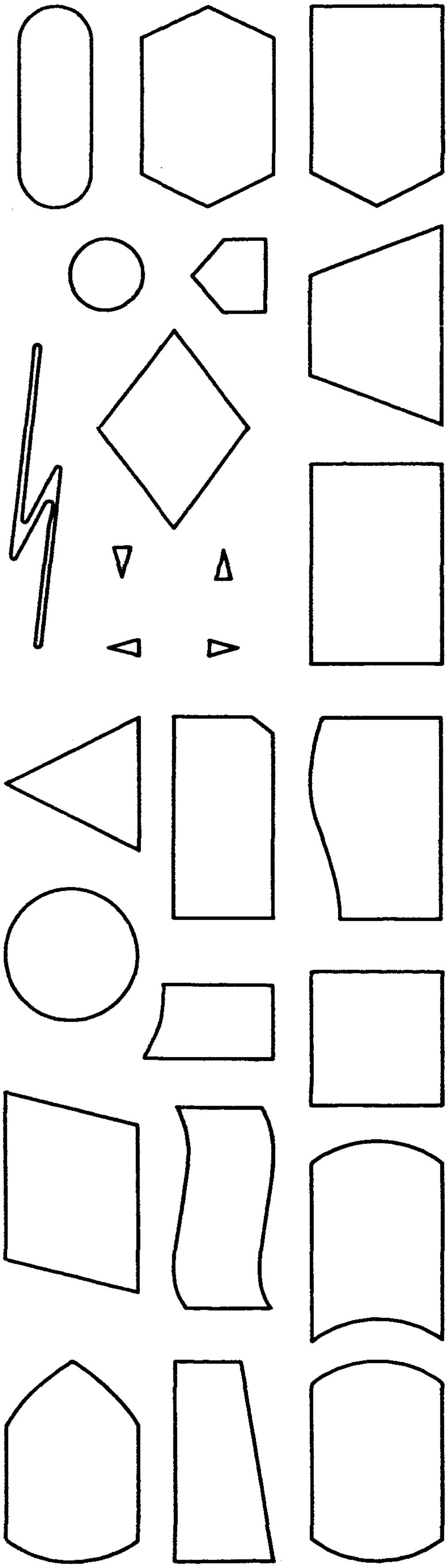
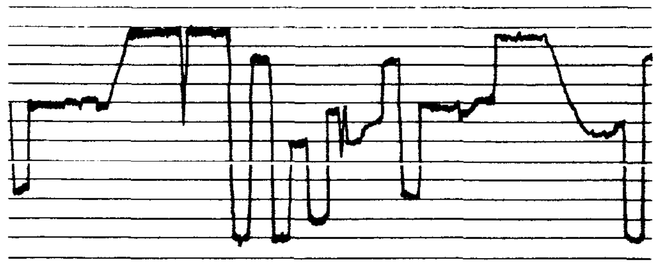


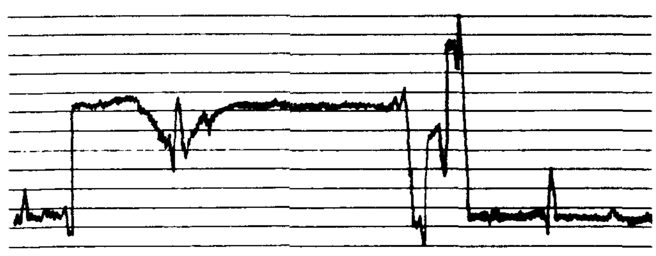


TELEMETRY DATA PROCESSING

BY

THE DATA PROCESSING BRANCH

Goddard Space Flight Center
National Aeronautics and Space Administration



CONTENTS

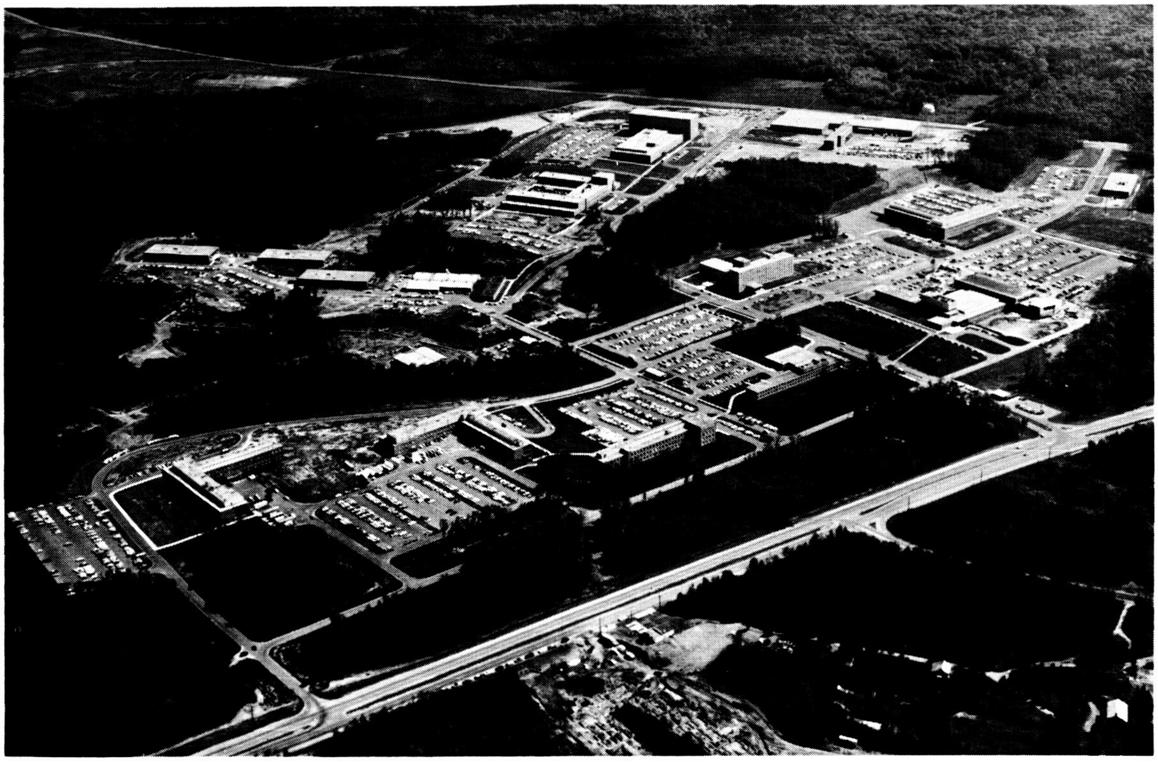
1605D

ABSTRACT

The data from scientific instruments aboard satellites are recorded on magnetic tapes at the data acquisition network stations and sent to the Information Processing Division, Data Processing Branch for evaluation, processing, reducing, and further preparation for analysis. Further responsibilities include spacecraft attitude computation, additional processing of experiment data by request of the experimenter, and processing of spacecraft subsystem data. This document tells how the above-mentioned tasks are accomplished by the Data Processing Branch.

Author

GODDARD SPACE FLIGHT CENTER



A part of the National Aeronautics and Space Administration complex is the Goddard Space Flight Center, first major United States laboratory devoted entirely to the investigation and peaceful exploration of space, located at Greenbelt, Maryland. Goddard Space Flight Center is responsible for the development of unmanned sounding rockets and orbiting spacecraft experiments in the basic and applied sciences. Projects include scientific, weather, and communications satellites. Goddard also serves as the tracking, communications, and computing center of NASA's worldwide satellite tracking, data acquisition, and manned spaceflight networks.

A full-range space science experimentation program is another major responsibility. The space science cycle begins with the scientific theory and ends with data computation and analysis. The means to this end are attained by scientific experiment design and construction, satellite fabrication and testing, rocket launching, tracking, and data acquisition.

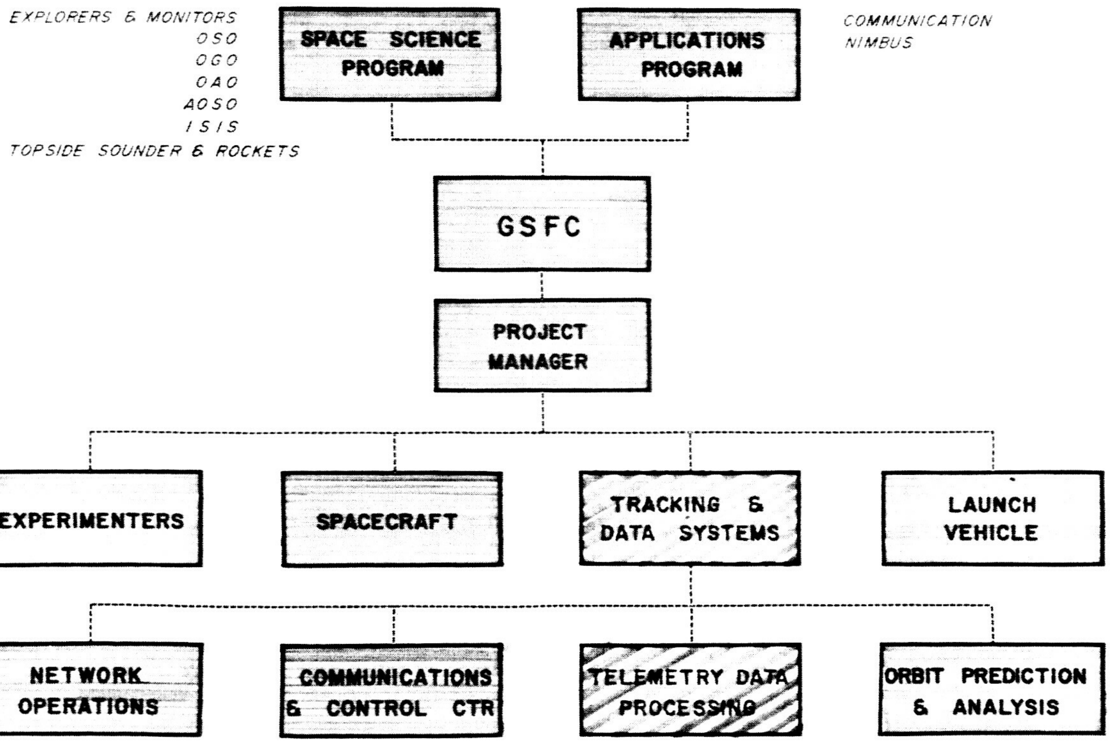
Present and future space programs emphasize the value of a global picture of the many physical processes in space that affect the earth. Whether it is the exchange of scientific data, the launching of an international satellite, or the tracking of a spacecraft, cooperation of the international community is required. Goddard Space Flight Center plays a major role in NASA's international cooperation program which currently consists of space agreements with 65 other nations.

EXPLORING SPACE

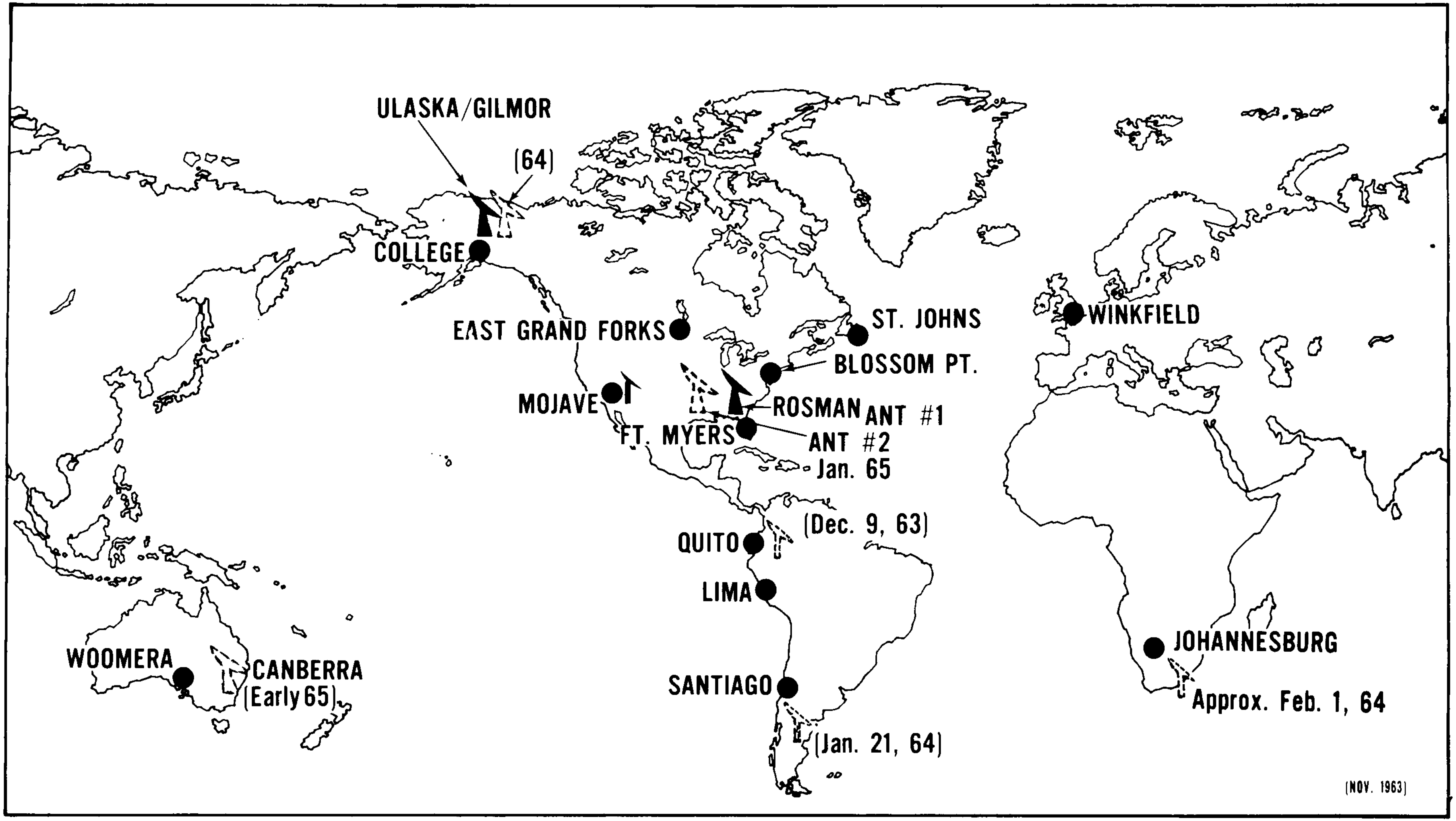
Space science is science in space. From the vantage point provided by an orbiting satellite or a space probe, scientists attack some of the most important and challenging scientific problems of today. Scientific disciplines that heretofore had gone their separate ways with only occasional interactions now tackle, in close partnership, the problem of understanding the phenomena and properties of outer space.

At the Goddard Space Flight Center, physicist, astronomer, geodesist, mathematician, geologist, engineer, astrophysicist, and many others explore the innermost workings of the universe. Each one of these disciplines is finding that it has a new frontier. The space science program provides the basic scientific data essential to a better understanding of the world and of the universe and produces the knowledge needed for both manned space flight and for applications (weather and communications) satellite projects.

The Space Science and Applications programs within Goddard Space Flight Center are organized to develop unmanned sounding and earth orbiting spacecraft experiments in the basic and applied fields. The Tracking and Data Systems Directorate, Telemetry Data Processing, and other coordinating areas are shown on the chart below:



SPACE TRACKING AND DATA ACQUISITION NETWORK (STADAN)



DATA ACQUISITION

Goddard Space Flight Center manages NASA's two worldwide tracking and data acquisition networks. Tracking and data acquisition are accomplished by the Space Tracking and Data Acquisition Network (STADAN). This network consists of special primary and secondary data acquisition stations and range rate tracking stations. For manned exploration of space, a global network has been established for tracking, telemetry, and voice communications on a real-time basis.

The STADAN stations are equipped for interferometer tracking and, according to established tracking priorities, track spacecraft throughout their active lifetime. Various spacecraft orbits are computed from the tracking data received from the real-time stations and processed according to standard procedures to accomplish the required orbital accuracy. These stations command the spacecraft, receive the data, and transmit the data over wideband communication circuits to a central data-handling facility at Goddard Space Flight Center. Special purpose telemetry is also received and recorded by the stations for shipment to the Data Processing Branch for processing.

