition station is evaluated soon after receipt. The purpose of this evaluation is to determine whether the equipment at the data acquisition station was operating properly, in order that abnormalities can be corrected as soon as possible. After evaluation the tapes are mounted on one of the Satellite Telemetry Automatic Reduction Systems (STARS) for the initial processing operation. In these processing lines the signals are conditioned and bit, word and frame synchronization are established. In the signal-conditioning operation, a best guess is made as to the original content of the signal on a bit-by-bit or tone-burst-by-tone-burst basis. This operation usually includes the integration of the signal for the duration of the bit or tone-burst period before a decision is made. At the same time that these operations are occurring, the times recorded on the tapes at the data acquisition stations are decoded and continuously compared with a locally running clock. Both the reconstructed telemetry data and the times are buffered in a core memory and then recorded on a computer-compatible buffer tape.

In the latest model of the processing lines, referred to as STARS Phase II, a CDC 3200 computer is included to perform two major functions[5]. The set-up of the processing line is under computer control to reduce the time required to prepare for each run, and to reduce the number of operator errors. Initial computer pre-editing is performed during this first pass to determine the quality of the data as early as possible. In addition, a simulator is included for system checkout. A photograph of a STARS II PCM processing line is shown in Figure 8. A drawing of the STARS area of the Central Processing Facility, shown in Figure 9, indicates the arrangement of the approximately 20 major processing lines.

After the first processing operation on the STARS lines, all additional processing is performed on general purpose computers. The operations performed in these computers are also indicated in Figure 7. Further editing of the buffer tapes checks the internal consistency and quality of the data. The times, either telemetered with the data from the spacecraft clock, or recorded with the data from a ground clock, or both, are converted to Universal Time (U.T.). Corrections are made for clock errors and propagation times. This step is especially crucial, since it is common practice to use time to correlate the flight data with orbital position and with other housekeeping and experimental data during the analysis phase.

The data, now including U.T., are arranged into a convenient format, and sorted (decommutated) onto separate data tapes for each experimenter. Thus, each output tape contains the data from a specific experiment, U.T., and various pertinent spacecraft data, such as the temperature of the experiment mounting plate, the voltage of the power bus, etc.

In parallel with the telemetry data processing, the spacecraft orbit is computed for each minute using inputs from the radio interferometer and range and range-rate tracking stations. This smoothed orbit, along with attitude control system error signals and attitude sensor output signals obtained from the telemetered spacecraft data, is used to compute the instantaneous look directions for the detectors. Both the orbit and attitude information are shipped to the experimenters along with their telemetered data tapes.

Since the identification of each command received by the spacecraft is not contained in the telemetered data, it is also necessary to decode the commands from the original acquisition station tapes where they are recorded at the time of command transmission. The complete command list is then furnished to the experimenters in the form of a magnetic tape, punched cards, or a listing. This task may be quite large by itself, since tens of thousands of commands are transmitted to some of the spacecraft.

In connection with the data processing operations outlined above, it is necessary to conduct a number of bookkeeping and library functions. The original data acquisition station tapes are catalogued when they are received and are eventually placed in permanent storage in the analog tape archive, which at present numbers approximately 100 000 reels of tape. An intermediate digital tape, referred to as the "edit tape", is also placed in permanent storage for use in the event that it is necessary to repeat the computer processing. A number of documents are generated during the processing operations which are used by the processing facility staff to evaluate system performance, and by the experimenters so that they may have an accurate record of the content of all of the tapes and the quality of the data.

Several significant changes from the data flow indicated in Figure 7 are being made. These include, first of all, the movement of some of the pre-editing and quality checking functions to the STARS Phase II data-processing lines. The objective of this change is to permit the determination of the quality of the data and success of the processing operation during the first pass through equipment in the Central Processing Facility. Thus, we hope to be able to provide more accurate system analyses at an earlier time for the further perfection of the information system.

A second change underway is the movement towards the generation of a Master Digital Data Tape near the end of the processing in the Central Processing Facility. This tape will contain all the raw telemetered data, commands, corrected time, orbit, spacecraft attitude and quality information, and will contain the data in chronological sequence with, most probably, overlapping portions of data removed. This Master Digital Data Tape will be the source of all further sorting and processing. In addition, it will become the prime archival medium replacing the earlier analog station tapes and edit tapes. A large step in the implementation of this new philosophy was taken on the Interplanetary Monitoring Platform-F (IMP-F), which was launched in May, 1967. A further step is being taken in preparation for the Small Scientific Satellite (SSS, or S^3).

VII. ADDITIONAL GROUND DATA REDUCTION

After the data are available in raw form, the experimenters must still reduce them into forms from which they can reach meaningful conclusions about the phenomena being investigated. This reduction commonly includes reformatting, sorting, merging, accumulation, statistical analysis, and mathematical manipulation of the raw data. It includes some provision for outputting the summarized data in a readable form such as line printer tabulations, x-y plots, motion pictures, etc.

In the understanding of this activity it is useful to remember that most experimenters make four different uses of their data:

1. Scan All Data

It may not be neccesary to perform a detailed analysis of every piece of data received from a particular experiment. It is generally necessary in these cases to scan all of the data to select the interesting portions, since it will not be possible to predict the time periods or regions in space which will produce those interesting data. To illustrate, bursts of particles are occasionally emitted by the Sun. One of the objectives of many of the experimenters is to detect these unpredictable bursts and analyze them in detail.

In order to simplify the process of scanning all the data, it is common to reduce them to strip chart or some other visually meaningful form for rapid viewing. One of the most recent techniques which shows great promise for this function is the production of motion pictures generated by taking sequences of photographs of a suitable display of the data. In one case the amplitude of the output of a swept, very low frequency (VLF) receiver was plotted as a function of the frequency to which it was tuned to provide a frequency spectrum. A picture was taken of this spectrum each time the receiver sweep was completed, or once every 256 telemetry frames. When viewed in rapid succession by the use of a motion picture projector it is possible to quickly spot interesting fluctuations from the steady-state condition.