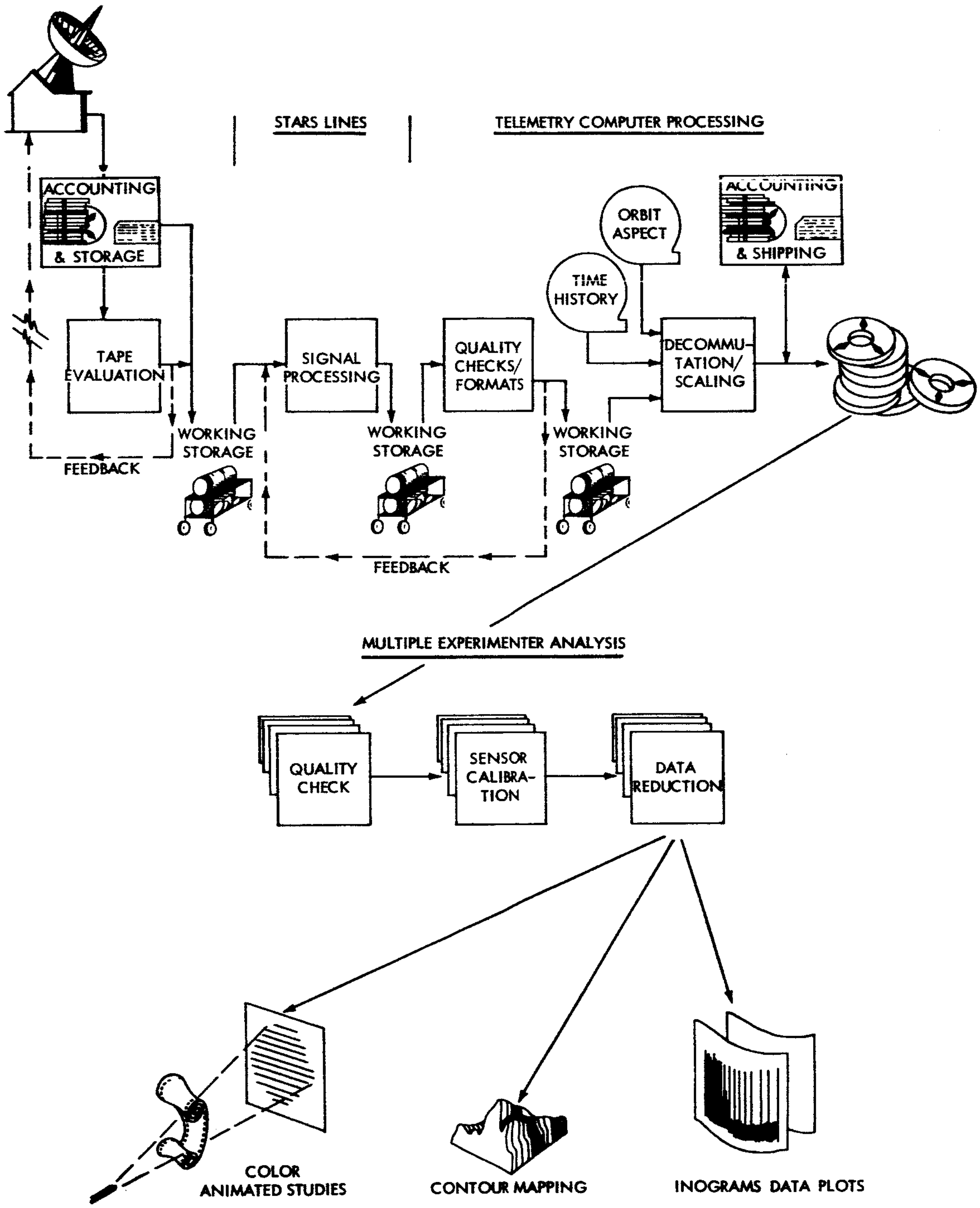
The space science experimentation program has now progressed from a phase that consisted of using a small lightweight spacecraft which carried a few experiments of an exploratory nature, highly integrated with the spacecraft subsystem, to the development of spacecraft with a high degree of flexibility for accommodating many types of highly diversified scientific and technological experiments. These spacecraft designs provide for numerous and diversified experiments, totaling possibly 50 experiments per mission. Consequently, an avalanche of data will be telemetered back from the series of sophisticated scientific satellites such as the orbiting, solar, astronomical, and geophysical observatories. The data from the observatories will be recorded on magnetic tapes at the data acquisition stations and then sent to the Data Processing Branch for the reduction to facts and figures so that scientists can analyze the results of the spacecraft experiments.

DATA PROCESSING

Data processing is only a part of the total efforts of the Tracking and Data Systems Directorate. Besides being responsible for the design and development of systems used in data acquisition and retrieval, the Tracking and Data Systems Directorate maintains an extensive tracking and data acquisition network, along with centralized facilities to compute orbital information and process telemetry data.

Currently, the operational functions, as shown in the Data Processing Operational Flow, have resulted from system analysis, design, and selective and appropriate implementation in correlation with the data processing applications and needs of the scientific and engineering community. The data processing operational flow can be grouped into the following four areas: (1) Analog tape evaluation; (2) conversion to digital computer format; (3) channel decommutation, telemetry calibration, and orbital data merging; and (4) further reduction and analysis of individual channels using digital computers.

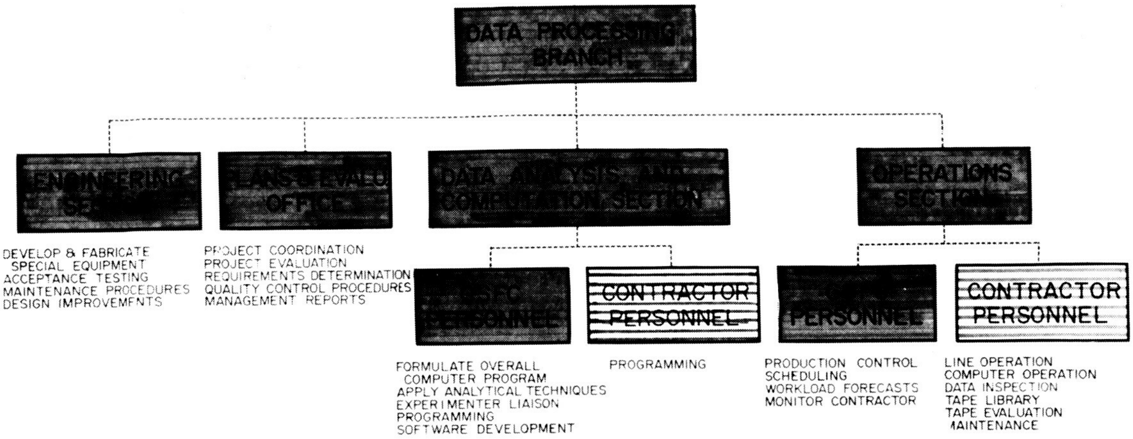
An operational flow of data through the Data Processing Branch is exemplified as follows by the Orbiting Astronomical Observatories Pass II master data processing program. Quality control checks will be concerned primarily with format consistencies and data manipulations appropriately flagged. Then the perform data voting routine will compare data memory dumps against successive data memory dumps and will attempt to assign a voting flag to each word. On the basis of all voting flags from each data memory dump, a best memory dump will be compacted. With the compact data group as the source data input, the ideal and actual orientation of all spacecraft will be computed. All narrowband and wideband status data will be processed. The Data Processing Branch will tabulate, plot, and maintain histories of all spacecraft status data. A statistical analysis then will be performed to attempt to assign figures of merit to the data quality for each spacecraft pass. Direct digital data will also be processed and reformatted and a plot tape produced. Identification, attitude, command, and experimental data will be formatted for each experimenter. Finally, all bookkeeping data will be provided that is required to maintain up-to-date and accurate records.



DATA PROCESSING OPERATIONAL FLOW

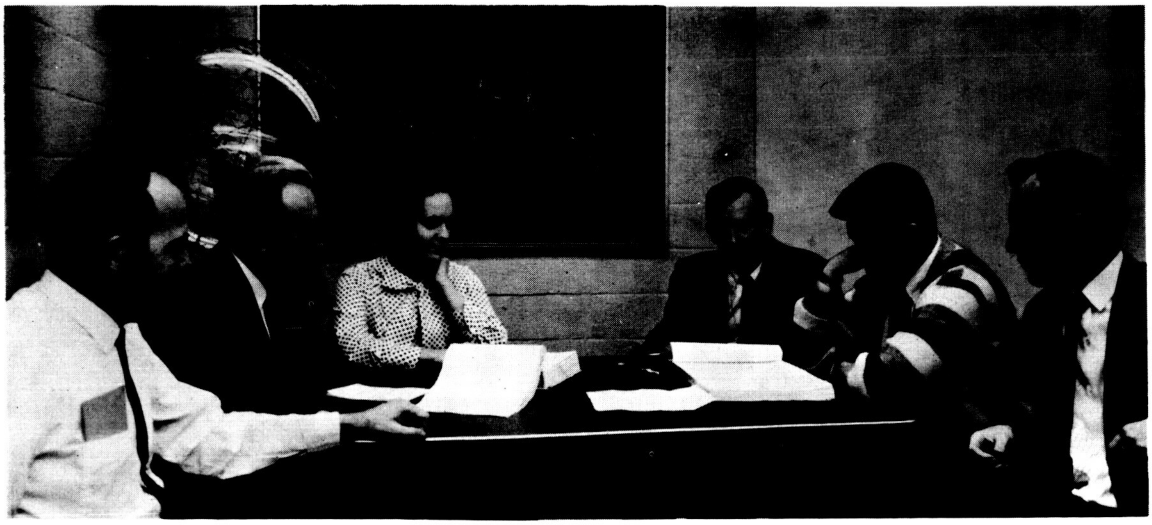
DATA PROCESSING BRANCH

The Data Processing Branch, Information Processing Division, now is concerned with near real-time data evaluation, reduction, and processing. Briefly described herein are the capabilities as well as the automatic state-of-the-art computers and peripheral equipment used for fulfilling a variety of satellite data reduction requirements.



The Data Processing Branch Head directs and coordinates the efforts of the Plans and Evaluation Office, the Data Analysis and Computation Section, the Operation Section, and the Engineering Section. The sections are staffed by personnel selected for their technical ability and experience in the fields of radio telemetry, electronic data processing, preliminary scientific data analysis, and scientific programming.

The Plans and Evaluation Office coordinates and evaluates the various satellite projects, participates in requirement determinations and quality control procedures and is responsible for management reports.

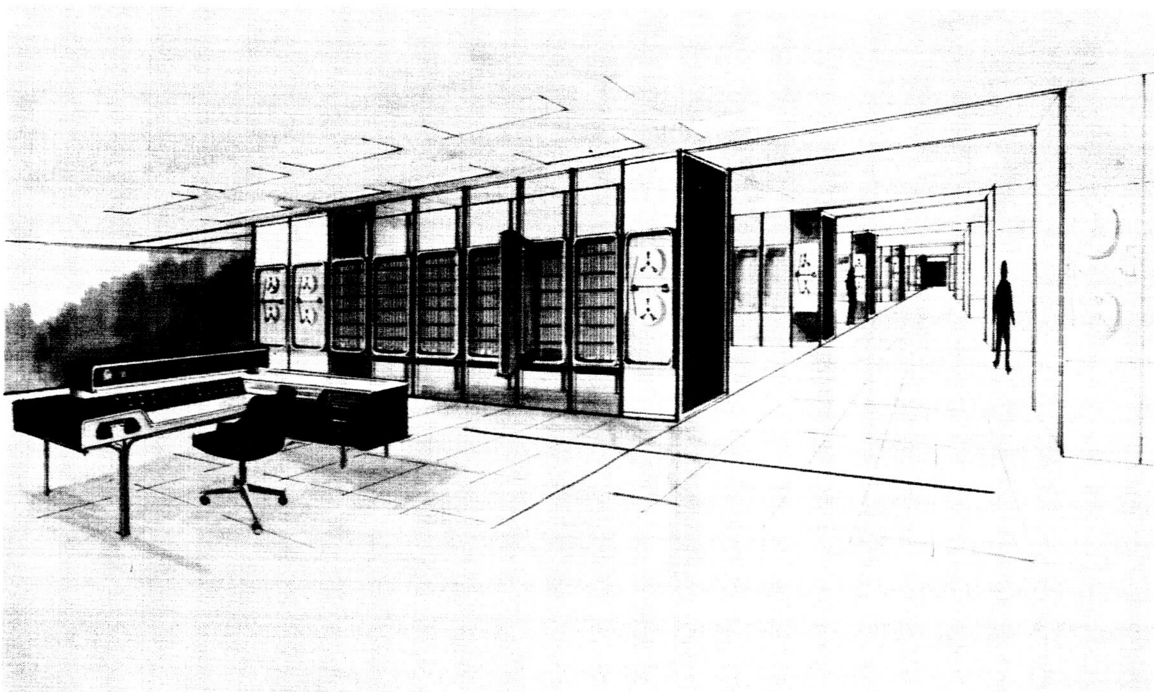


Conferences where minds meet to discuss problems and arrive at possible solutions are an important part of Data Processing.

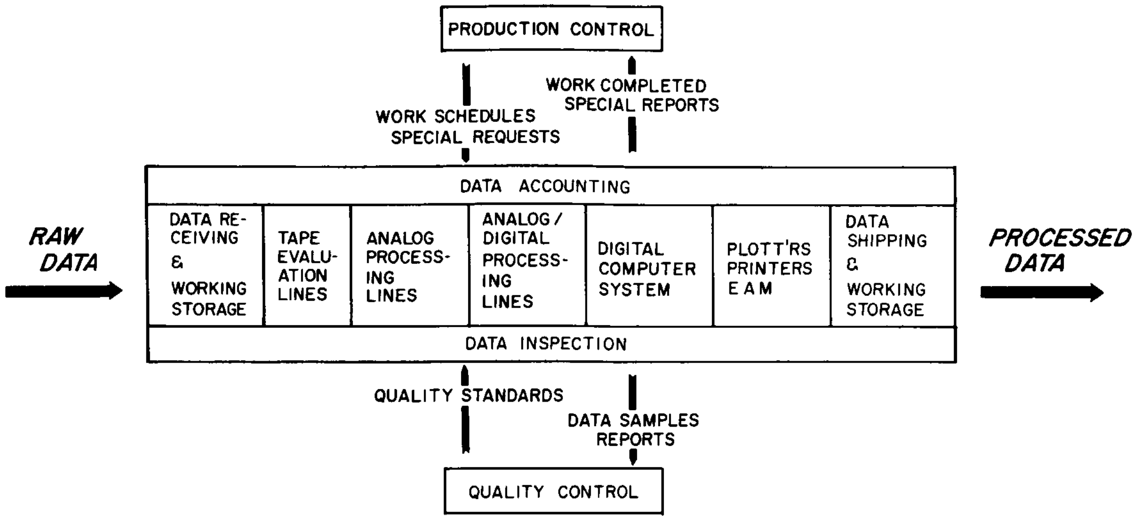
Staffed by both Goddard and contractor personnel, the Data Analysis and Computation Section formulates overall computer programs, applies analytical techniques, and develops appropriate software for satellite data reduction. Computing is accomplished either by a specific programming computation or by using versatile utility programs with patching techniques. Liaison with experimenters in regard to data evaluation and reduction of scientific experiments is another significant responsibility.

Also staffed with Goddard and contractor personnel is the Operations Section where the data signal processing lines and computer operations are monitored by the use of data production control and data quality control techniques. Production control, scheduling, and workload forecasts as well as operation of various satellite data reduction lines, computers, data inspection, and data tape storage are other areas of responsibility.

In support of the above-mentioned sections, the Engineering Section develops and fabricates special electronic equipment, and improves or modifies the design of this equipment. Part of the duties involve maintenance procedures and acceptance testing of new or modified electronic equipment. The Engineering Section is also constantly striving to devise systems which are both expedient and computer-compatible in the reduction of satellite data.



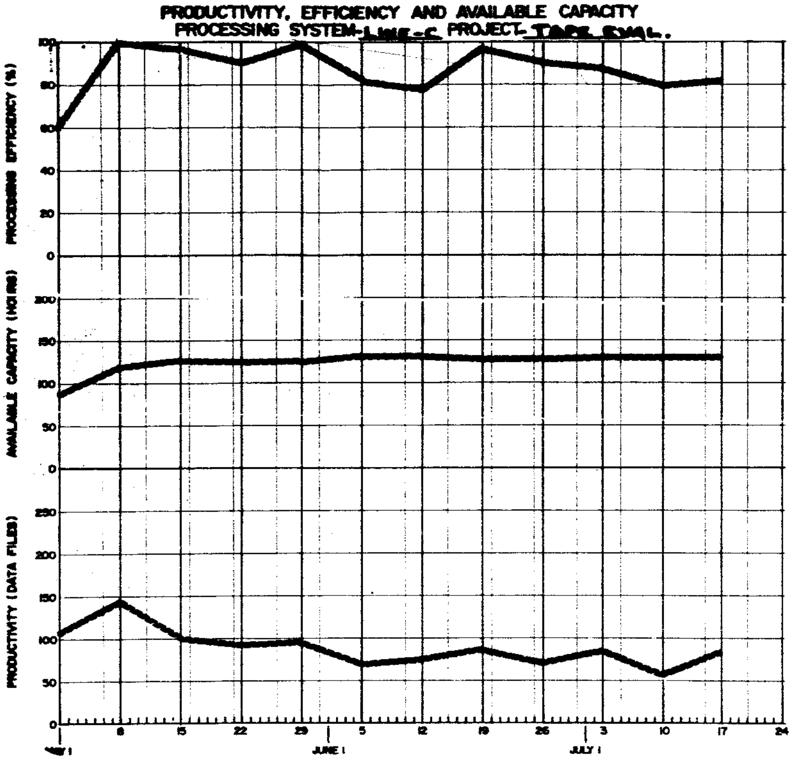
Artist's Conception of Data Processing Branch

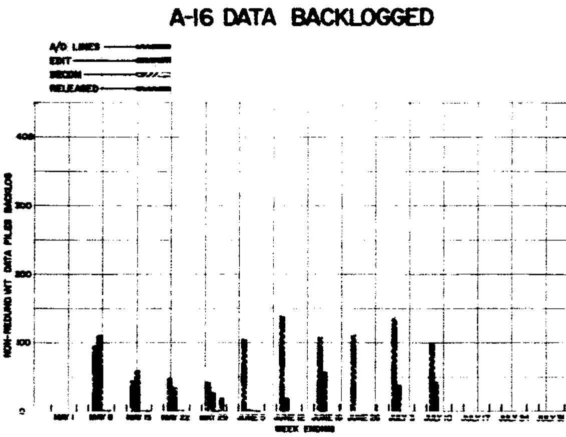


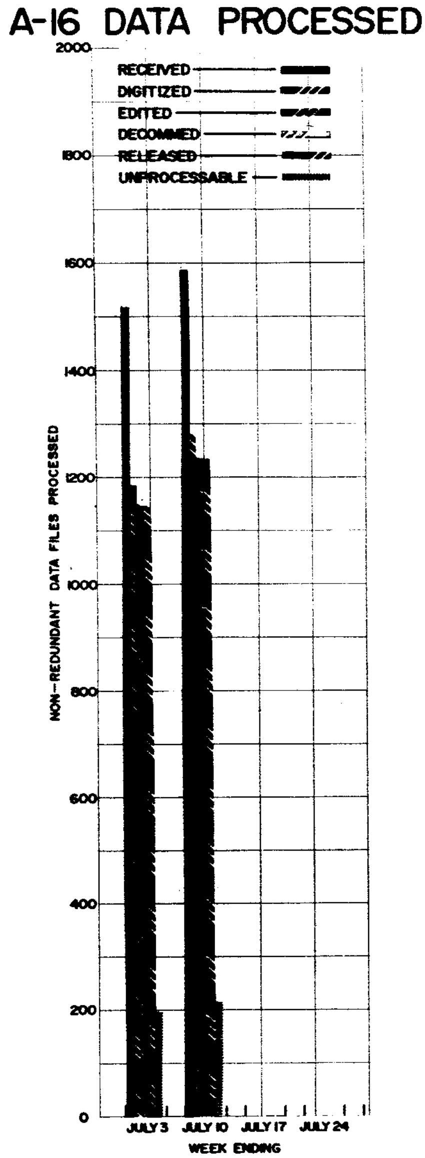
PRODUCTION CONTROL

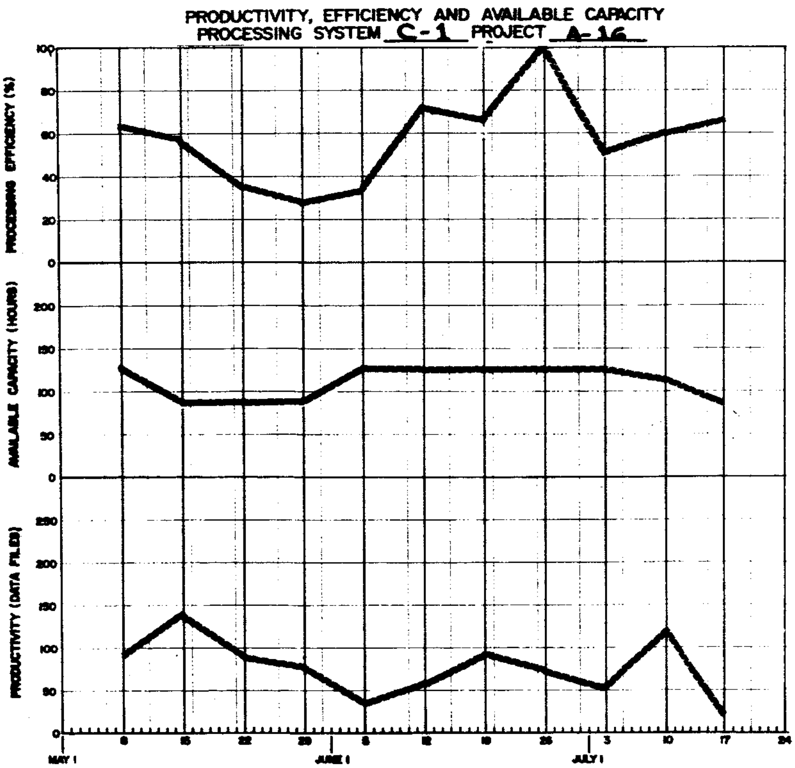
The purpose of the production control system is to keep management informed on the status of the data processing operation at all times. The system also provides management with the appropriate control of the operations. Significant objectives are as follows:

1. Reports on work being accomplished by each operational function
2. Reports on work backlogged by each operational function
3. Reports on unused capacity existing at each operational function
4. Reports on the productive efficiency at each operational function
5. Reports on the quality of the output scientific data released to experimenters
6. The ability of specifying the work to be accomplished by each operational function
7. The ability of specifying the required quality of the output scientific data released to experimenters

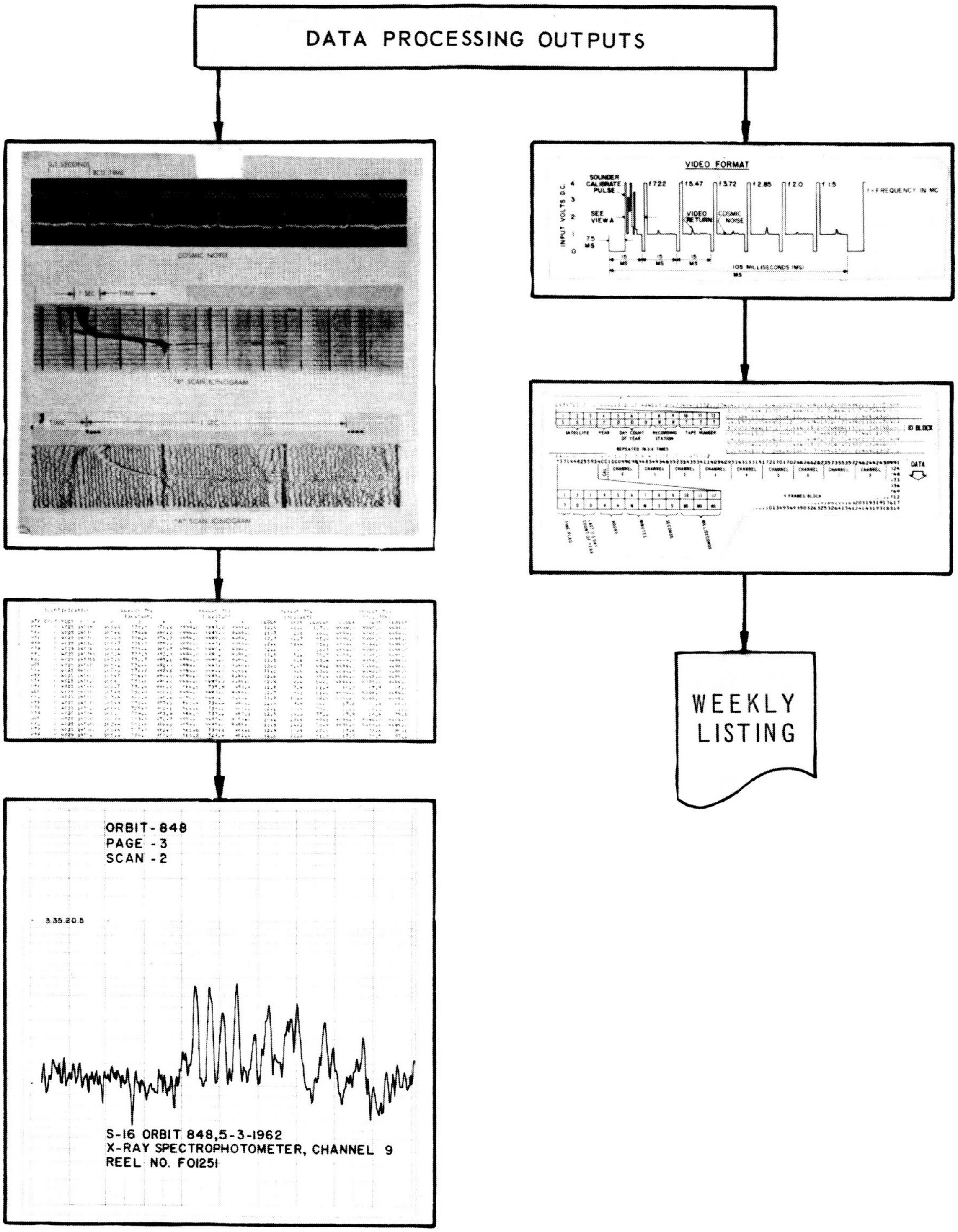








Charts for Recording Production Control



Typical Forms of Reduced and Processed Satellite Data for Scientific Analysis

EXPERIMENT COMPUTATION

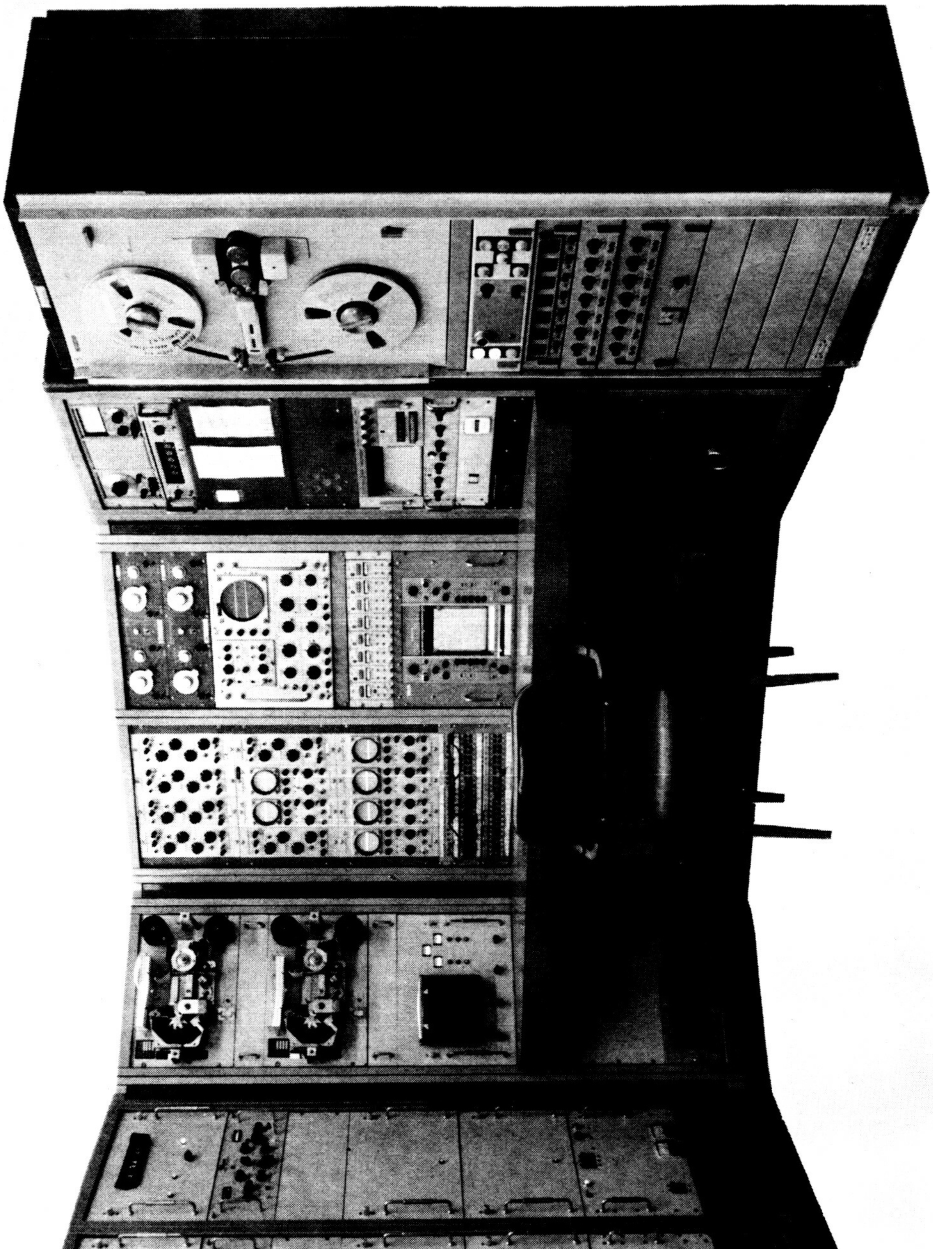
The process of reducing data from the form generated by the instruments used in experiments to a form indicating a useful experimental result gradually became more and more laborious and time consuming as the complexity and scope of the experiments increased. In many instances it was found that unless an inordinately large amount of effort and time was placed on the data reduction part of the experiment, the time lag between the performance of the experiment and the learning of results became a matter of years. To help solve this problem, the Data Processing Branch now has progressed to a point of near real-time data evaluation, reduction, and processing.

The technique of reducing and processing the data also requires specific knowledge of each experiment. The type, the environment, the system components, and the parameters of each experiment are pertinent to the processing of data. The Data Processing Branch has acquired knowledge of all past experiments in this regard and is continuing to acquire knowledge of each new experiment that is presented for data reduction and processing. An effort therefore is made to acquaint everyone working on a data reduction problem with all of its aspects, from the experiment in the spacecraft to final preparation for data analysis. As a result, the data processing staff is responsive to the needs of the experimenter.

In performing mathematical operations with information obtained by controlling or computing devices about the changes in the controlled or regulated physical values, the highest precision in performing such operations is obtained with the aid of digital computers. The Data Processing Branch provides a rapid and accurate processing of essential satellite data using state-of-the-art digital computers, signal processing lines, and special purpose equipment. The present facility is equipped and staffed to provide each experimenter with a reduced, accurate, and useful form of data as expediently as possible. The photograph to the left shows typical forms of satellite data reduced for scientific analysis.

QUALITY CONTROL

The personnel in quality control analyze the data processing procedures and establish the required quality control standards for each satellite project. During the various phases in the processing operations, the scientific data and time are inspected and compared with the standards. The prime objective of quality control is to assure correct processing of the data into the form specified by the experimenters.