2. Analyze Selected Portions of Data

Limited portions of the data may require detailed analysis. These may include, for example, data obtained during the crossing of the magnetospheric boundary surface, the transition region, and the shock front if one is studying the interaction of the solar plasma with the Earth's magnetic field. Another example is the detailed study of the ionized layers surrounding the Earth at heights of from one hundred to several hundred kilometers. Additional examples of interesting subjects for detailed study include solar storms, day-night effects, high-altitude nuclear explosions, the auroral zones and the astronomical investigation of certain portions of the celestial sphere.

3. Map in Either Space or Time

A frequent scientific objective is to determine the spatial extent of specified phenomena. Thus, it is necessary to take the data from various periods during which the spacecraft moves from position to position in its orbit, and the location of the orbit moves in a sun-earth coordinate system. Thus a complete mapping in space may require a year or more. It is frequently necessary to reduce these data to one or a few plots to provide a map of the phenomena.

In addition to the requirement for mapping in space, it is also frequently necessary to provide a map in time, with scales ranging from minutes or hours to many years. For example, in studying numerous solar-related phenomena, some changes occur in a few minutes during the build-up of a solar flare. On the other hand, other changes involve a time scale equal to the length of the sun spot cycle of eleven years. Thus, it may be necessary to investigate the data from a particular type of sensor for at least that period of time in order to have a complete understanding of the phenomena.

4. Analyze All Data

Some experimenters may require the full analysis of all of the data for extended periods of time. Most generally, this will be for those experiments which have event accumulation rates low enough to require data from long operating periods to obtain statistical significance. An example of this type of investigation is a cosmic ray experiment, where only a few heavy particles of some types may be seen each week. Thus, data must be accumulated over a period of many months to be significant.

Note that the processing techniques for meeting each of the four data analysis requirements listed above may be considerably different. Any one experiment may require processing programs for several of these four analysis functions.

At the present time these reduction programs are usually prepared by the individual experimenters, with frequent parallel development of similar subroutines by different groups. To assist the experimenters in their tasks, several new development activities are needed:

a) Basic Computer Programming Techniques for Telemetry Data Manipulation

Present programming techniques such as FORTRAN, COBOL, etc. are rather poorly suited to the rapid development of new programs for data manipulation. New modular programming systems for data manipulation are required.

b) Subroutine Organization

Subroutines (computer programming modules) for performing specific functions (e.g., scale factor correction) need to be assembled into a library system and made available to the community of users. This subroutine structure needs to be built into the program structure discussed in item *a* above.

c) Better Display Techniques, Devices and Programs and the Use of These for Developing the Programs

Many experimenters still obtain their data outputs as printed tabulations and then use considerable manual effort to reduce them to charts, etc. Dynamic cathode ray tube (CRT) displays, motion pictures, the use of color, three-dimensional displays, and other forms of display can be expected to provide a more rapid means for arriving at the desired processing programs, and a more rapid and comprehensive understanding of the phenomena being investigated.

Several efforts are underway to develop some of these techniques. The Data Reduction Laboratory (DRL), pictured in Figure 10, is being developed by the GSFC Information Processing Division to provide several operator stations with two consoles each. One alphanumeric CRT and keyboard at each station will provide dialog communication with the central Univac 1108 computer for rapid program development. The second CRT will display alphanumeric and graphic data in either static or dynamic form. It will be possible to add remote communications consoles later so that experimenters may develop programs from their own laboratories. It will be possible to enter data either in real time via the data link from several of the STADAN stations, or off-line from either analog or digital tapes. In addition to its capability for rapid program development, its dynamic display capability will provide operational real-time and near-real-time data presentation for the support of experiment/spacecraft operations, especially during critical operating periods. This basic DRL is scheduled for completion in early 1969.

VIII. CONCLUSIONS

The information systems for space sciences experiments continue to undergo an evolutionary process. There continue to be improvements in the performance of individual components of the information system, for example in the speed, efficiency, and frequency ratings for transistors employed in the telemetry transmitters. However, the most significant changes foreseen during the next three to five year period involve the use of additional onboard data processing, improvement of the operation of the Central Processing Facility, and the development of new computer programming and display techniques. These activities are needed if we are to avoid falling further behind in processing the very large volumes of data being returned from our orbiting spacecraft.

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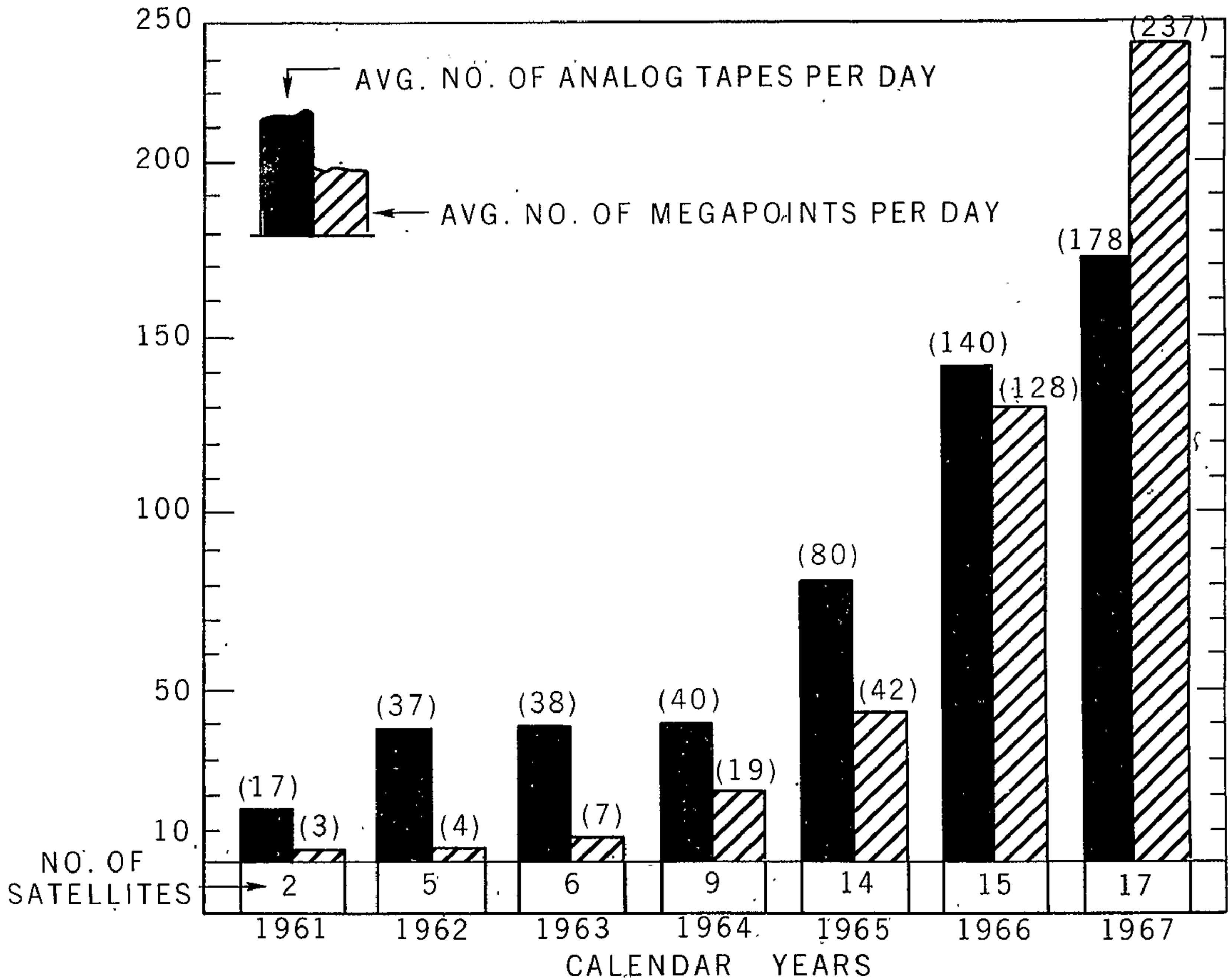

Figure 1. Growth in space sciences data volume, in millions of data points per day. A data point is a measurement such as a temperature, voltage, etc., generally corresponding to from 8 to 10 binary digits.

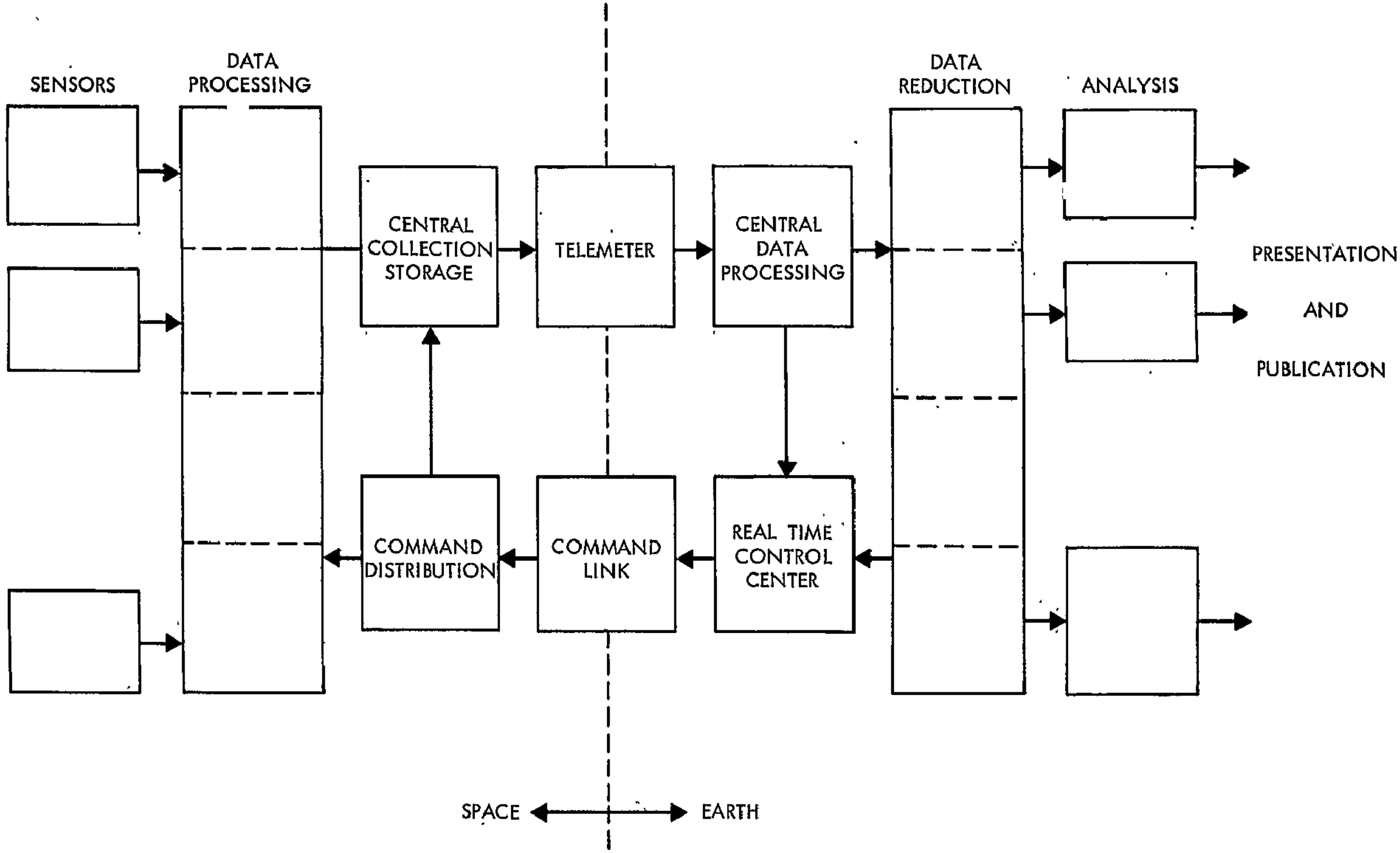

Figure 2. A generalized space information system.