Tape Evaluation System

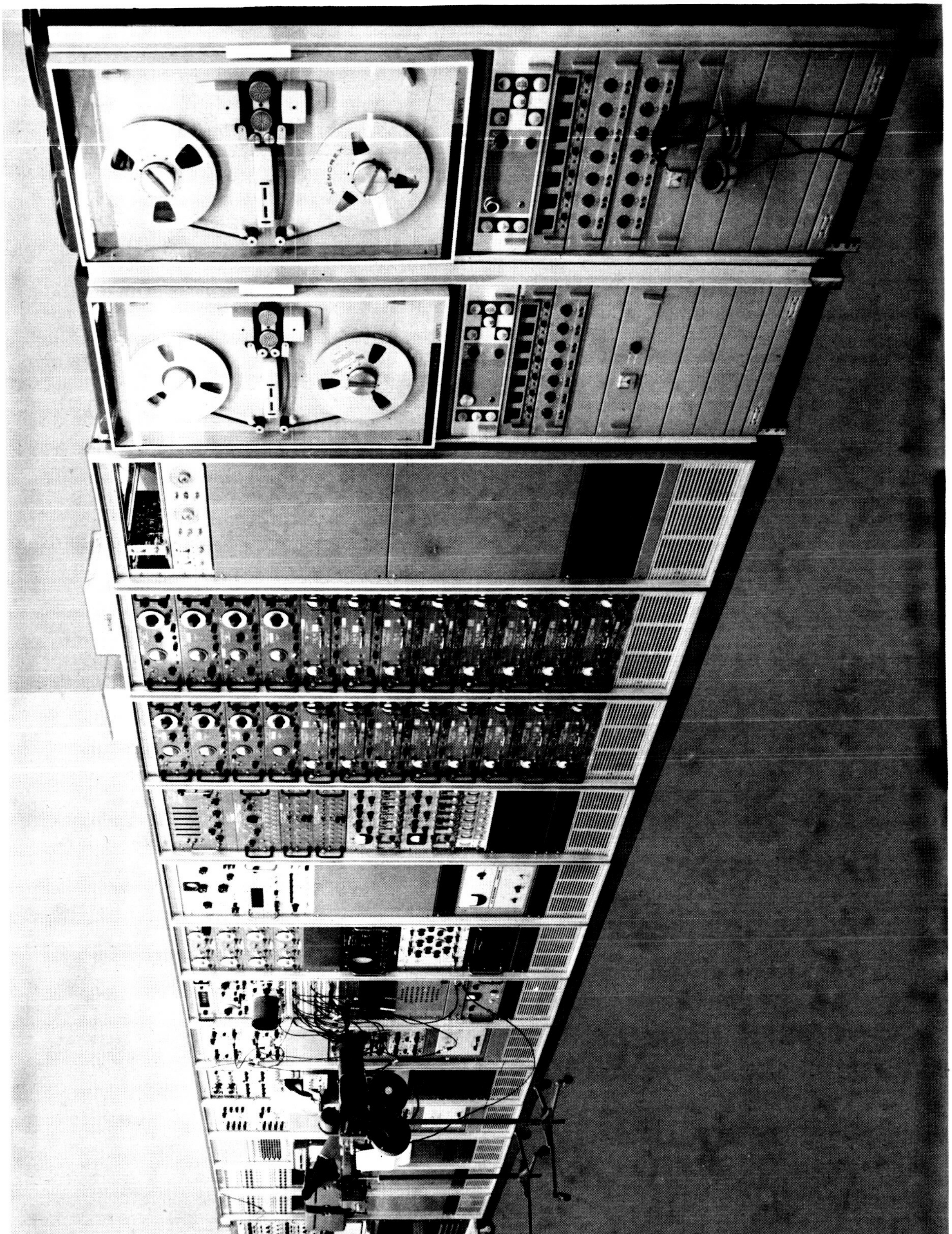
MAGNETIC TAPE EVALUATION

The Data Processing Branch has several tape evaluation units which on a sampling basis are equipped to monitor the incoming data magnetic tapes from the various NASA ground data acquisition stations. From past data processing experience, an operational flow scheme has been devised to evaluate, process, and reduce all incoming data accurately and efficiently. The first step of the data processing operational flow consists of analog tape evaluation. Further processing in the subsequent operational flow depends on the initial results.

A form entitled "Tape Evaluation Log," is used to record the quality of data on all analog tapes that are received from the NASA ground data acquisition stations. A check is made to be sure that assigned signals are recorded on the proper tracks. Also that the signals on the tracks are of proper frequency, amplitude, and/or modulation. The data are evaluated as being good, questionable, or unusable. The analog tape data quality is assessed as processable, limited, questionable, or useless.

Magnetic tape evaluation provides information whether or not respective ground stations are using the proper receiving and recording techniques for acquisition of the satellite data. (The Network Operations Branch of the Network Engineering and Operations Division is notified immediately of any gross anomalies detected.) A typical recording procedure is as follows: (1) record 2 complete passes on each reel. These passes shall be separated by approximately 60 seconds running time to simplify later processing at the Data Processing Branch; (2) record 2 minutes of low-speed (400 bits per second) data before sending the playback command. (More than 2 minutes is desirable, but the playback command shall not be delayed in an attempt to obtain so much low-speed data as to risk losing any of the 5 minutes of playback or the return of the low-speed signal.)

The functional operations of the tape evaluation system are centered about the following procedures. A patch panel hookup is used to evaluate PCM or PFM tapes. A high frequency discriminator obtains correct information from the AGC and FM data. The Visicorder presents photographic recordings of the time standard (WWV) and two time codes, binary decimal time and serial decimal time code. A dual channel dc amplifier recorder (a two-channel recording system) is designed for general purpose dc measurements and recordings. Used for both recording and reproducing (playback), a recorder-reproducer is also part of the tape evaluation system.

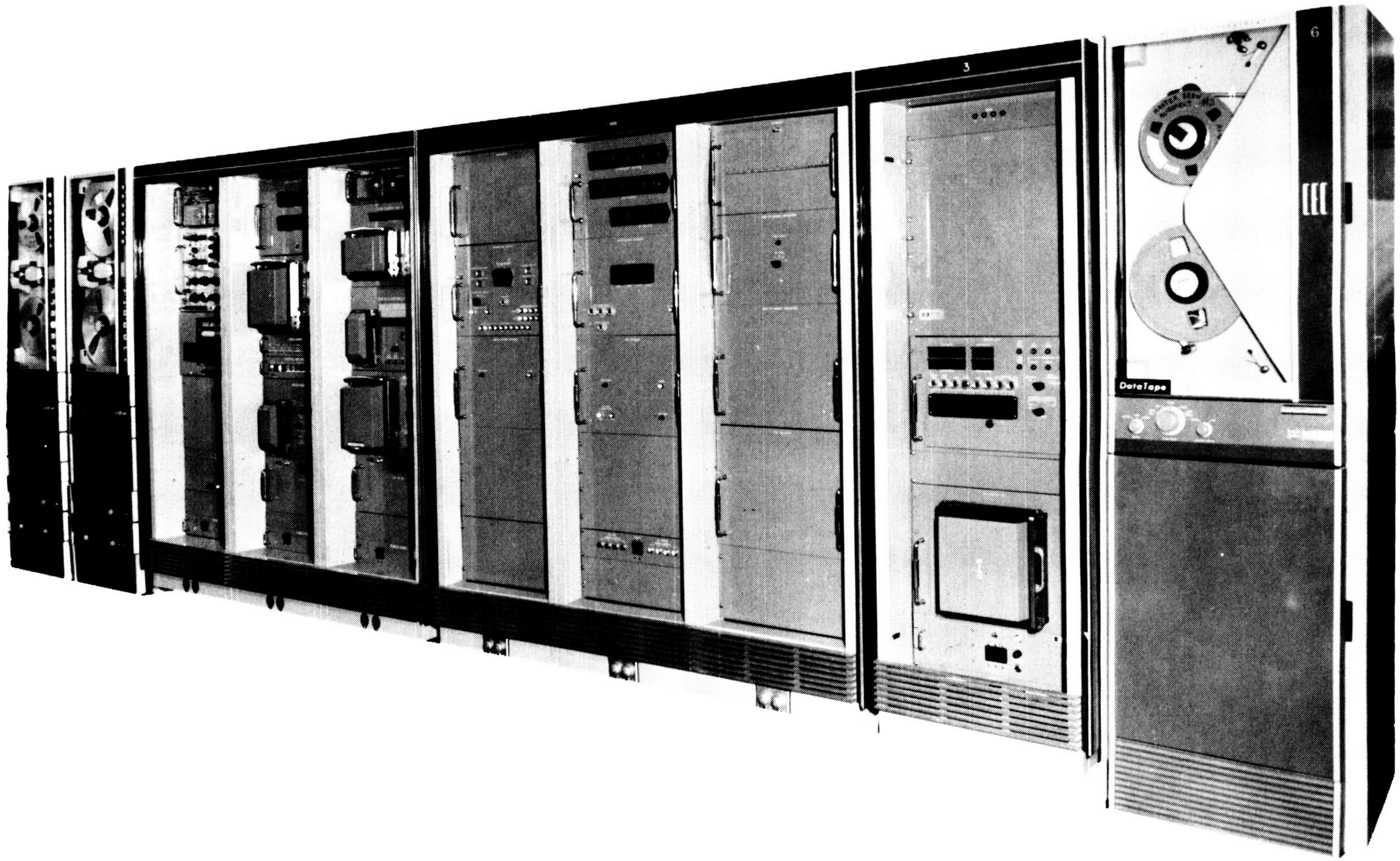


Analog Conversion Line

ANALOG-TO-DIGITAL CONVERSION LINE

Normal track assignments of an analog tape received from a data acquisition station for processing are as follows: Track No. 1 records a multiplex AGC and signal-conditioner clock signal from the summary amplifier, track No. 2 the Minitrack time-standard control track generator, track No. 3 the output of the signal conditioner, track No. 4 the Minitrack time standard (serial decimal 10 kc reference frequency), track No. 5 the output from the diversity combiner, track No. 6 the Minitrack time standard, frequency modulated, and track No. 7 the audio amplifier or WWV, voice, or commands. (The track assignments mentioned above and in the following paragraph are recorded on analog tape from the Orbiting Solar Observatory B-2.)

Analog tapes with the track assignments as mentioned above are converted into a digital format for digital computer processing on the analog-to-digital conversion line. The signal from a data track is transmitted into the pulse code modulation processor where the waveform is reconditioned. After bit synchronization is established in the bit synchronizer, search commences for the 16-bit frame synchronization word. After a 16-bit word conforming to the expected synchronization word is found, it must be verified by appearing five consecutive times in the proper location with no more than one bit error per synchronization pattern. The proper location within the frame is decided by starting the word counter assuming the first appearance of the synchronization word to be correct. If the 16-bit word is found at some location other than the expected one, the process is repeated using the most recently located 16-bit word as the starting point. Once frame synchronization is established, 3744-character buffer records are written. Both time codes (binary coded decimal and serial decimal, tracks 2 and 6 respectively) are decoded. A calibrated tracking oscillator is used to update the accumulator which in turn is compared periodically against both time standards. The input to this oscillator is a 10-kc reference frequency recorded on track No. 4. An elaborate system of flags is generated by the line which, if properly analyzed, indicates the quality of the time recorded on the buffer tape. (These flags are used in the quality control and edit program to facilitate the time computation.) The analog-to-digital processing line produces buffer tapes containing files in chronological order by station, each file representing the data collected during one pass of the satellite over that station.



Pulse Code Modulation Line for the Orbiting Geophysical Observatories

PULSE CODE MODULATION

The pulse code modulation line is designed to process any pulse code modulated telemetry data that uses split phase or non-return-to-zero coding. Spacecraft data that is recorded in serial binary code at the ground receiving stations are the inputs to the pulse code modulation processing line. The pulse code modulated signal as received from the spacecraft, recorded by the ground station, and reproduced by the pulse code modulation line tape recorders can be noisy, distorted, and degraded. To reconstruct its waveform, the signal is transmitted to the bit synchronizer unit where it is filtered, bit synchronized, and reconditioned for use by the search and lock unit.

The main purpose of the pulse code modulated data reduction system is to reduce the analog data received from the satellite into a format acceptable by an IBM 1401 or 7010, Univac 1107 or equivalent computer for complete decommutation and generation of experimenter's tapes. The above goal is accomplished by use of the data processer to: (1) present to the buffer the serial train of telemetry data in terms of digital words of proper length and location in the main frame, (2) supply the required commands to the buffer to sample the presented data in proper order, as well as sample time presented by the time decoder, (3) generate special buffer commands to properly begin and terminate data blocks, (4) check the frame synchronization code and bit errors, and flag the status thereof, and (5) generate special flags such as subcommutator word(s) location, signal mode, etc., to minimize the effort required in decommutating and further processing of experimenter's data.

The programming includes selection of word length, frame length, permissible frame synchronization bit errors, subcommutation frame length, number of frames to acquire frame synchronization, number of frames to flywheel, number of bad frames after which to revert to search mode, and setting up the frame and subcommutator frame synchronization recognizers for particular frame synchronization codes. In addition, patching is used to program the generation of buffer command signals in accordance with the desired buffer tape format and buffer requirements to produce buffer tapes. Because of the variation of telemetry formats used, the data processor must be programmed for each specific format associated with a particular spacecraft. Programming tables describe the functions to be selected and the patch panel pins to be interconnected to accomplish the desired programming.

Pulse Frequency Modulation Line

PULSE FREQUENCY MODULATION

The computer format control buffer of the pulse frequency modulation data reduction system accepts parallel entry of digital data, stores the data until a preset volume of the memory is filled, and then reads the data onto low density magnetic tape in a computer compatible format. The dual time decoder is a separate unit within the computer format control unit which accepts either of two time codes from the analog tape and translates the time codes to a form compatible for entry into the buffer memory between data samples as commanded.

The primary analog tape signal treated in the system is the demodulated pulse frequency receiver signal that is first applied to the input of one of three 128-tooth comb filters which quantize all frequencies within the data band, into 100-cycle increments; or, when processing at speeds greater than normal, into increments greater than 100 cycles by a factor proportional to the change in the processing rate. The outputs of each comb filter are 128 individual channels which are brought into a programmable patch-panel where the proper band of 128 channels commensurate with the processing speed is patched onto the system.

To establish system synchronization with the incoming signal, the summed detected response of the individual comb filters is used as a frequency and phase source with which burst-by-burst signal synchronization can be made. Synchronization is accomplished automatically by means of a servo technique.

Through frame and channel decommutation, those channels allocated in the satellite format as being analog and those as being digital are sorted. Then, through command pulse and strobe pulse generation, the appropriate converted comb filter data for each channel are read into the computer format control buffer through level matching circuitry.

Besides processing the pulse frequency modulated signal into digital form, the system performs signal conditioning on various other analog tape signals. The binary coded decimal time signal is stored within the system before being applied to the dual time decoder; the time signal is present at the tape deck reproduce output as one component of a mixed signal where the other signal is a servo control signal for the tape deck. Extraction of the pure binary coded decimal time signal from this mixed signal is performed within the system.

Rubidium Magnetometer Data Processing Line

RUBIDIUM VAPOR MAGNETOMETER DATA PROCESSING

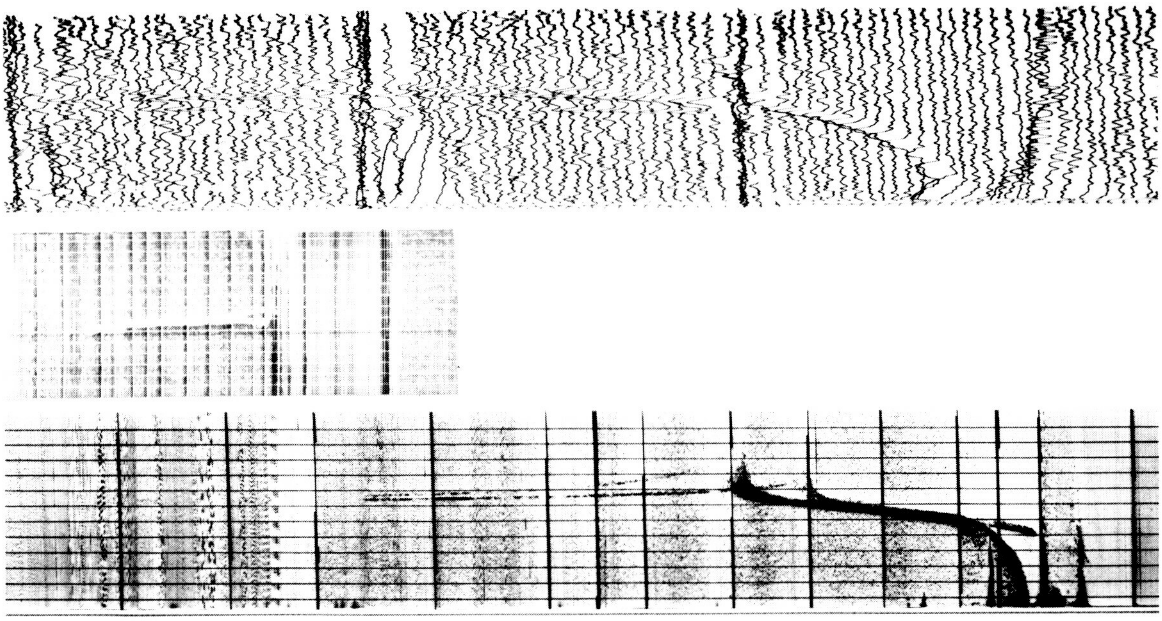
A special processor is designed for the Orbiting Geophysical Observatory magnetometer data. The recorded telemetry signal, the ground station time signal, and the station standard frequency are obtained from the reproduce analog tape deck. The station standard frequency is either 1 kc, 10 kc, or 100 kc. The tape deck can be made to reproduce the signals at either 1, 2, 4, 8, or 16 times the recorded speed.

When processing the direct magnetometer signal (channel No. 1), the "A" phase lock tracking filter is locked to the noisy magnetometer telemetry signal, and the output of the tracking filter is a relatively clean signal which is phase locked to the magnetometer signal. The frequency of this clean signal is measured in the counter unit. The frequency is determined by measuring the number of cycles of the signal in a period of time, which can be selected by means of a set of switches on the control panel. The range of selection is 1 millisecond to 9.999 seconds. The standard frequency, extracted from the analog tape signal by a time decoder, is multiplied to 5 Mc to be used for the timing in the frequency measuring unit. By using this recorded standard frequency in this manner, compensation is obtained for effects of tape recorded wow and flutter. Specifically, a counter is started counting cycles of the multiplied standard frequency at a zero crossing of the tracking filter reproduction of the magnetometer signal. The counter is turned off at the second integral signal cycle after the preset time is reached. The number of signal cycles in this period is also counted. The ratio of these two counts gives the frequency of the magnetometer signal. At the shortest time period, the resolution is limited to one cycle of the 5 Mc timing waveform, or 1 part in 5000. At the longest period, the resolution is approximately 1 part in 5×10^7.

When processing the channel No. 2 signal consisting of the subcarrier modulated with the magnetometer signal, the subcarrier is demodulated in the phase-locked PM detector. The resulting noisy low frequency magnetometer signal is fed into the "B" phase lock tracking filter. The output of the tracking filter is sent to the frequency measuring counters through switch position B. The magnetometer frequency data from the counter registers are put into the buffer where they are merged with ground station time from the time decoder and written on a digital tape in computer format.

RECORDING AND PRESENTING DATA ON STRIP CHARTS AND MICROFILM

Strip Chart records allow selection of data and fast retrieval per data point with advantages of: (1) Examination of trends, (2) determination of correlation between different variables, and (3) extraction of quantitative decision data for exacting calculations. Microfilming used as a storage medium, permits display of data for sight analysis, and is compatible **with automated processing** techniques.



Strip Chart Record and Microfilm

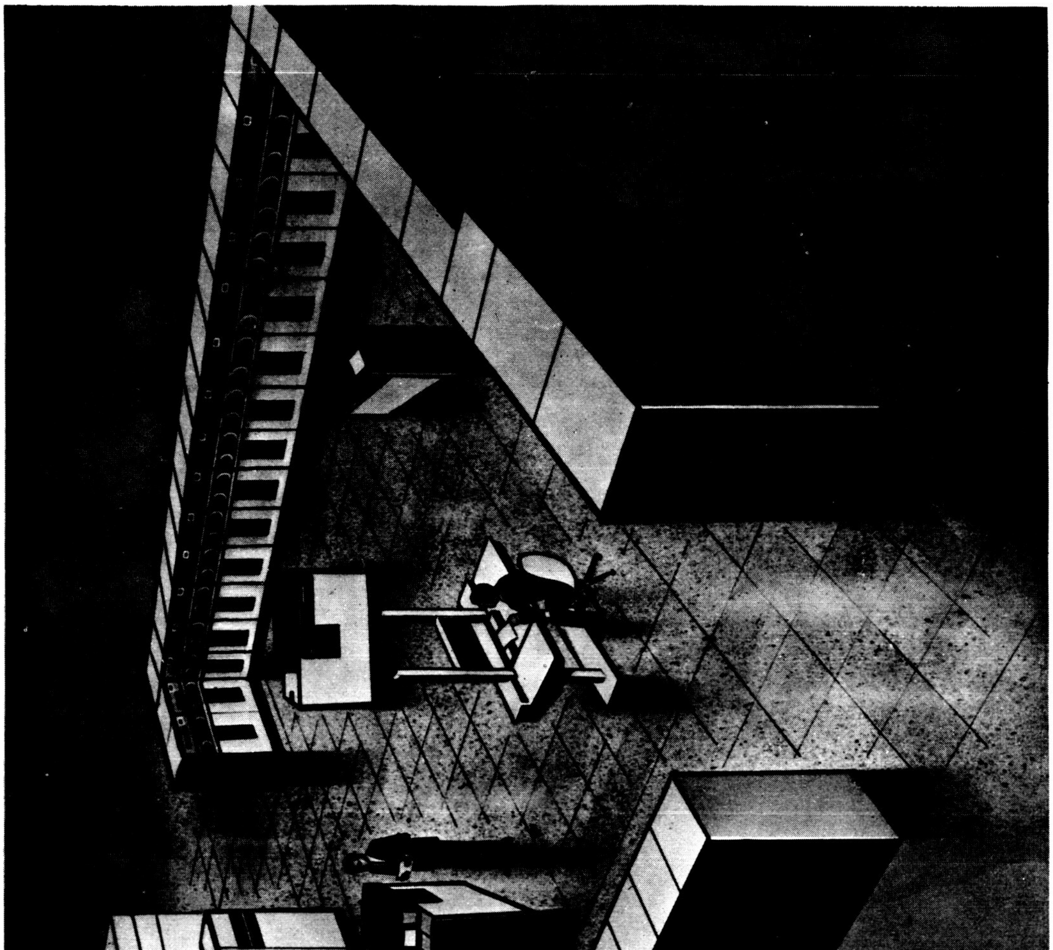
SOFTWARE

To gain the full benefits from the Data Processing Branch's computing systems are various programming aids such as assembly programs, compilers, program generators, utility routines, and subroutines. Although an extensive software library is available for the programmers and analysts, there are occasions when appropriate software for certain special telemetry data reduction requirements must be developed new or modified from existing programs. Presented in the following paragraphs are some of the Data Processing Branch's programming aids, mainly computer oriented.

A program, or set of instructions, telling a computer what steps must be performed to solve a problem should ultimately be given to the computer in its own language because every computing system is designed to respond to a special code. The FORTRAN system has been designed to enable the programmer to state the steps of a procedure to be carried out by the computer and automatically obtain an efficient machine language program. Following are some of the advanced FORTRAN programs and subroutines used for data processing: (1) Polynomial curve fitting routine using the least squares technique, (2) Macillwain's B and L coordinate transformation code, (3) Attitude determination programming method for the Orbiting Geophysical Observatories, (4) Subroutines (Sleuth and FORTRAN) to compute and store required values. A typical Sleuth subroutine is IBMNEG, a self-inverse routine – a dual application restores a number to its original form. Given a count and a starting address this subroutine converts a record of data from Univac negative numbers to IBM negative numbers. A typical FORTRAN subroutine is subroutine SOLVE I. Given the position vector of the satellite, the velocity vector of the satellite, and the solar vector from satellite to sun, SOLVE I computes the ideal coordinates of the OPEP in reference to the celestial coordinates for the OGO orbit tape main program.

SLEUTH II is an assembly system designed to process symbolic coding into machine language. The system permits further use of procedural statements and mathematical expressions normally associated only with compiler languages.

The S-C 4020 symbolic programming consists, presently, of 30 compiler macroforms designed to facilitate the production of a plot on the microfilm recorder. The commands of the symbolic language program operate on data transmitted to the computer by means of a binary coded decimal input tape. To avoid the laborious procedure of printing data out when generated by another program and converting it to a form acceptable to the compiler, subroutines corresponding to the compiler macroforms accomplish the same objective. The S-C 4020 plots on a grid of 1024 horizontal by 1024 vertical points. There are therefore over 1 million addressable positions. The center of any character can be plotted at any of these positions.



1107 Computer System

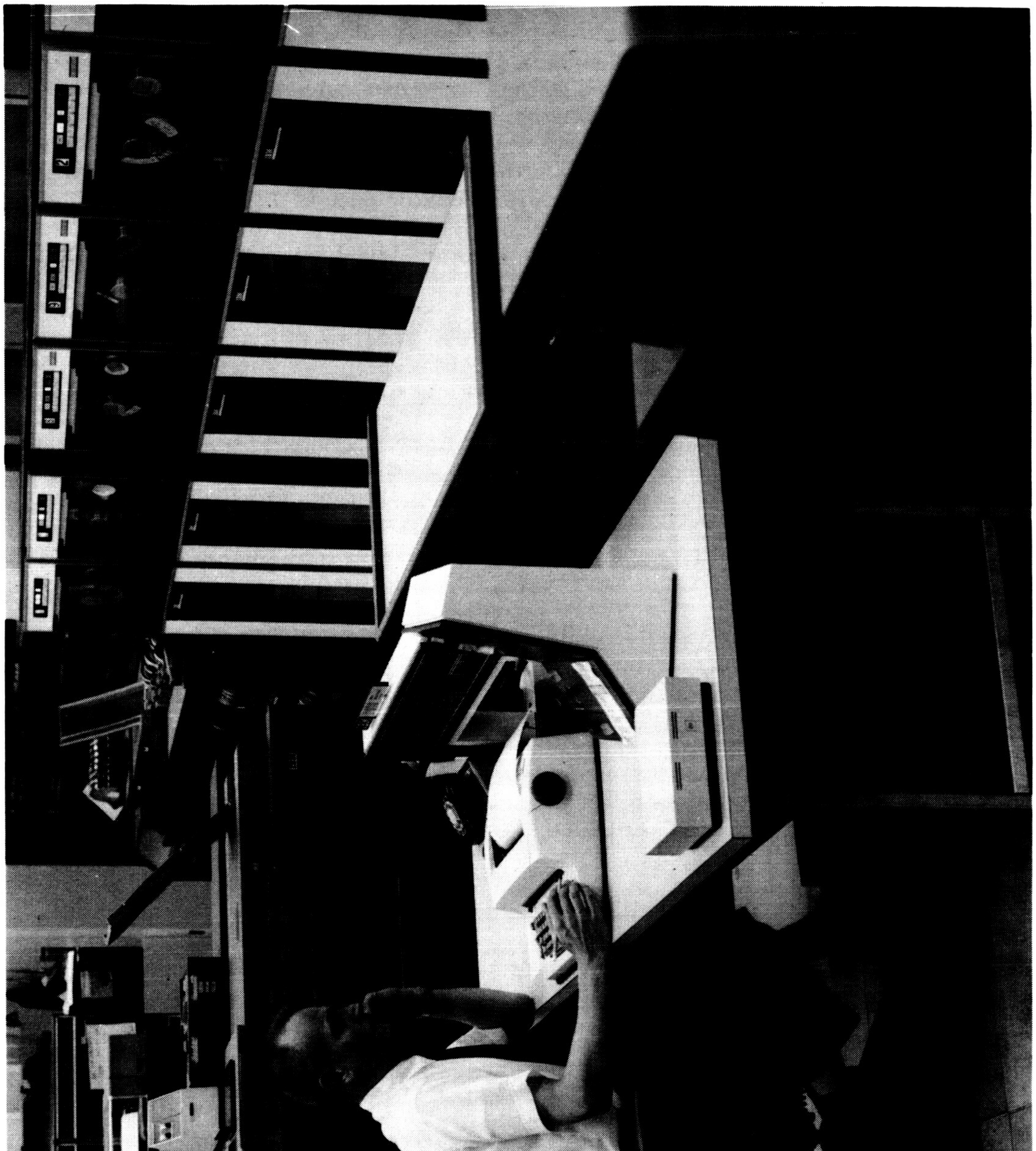
DATA PROCESSING 1107 COMPUTER

The following excerpts of the Orbiting Geophysical Observatories data reduction plan illustrate the significance of the 1107 computing system. During the operation of Phase II OGO data reduction plan, the 1107 computer checks data quality as well as performing data decommutation. The computer ascertains whether the data quality has deteriorated in the satellite or ground station telemetry links or in the Phase I operation. Multiple labels in a file, record length, and frame length are checked to verify the buffer tape format. (A buffer tape label contains the satellite number, station number, date of reception at ground station, and station tape number.) Additional checks involve the form of the data; the synchronization word is checked for bit errors, the subcommutator count is checked for proper sequencing, and data words are checked to ensure that the first three bits of the 12-bit field are zero. A representative sampling of the analog channels is checked to ensure that the first bit of the 9-bit field is zero. Certain channels in the frame which are kept at a nearly constant level are also checked.

The following decommutation routine is the next step of the Phase II operation and is also processed by the 1107 computer. A data matrix is formed in which i denotes the column and j denotes the row. Each row consists of three flag elements, three corrected universal time elements derived from spacecraft time, one day count of the year element, and the 128 data words from the main frame (i = 8 to i = 135). The first row includes subcommutator words one. The j in the matrix denotes a subcommutator word number. A value (i, j) designates a word in the telemetry format; a row represents a main commutator cycle or frame; and the entire matrix represents a subcommutator sequence.

Following the formation of each matrix in the computer memory, after receipt of data for each complete sequence, the decommutation process extracts selected portions from a number of data tapes equal to the number of experiments on the spacecraft, and the elements which the experimenter has selected from this matrix.

Generation of the orbit-attitude tapes on the 1107 computer occurs in the Phase III processing. An orbit tape and an aspect housekeeping tape are used as inputs. The orbit-attitude tapes contain the orbit and satellite attitude information in binary floating point format, with 36 bits to a field. A label record, at the beginning of each tape file, contains the time covered, the time interval between sets (normally 1 minute), the day of the year at the beginning of the present orbit, the orbit number, the orbital elements, the sun vector data, the time of the noon-turn, the times of entering and leaving eclipse, and other data. For each minute, the following information is listed: time in milliseconds of the day; position and velocity in celestial inertial coordinates; geographic coordinates of subsatellite point; height above the grid; ideal and actual main body, solar array and OPEP orientation; and time anomaly.



7010 Computer System

DATA PROCESSING 7010 COMPUTER

The 7010 data processing system has a core storage of 60,000 characters, up to two data channels with buffered input-output operations, magnetic tape processing at eight data rates, and a large capacity dish storage providing a large volume random access storage for in-line data processing to frequently used tables, to programmed subroutines, or to other data. Following is an example of one of the Data Processing Branch's programs designed for use on the 7010 data processing system.

The purpose of the Energetic Particles Explorer-D data reduction system is to reduce satellite data for experimenters. The original analog data is digitized, then edited and decommutated. The basic function of the Energetic Particles Explorer-D reduction system is correcting the satellite data time and decommutating converted satellite data.

The Energetic Particles Explorer-D processing system consists of four phases, each of which is a separate computer run. A phase run consists of processing all files for a sequence of four orbits. The smallest unit of processing is a file (the contents of one analog tape). The four phases perform the following functions:

Phase I reads in digitized buffer tapes, extracts and checks all identification information and writes this on the data extract and analysis tape. Quasi-clock steps are also determined, and values and times of occurrence are written on the data extract and analysis tape. The full contents of the buffer tape is written on a converted data tape after checking for proper end-of-file placement and converting data to the value range 100 to 900, if necessary.

Phase II consists of reading in one data extract and analysis tape and writing a plot tape of all quasi-clock points. Residues and differences are tabulated for a printout. Time and identification correction input cards are accepted and then a catalog tape is written with these correction values incorporated.

Phase III consists of editing and correcting the converted data tapes by referring to the identification and time correction presented by the catalog tape. Frames are flagged with quality indicators. A tape is provided for calculations of sun angle and spin rates. Also produced as output are master data tapes with quality control readings for decommutation. Master tapes are checked to ensure correct times.

Phase IV consists of checking the master data tape to ensure correct input. On each experiment output tape, a strip identification and output is labeled as a header. Then, data is decommutated, experimental channels and quasi-clock readings are combined, and the individual output is produced in block form.