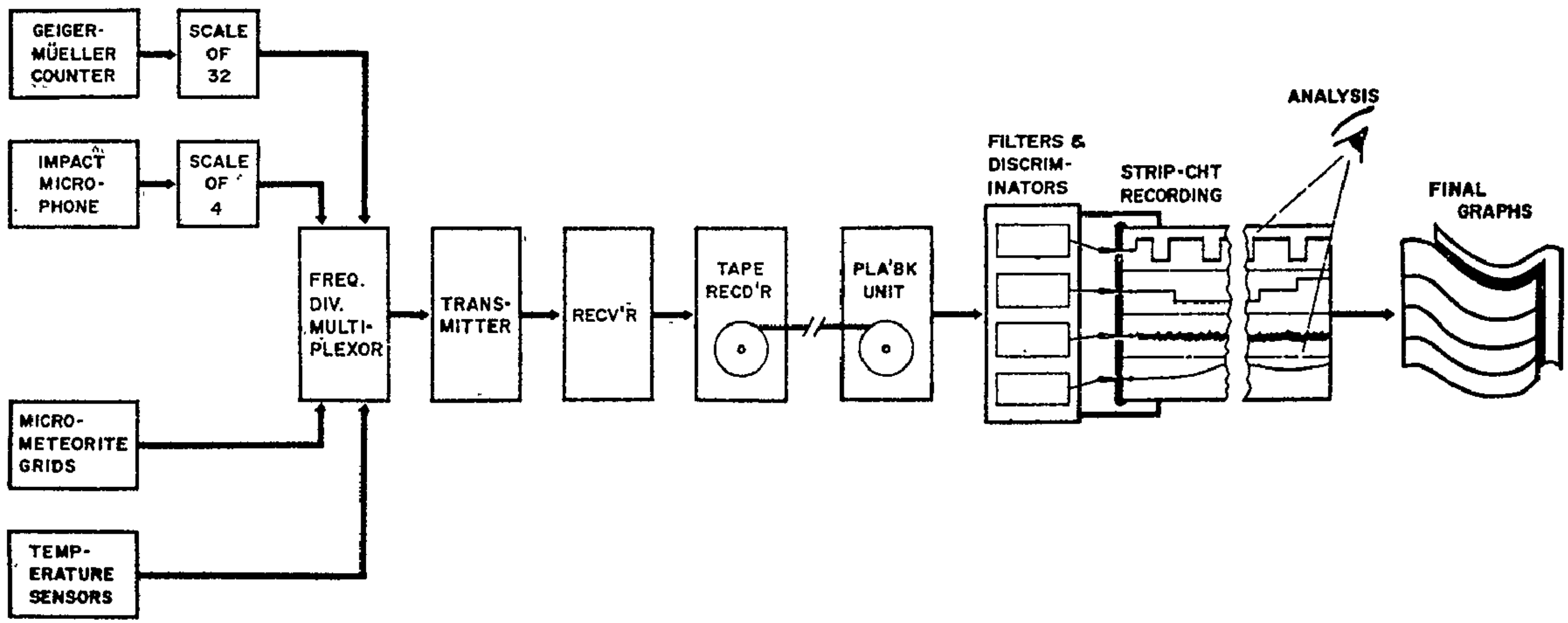

Figure 3.- The Explorer I information system.