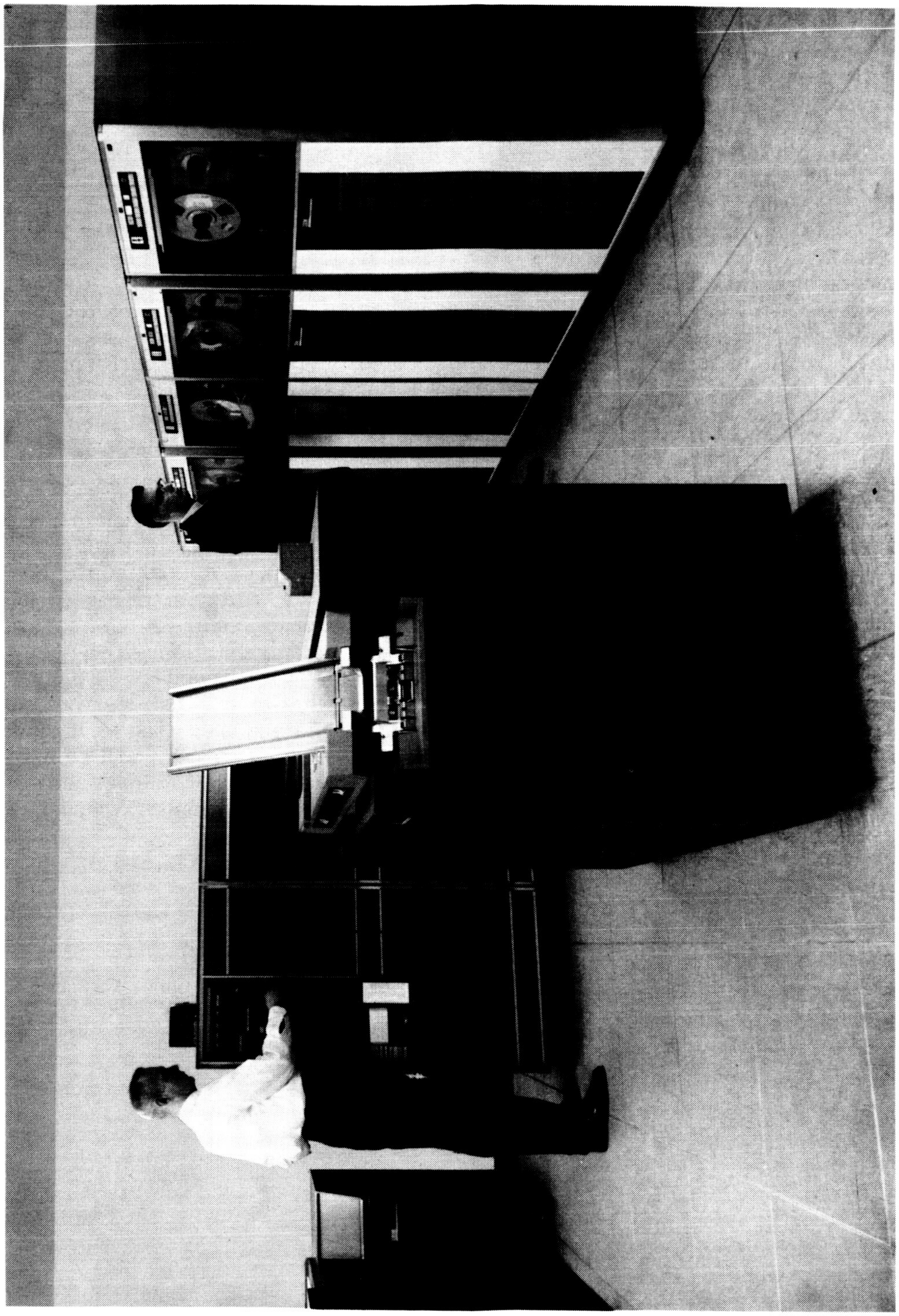
3200 Computer System

DATA PROCESSING 3200 COMPUTER

The 3200 computer system is a medium-size computer constructed in modular form. The storage module can contain 16,384 words, or 65,536 characters of magnetic core storage. Each word or character is parity checked. The basic processor operates in a 6-, 24-, or 48-bit mode.

Following is the significance of the 3200 computer system. The processing of the Orbiting Astronomical Observatory data is complex because of the various bit rates, word lengths, and frame lengths in the telemetry data format. Consequently, the Data Processing Branch is planning to use the 3200 computer system as part of the STARS II system for telemetry data processing of the Orbiting Astronomical Observatories. The Orbiting Astronomical Observatories processing system will perform the following operations on the telemetry data and/or time data received from the recording and tracking stations. Bit synchronization will be established and the serial time code will be converted to a parallel time code. Frame synchronization will be searched and checked. The data will be reformatted by use of telemetry data frames. A quality check will be performed. The binary coded decimal time code will be converted to binary. And, output digital tapes will be made compatible for further processing on a large-scale digital computer. The following operations will be performed on the spacecraft data under control of the overall data processing program.

Quality control checks, mainly, will be concerned with format consistencies, overall data manipulations, data retrieval qualities, etc. Based upon a sufficient set of redundant data groups, voting and data flags will be used as marks of comparisons. Based upon the results of the voting subroutine, a compact data group will be constructed and used throughout the master data processing program for attitude computations, subsystem analysis, etc. In regard to the attitude subroutine, spacecraft orientation will be computed for the ideal and actual case. A formatted status tape will be produced from a status analysis of all narrow-band and delayed mode status data. Statistical analysis routines will yield data to be used for comparing station performances and also used as input for off-line analysis programs. History graphs of spacecraft status functions will be produced for interpretation and analysis. From a plot tape, direct digital pictures will be produced. Experimenter data tapes, a quick-look listing, and experimenter account cards will also be produced.



1401 Computer System

DATA PROCESSING 1401 COMPUTER

The 1401 system's processing unit handles variable length data and instructions having a storage capacity of 8000 alphanumeric characters. The system is well suited to edit and decommutate data telemetered at low frequency transmission rates, as well as rocket probe data. Accounting, program reports, management reports, satellite tape production, corrections, and dubbing of tapes are some of the outputs.

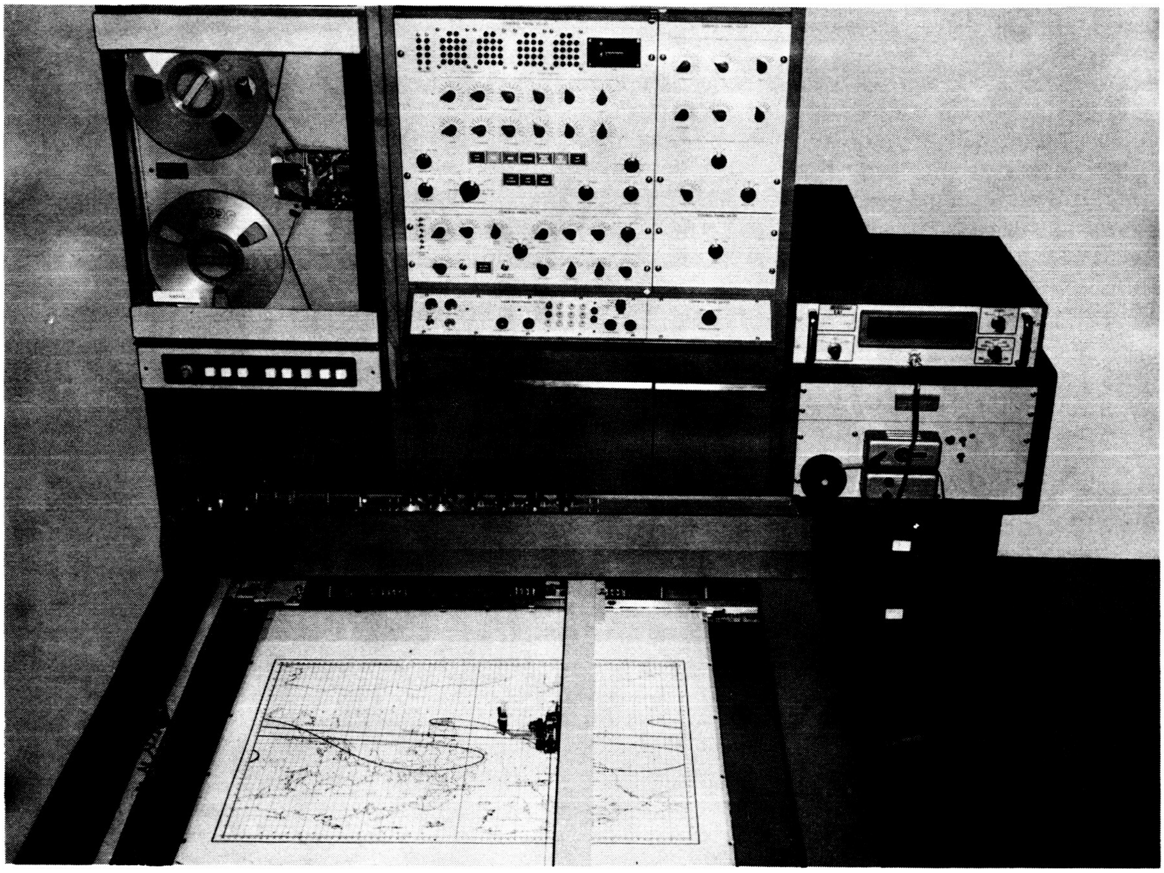
The analog and digital library accounting systems updates are done weekly. The program updates, correct time, and dates of the files received are shipped to the experimenters, as well as the number of passes, orbits, recorded dates, start and stop times of each file.

The 1401 computer experience includes processing of scientific data from the Ariel I satellite. Frequency bursts of both low- and high-speed data were digitized, computer edited, and quality checked. Intervals of time between frames were checked. If the time interval did not lie within a certain tolerance, the frame was denoted by an asterisk in place of the period which indicated end of frame. When a bad time interval was found, the start and end time of the interval along with the time difference in milliseconds was printed. Each data character was checked for legality. Each illegal character was replaced with a dash, except for three plus characters which indicated the synchronization pulse in low speed data. A data point was considered bad if one or more of its characters was illegal. A count of all bad data points was retained. After each group of data was processed, a final printout contained the following information. The identification label of the group, the start and end time of the group's data, the total time of the group in milliseconds, the amount of time lost in the group in milliseconds, the percentage of total time less time lost divided by total time, the number of bad data points in the group, the number of frames processed in the group, the type of data processed, and the tolerance used for determining correct frame time intervals.

SPECIALIZED EQUIPMENT

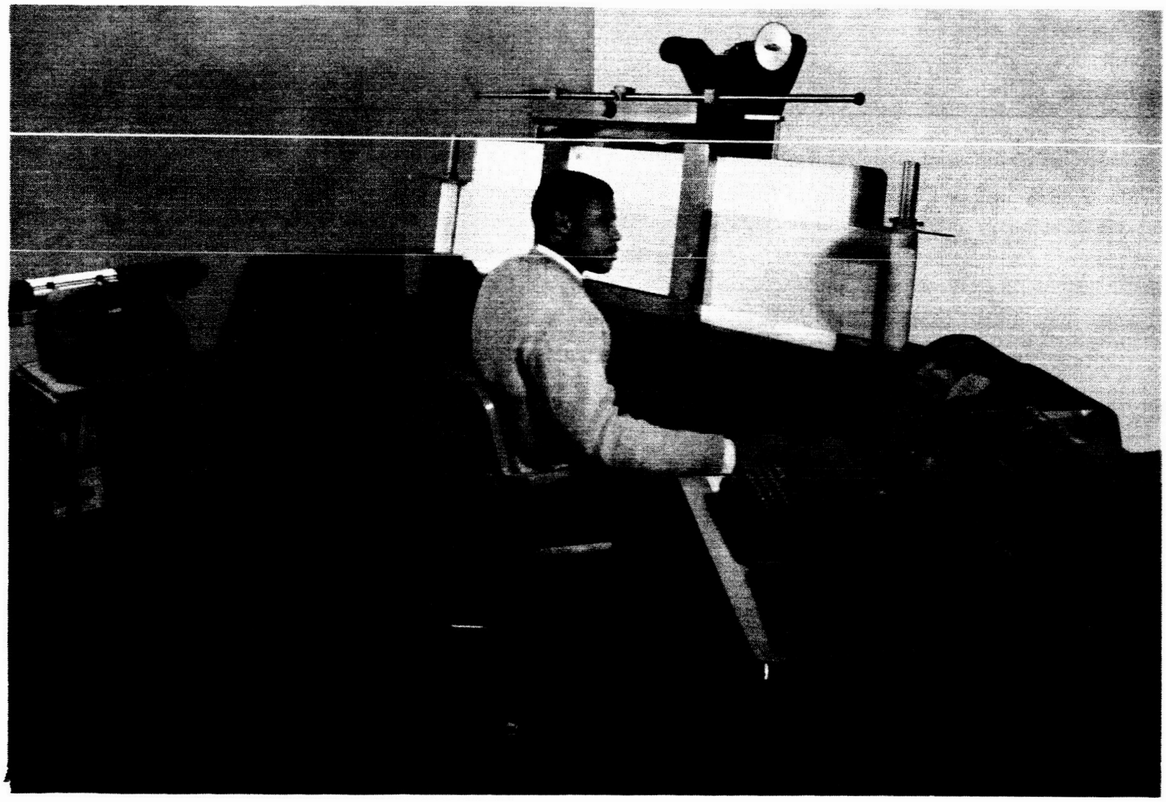
The X-Y plotter, the analog data reduction system, and the computer recorder, are some of the Data Processing Branch's special-purpose equipment. A brief functional description of each system is presented on the following pages along with a photograph of the equipment.

X-Y PLOTTER



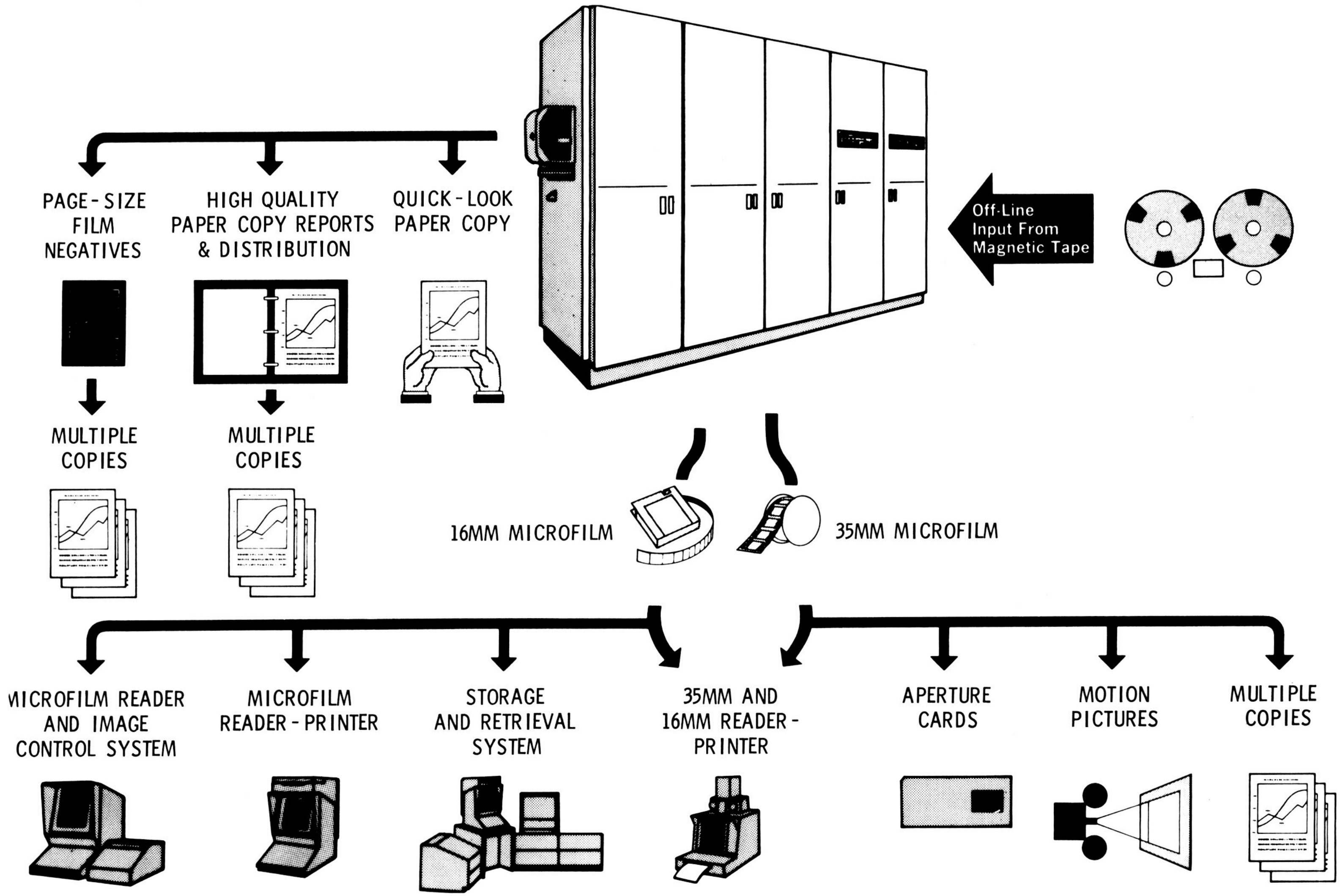
The X-Y plotter is capable of plotting points, symbols, or lines, or any combination thereof and accepts data input from either magnetic tapes written in binary coded decimal form, IBM cards, or from punched paper tape. When there is a frequent sampling of data points, the plotter can be used to reject data rather than connect the points. A card or tape input can provide a number of commands which can be selected automatically to provide up to 48 alpha-numeric characters, origin offset scale selection, or automatic switching between lines, drawings, or symbol plotting.