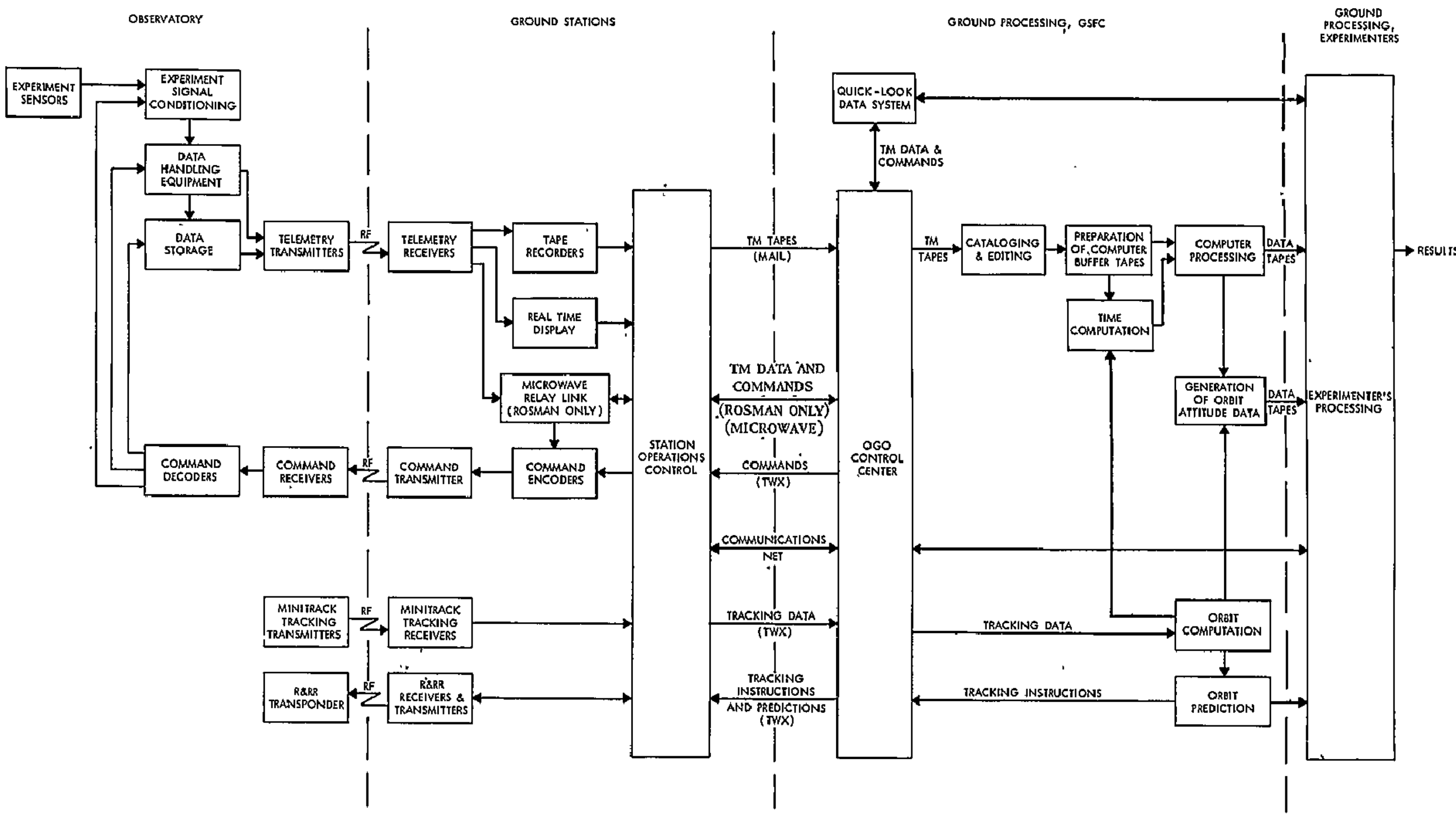

Figure 4. The information system for the Orbiting Geophysical Observatory.

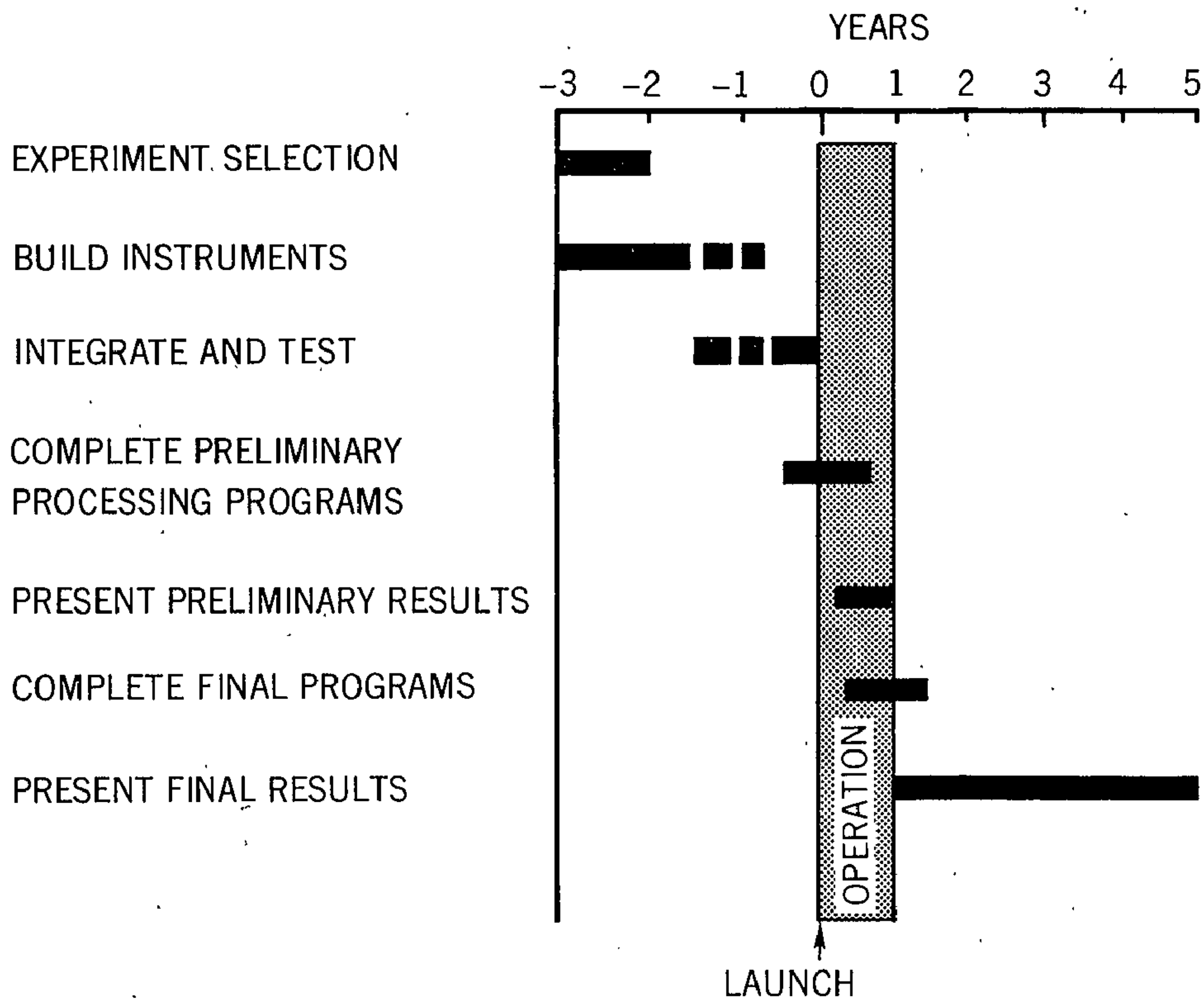

Figure 5. A space sciences experimenter's timetable.

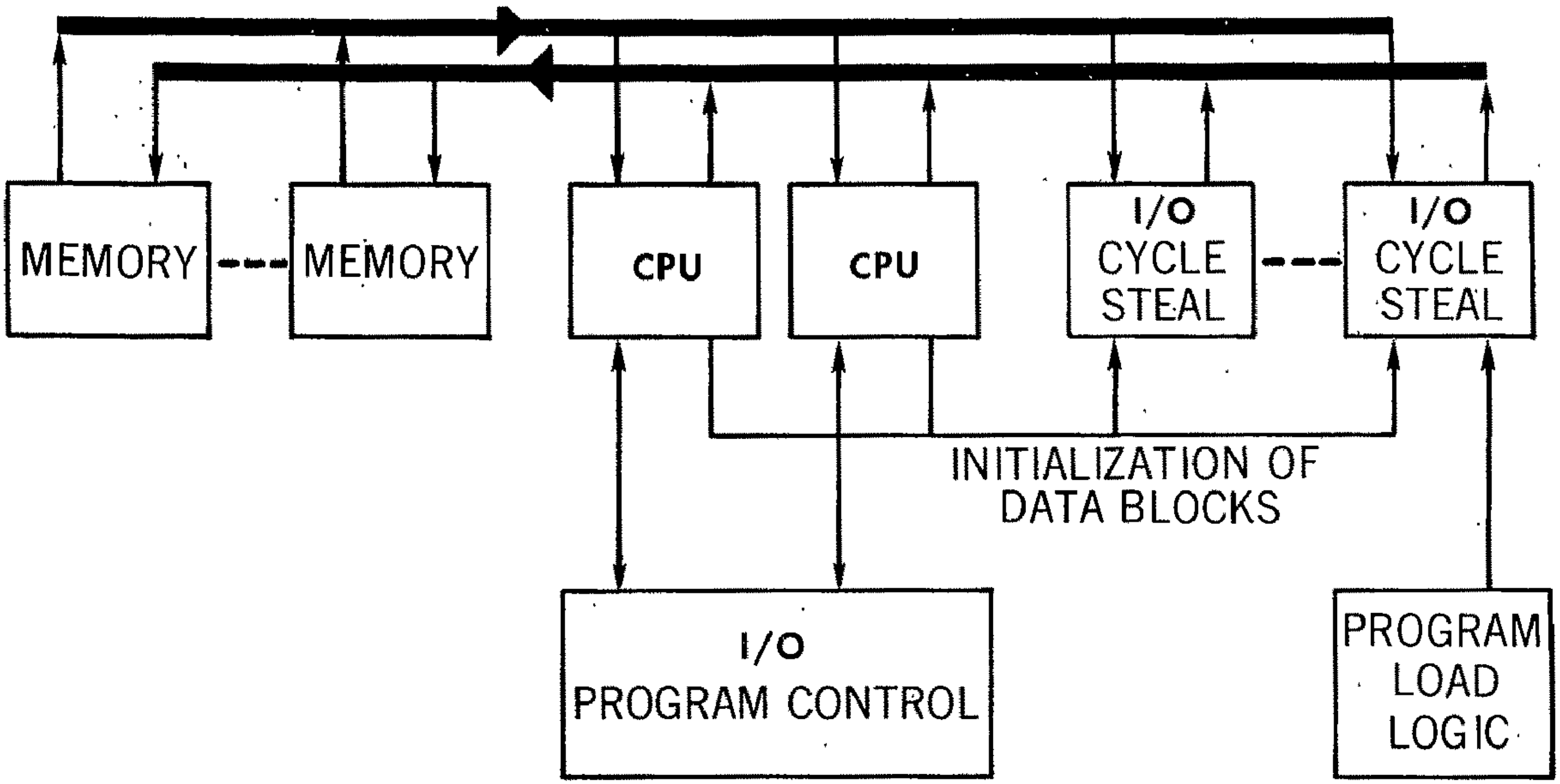

Figure 6. The organization of the on-board computer being developed by the Information Processing Division, GSFC.

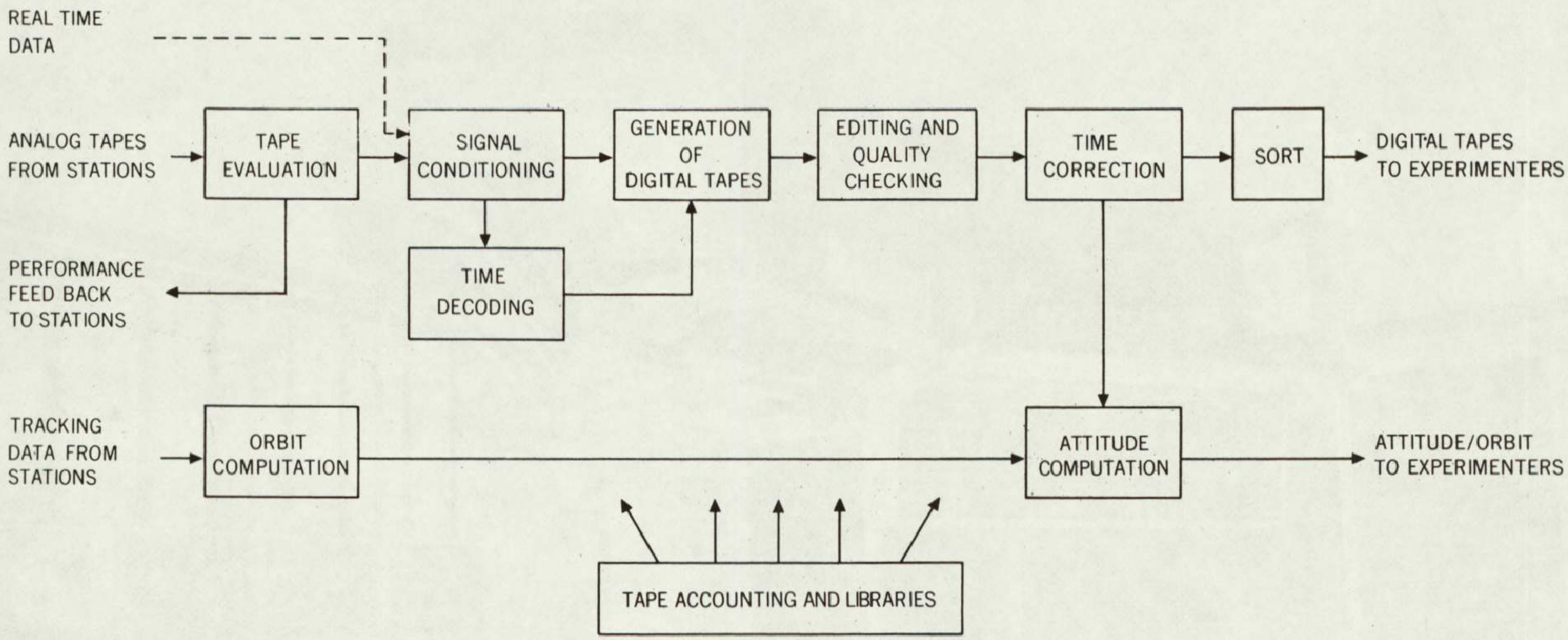

Figure 7. The functions performed within the GSFC Central Processing Facility.