ANALOG DATA REDUCTION SYSTEM



The analog data reduction system is a general purpose oscillogram reading system for rapidly digitizing, tabulating, and displaying information on strip charts. A standard typewriter is normally used to record the system output. Other output mediums are available such as an adding machine with punched paper tape output, a keypunch, or a flexowriter.

The data processing plans of the advanced observatories, sounding rockets, and other satellites specify data outputs in various forms. Outputs in the form of strip charts at various phases of data reduction are frequently specified. After the analog tape data is converted to a strip chart record on the Data Processing Branch's analog conversion line, further reduction is accomplished either manually for small selected portions of strip chart data or with an automatic system such as the analog data reduction system for volume amounts of strip chart data. Typically, the analog data reduction system performs time readings and level readings on strip charts containing data from sounding rockets; measures time differences in pulses from data on strip charts as from the Relay satellites; and performs the same functions on inogram readings from data recorded from satellites such as the Swept Frequency Topside Sounder.



4020 Computer Recorder

COMPUTER RECORDER

The 4020 computer recorder is an electronic system capable of accepting digital magnetic tape signals and converting binary or binary coded decimal codes into combinations of alphanumeric printing, curve plotting, and line drawings. Recording the information on both microfilm and photorecording paper, the system translates coded data into complex annotated graphs and drawings. (The outputs are to the left.) The heart of the system is a charactron shaped beam tube. Basic units of the system include a typewriter simulator, vector generator, variable stop point axis generator, forms projector, rotatable tube mount, programmable expanded image, and a recording camera.

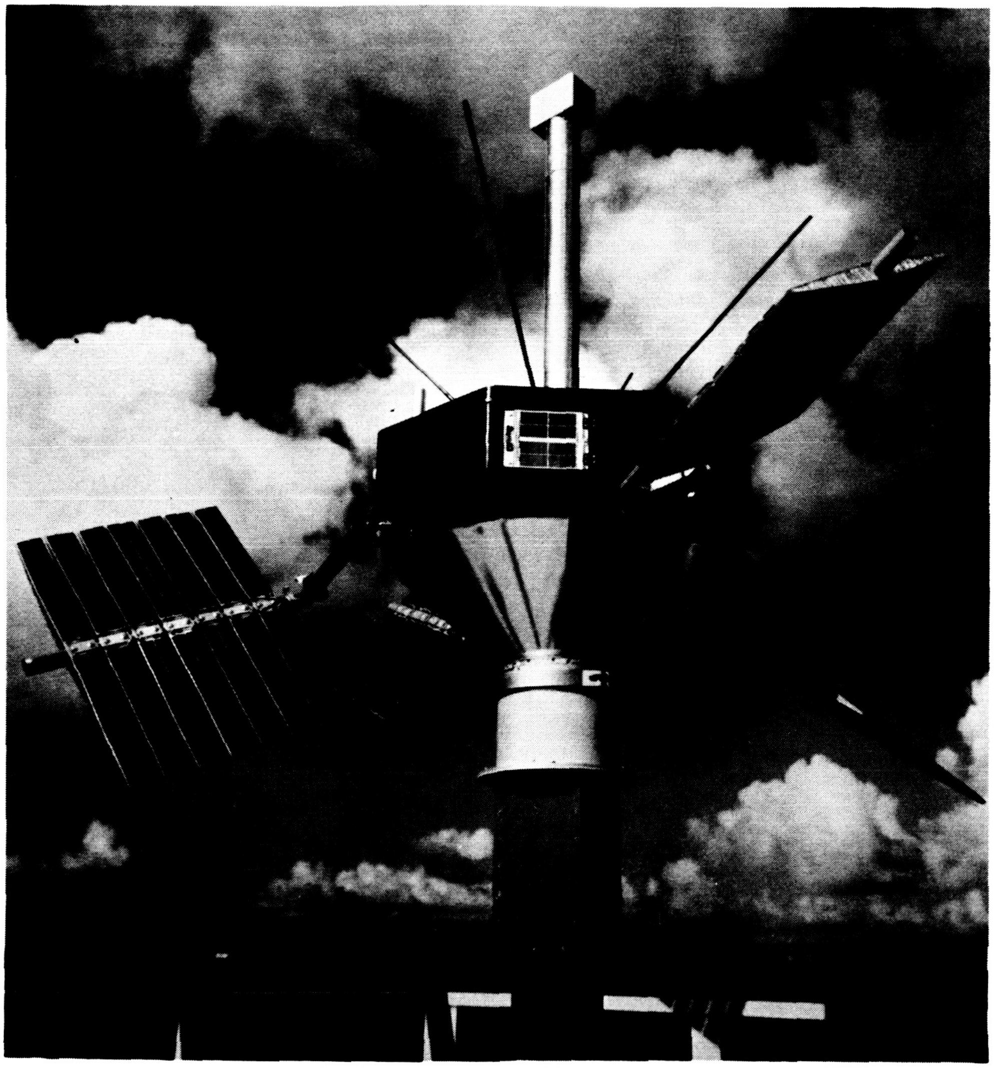
The 4020 computer recorder uses a charactron shaped beam tube as a generator for characters, lines, or curves. The heart of the tube is a stencil-like matrix, a thin disc with alphanumeric and symbolic characters etched through it. The matrix is placed within the neck of the tube, in front of an electron gun. The stream of electrons emitted from the gun is extended through the matrix, cutting the desired character from the beam. When the shaped beam impinges on the phosphor-coated face of the tube, the character is reproduced.

The 4020 computer symbolic programming consists of 30 macroforms designed to facilitate the production of a plot on the microfilm recorder. These macroforms and related information are punched on cards which are read onto magnetic tape to become input to a digital computer.

SCIENTIFIC SATELLITE DATA PROCESSING REDUCTION EXPERIENCE

Scientific satellites usually have special data processing requirements. The Data Processing Branch provides data processing services, therefore, some of the prior and current experience concerning data processing of specific satellites is discussed here.

EXPLORER XII



Explorer XII

The Explorer XII, first of the Energetic Particles Satellites, was launched to investigate solar wind, interplanetary magnetic fields, distant portions of the earth's magnetic field, energetic particles in interplanetary space and in the Van Allen belts. The satellite transmitted 2568 hours of real-time data which was reduced and analyzed to provide significant geophysical data on radiation and magnetic fields.

EXPLORER XIV

The primary objective of this project was to describe the trapped corpuscular radiation, solar particles, cosmic radiation, and the solar winds, and to correlate the particle phenomena with the magnetic field observations.

Upon arrival at the Data Processing Branch, a representative sample of the magnetic tapes from each receiving station underwent a preliminary evaluation and quality check. The evaluation and quality check determined that the ground station was functioning properly, and the tapes were of a quality good enough for further processing. The data on the magnetic tapes were then converted from an analog to a digital form. The raw data from these tapes were merged with coded time and sensor data onto buffer tapes. The buffer tapes were then processed on a small-scale computer which edited and formatted the information into edit tapes. Further processing was accomplished on large scale computers which formatted the experimental data into a form designated by the experimenters for final analysis.

Explorer XIV

ATMOSPHERIC EXPLORER

The Explorer XVII was designed to make direct measurements of atmospheric pressures, densities, temperatures, composition of neutral particles, and electron and ion temperatures and densities. The satellite marks the first use in Goddard satellites of the more precise pulse-coded modulation telemetry system. Earlier satellites used the FM/FM telemetry system. The data from this satellite confirmed that the earth is surrounded by a belt of neutral helium at an altitude of from 150 to 600 miles.

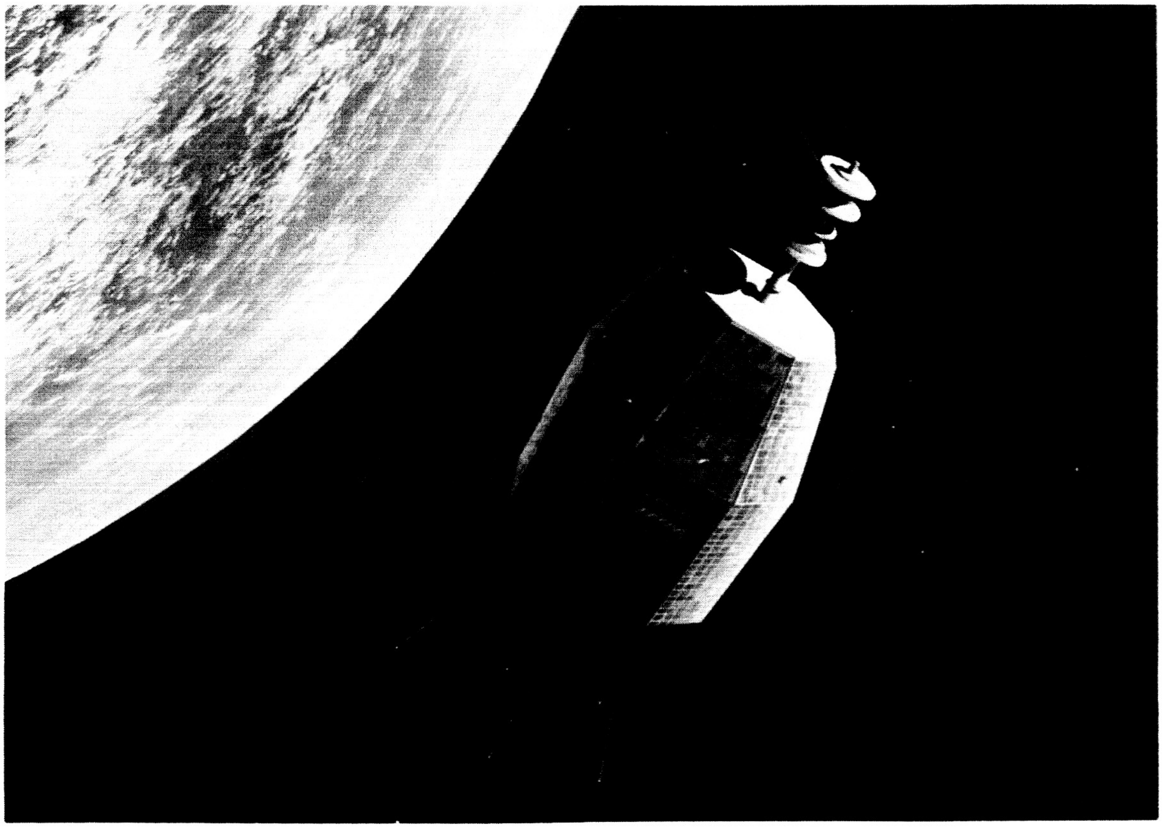
In this case, the essential processing operation was the conversion of the analog signals into digital forms with a buffer tape as an output. The buffer tape was processed and in turn yielded as outputs edit error lists, formatted tapes, and documentation cards. The formatted tape along with the orbit tape was then further processed on computers to yield (upon experimenters' request) an intermediate tape from an experiment analysis program, housekeeping reports, and a listing of calibrated raw data which also went to the experimenters.

Explorer XVII

RELAY SATELLITE

The primary objective of the RELAY series is investigation of the technology involved in using an active repeater satellite for wideband communications. The secondary objectives are to determine the effect of radiation on electronic components through measurement of damage incurred by semiconductor devices protected by various types of shielding, and to monitor particle radiation with respect to type or particle, intensity, and direction.

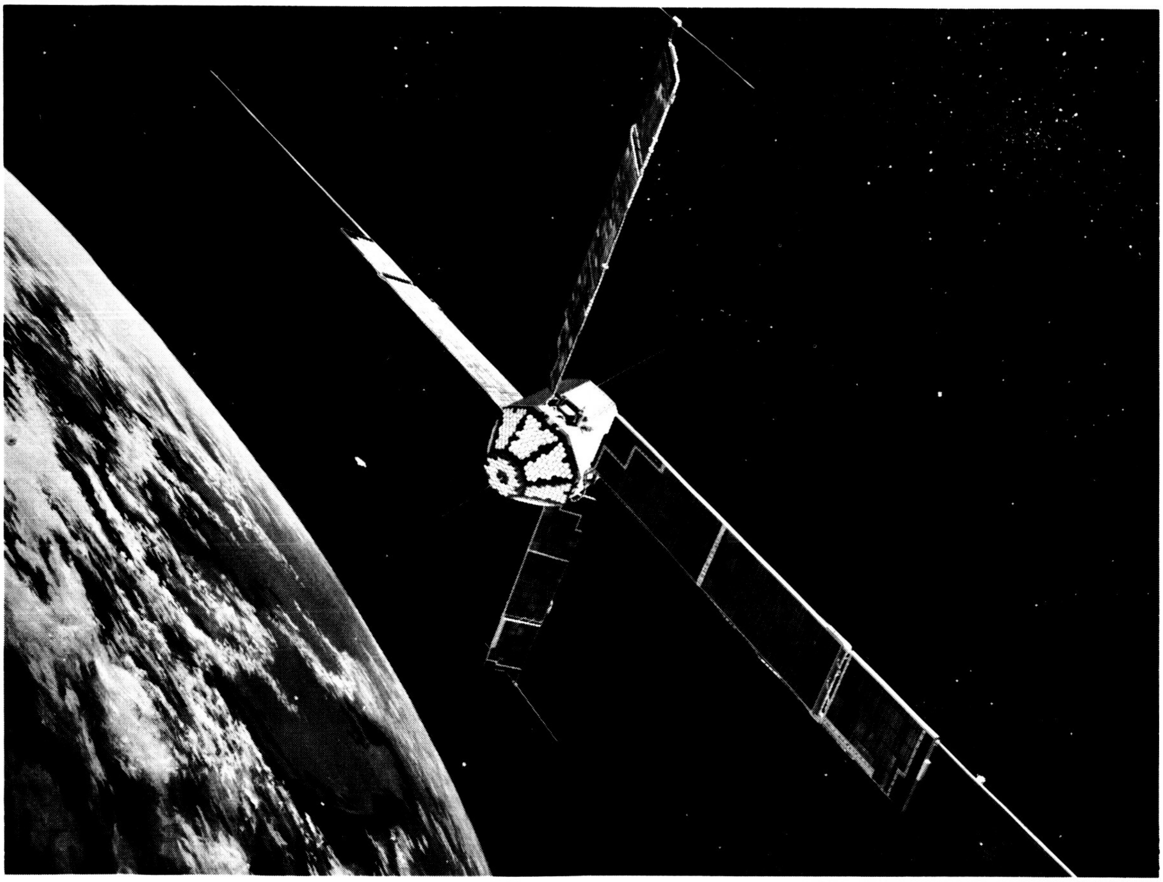
After the analog tape was converted to digital form, the outputs were a buffer tape printout for launch and diagnostic checks and a buffer tape. Upon further processing of the buffer tape, a documentation card and edit error list was produced. Decommutation of the buffer tape yielded radiation monitor tapes for analysis. For certain selected orbits, an option of the edit, decommutation, and format program produced a tape containing only processed radiation damage data.