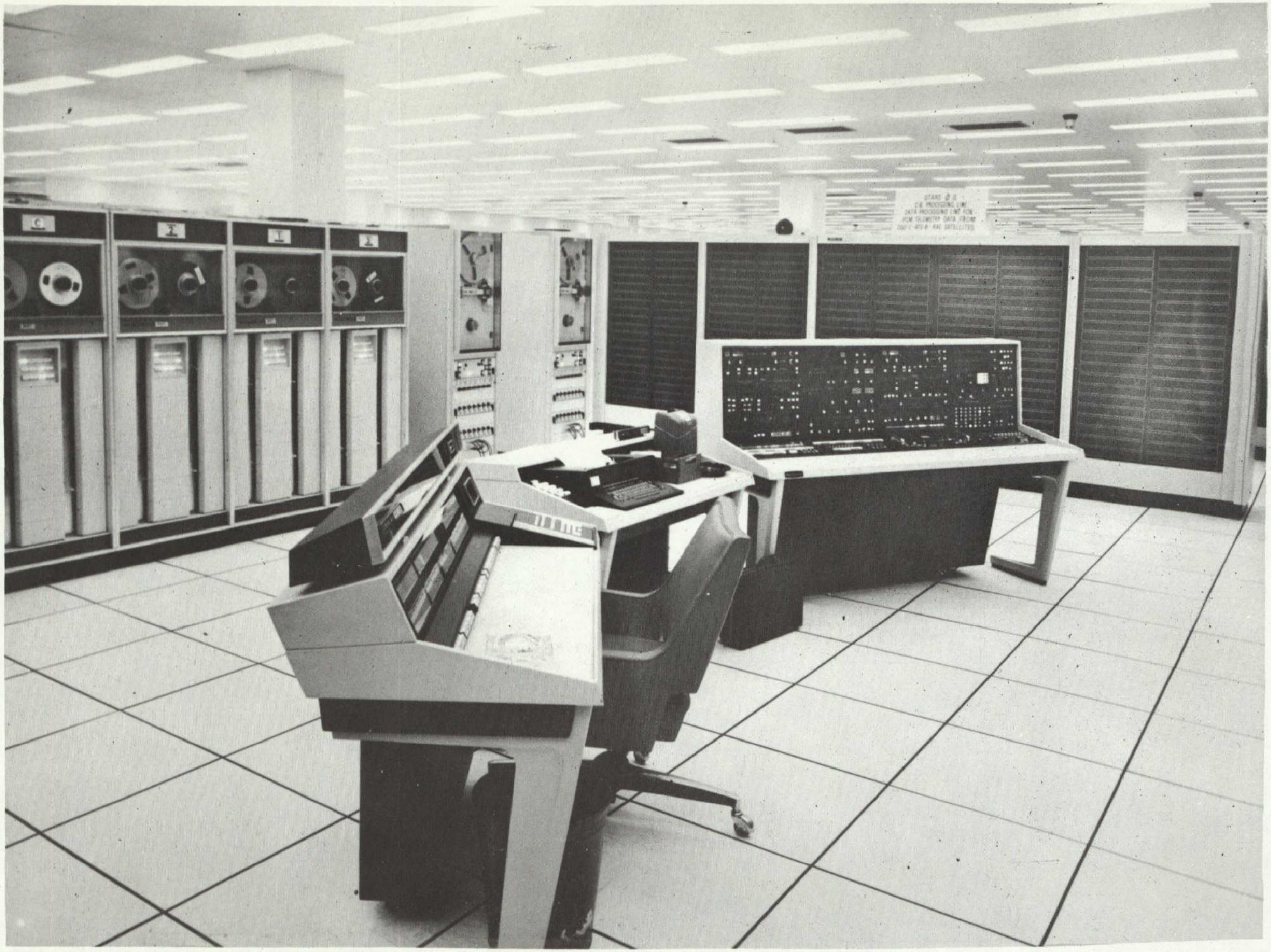

Figure 8. A view of one of the Phase II Satellite Telemetry Automatic Reduction Systems.

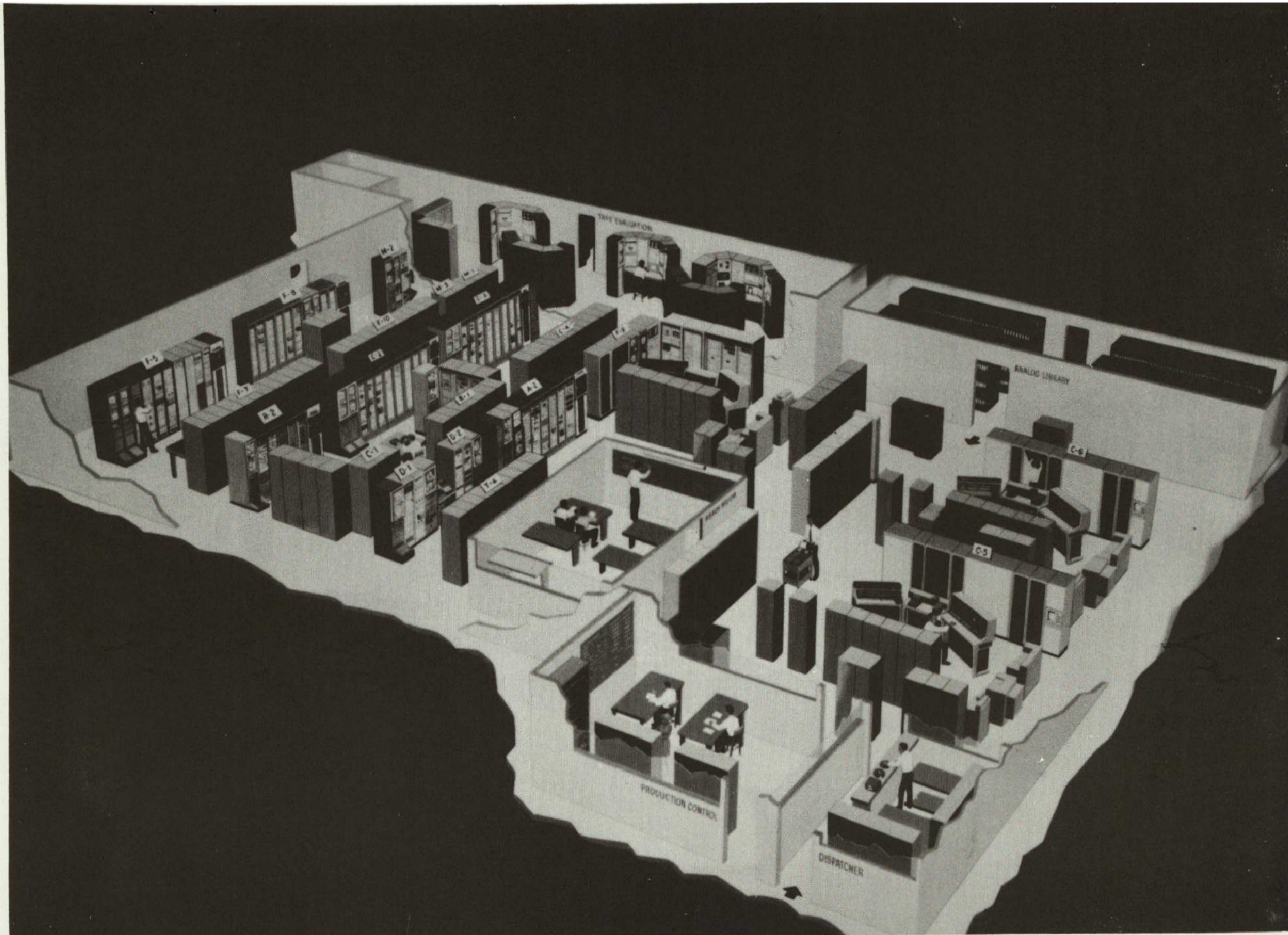

Figure 9. Artist's sketch of the telemetry processing portion of the Central Processing Facility, showing the tape evaluation lines (upper left), the analog library (upper right), production control and dispatching (lower right), and the digitizing lines in the center. The letters on the lines represent: A - PAM, PDM, FM; C - PCM; D - Command Decoding; F - PFM; M - Misc. (mostly tape-to-picture); R - Magnetometer Digitizing; and T - Tape Dubbing.

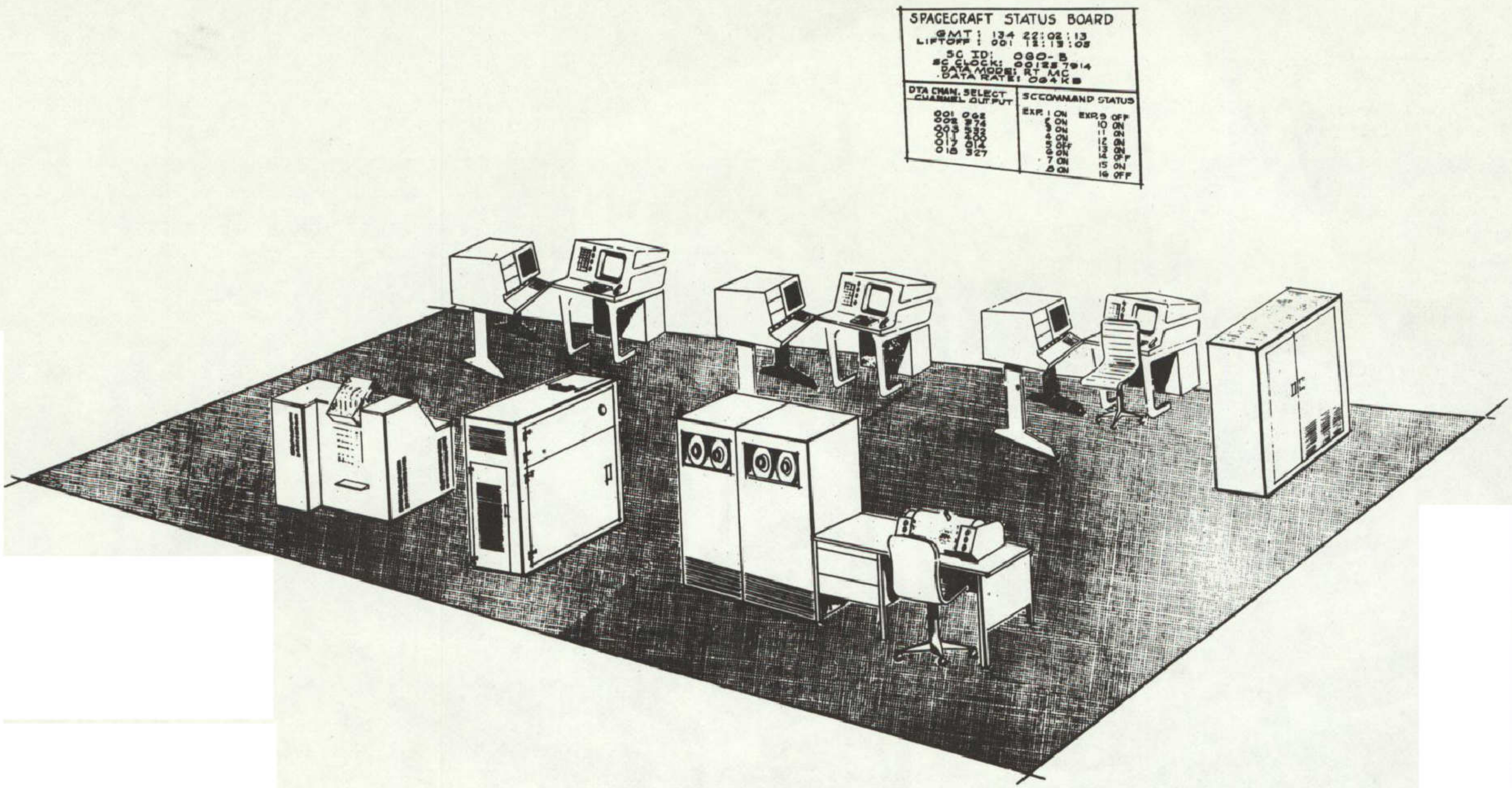

Figure 10. A drawing of the Data Reduction Laboratory.