ARIEL I

The Ariel I, a United Kingdom satellite, was designed to acquire increased knowledge of the ionosphere and how it is affected by solar radiations, and to obtain data on primary cosmic radiations. The combination of instruments permit the experimenters to correlate the various measurements to establish relationships between various phenomena.

The project is under the joint management of the U. S. National Aeronautics and Space Administration, and the Office of the U. K. Minister for Science. NASA's Goddard Space Flight Center and the U. K. Department of Scientific and Industrial Research are jointly responsible for data acquisition. Processing on a selective basis was performed by the Data Processing Branch. Frequency bursts of both low and high speed data were digitized and computer edited and quality checked. Then, the data was delivered to the United Kingdom for further processing and interpretation by the experimenters.

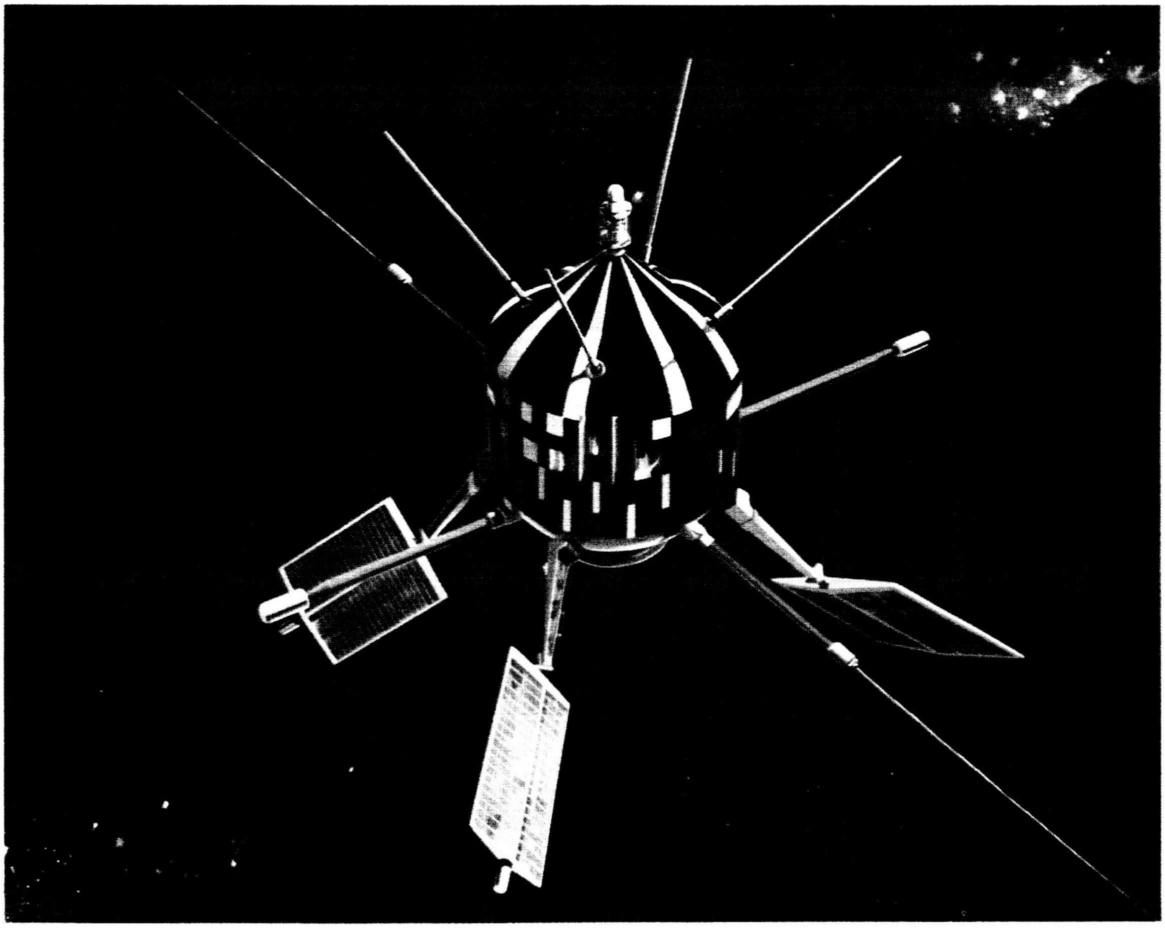


Ariel I

BEACON EXPLORER

The primary objectives of this satellite are to study the electron content between the satellite and the ground, behavior of ionosphere to solar radiation, and detailed studies on ionosphere in respect to communication and UHF.

Analog magnetic tapes containing BE-B data are to be evaluated, processed, and reduced upon receipt at the Data Processing Branch. After tape evaluation, the magnetic tape will be processed through 10.5 Kc and 5.4 Kc discriminators resulting in an analog voltage output. Strip charts or oscillographic records containing the PDM/PAM telemetered data will then be made of the resulting analog voltages. After further reduction the outputs will be in the form of status data, magnetometer data, and electron density data.

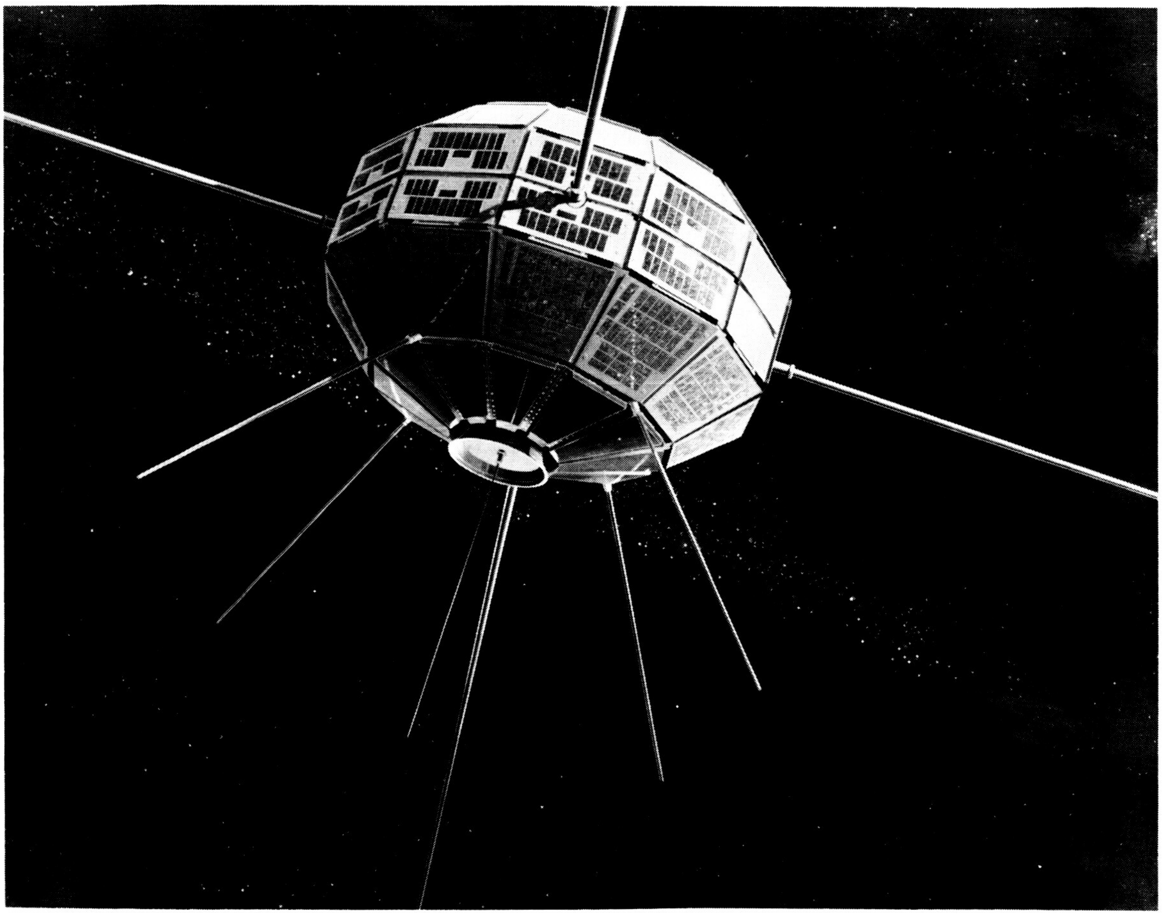


BE-B

ALOUETTE

The primary objective of this experiment was to examine the structure of the ionosphere from above in a manner similar to that now being used by ground-based sounding stations. In particular, information was desired about the ionosphere in the region above the maximum electron density of the F layer, usually about 188 to 250 statute miles above the earth's surface. Other objectives were galactic-noise measurements, study the flux of energetic particles, and investigate whistlers.

After tape evaluation, the Data Processing Branch recorded ionograms of the data for further analysis. Plans also included digitizing of data on microfilm.

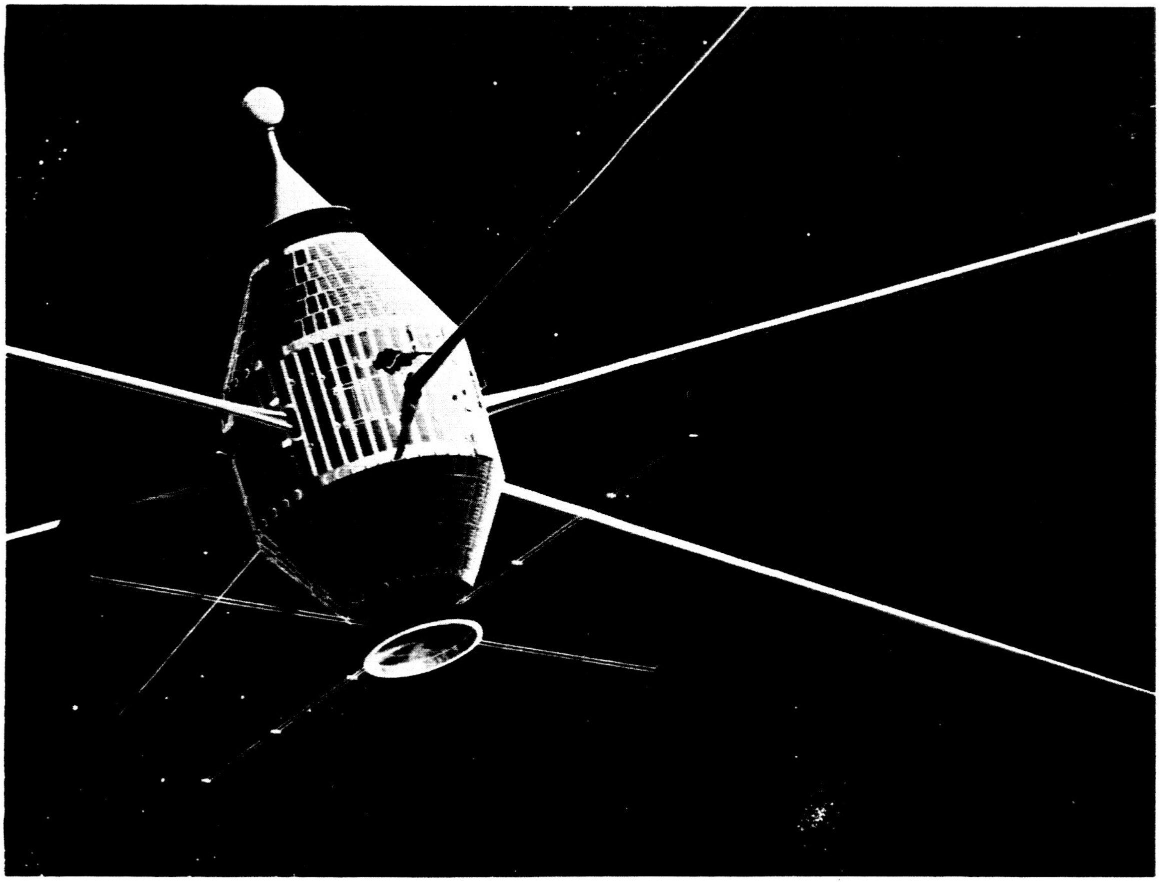


Alouette I

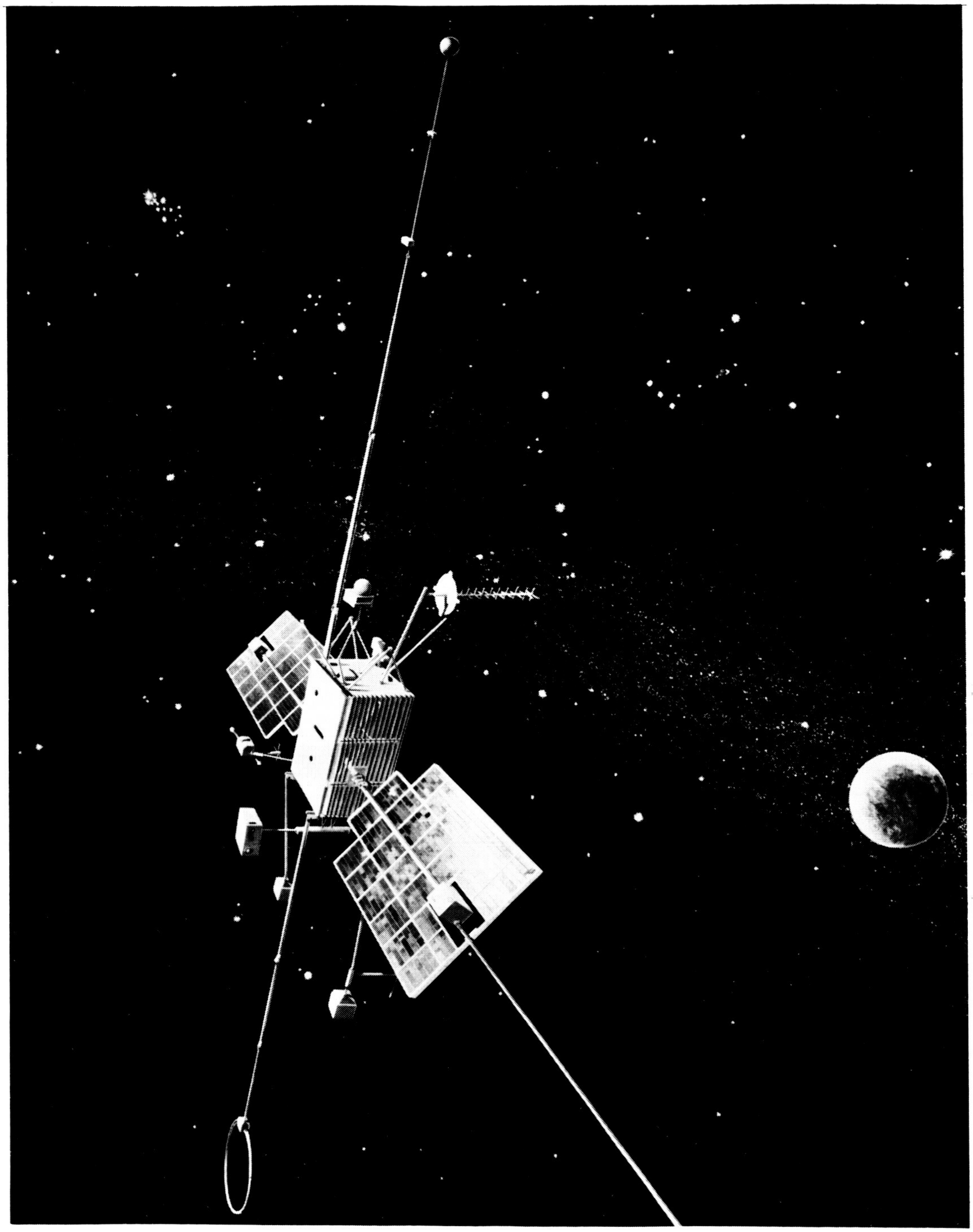
IONOSPHERE EXPLORERS

The primary objective of this project is to measure the electron density distribution in the region above the maximum electron density of the F2 layer (approximately 188 to 250 miles).

Reduction of all ion trap data plus processing of cosmic noise and ionogram data will be performed by the Goddard Space Flight Center. After evaluation at the Data Processing Branch, strip charts containing cosmic noise data will be selected, then digitization (conversion of the pulse amplitude modulated telemetry signal and binary coded time on the analog tape into a computer compatible format) of ion trap data will be performed after which the tape will be shipped to the National Bureau of Standards. Ion probe information will be presented to the United Kingdom on digital magnetic tape in high density, even parity IBM compatible format, with no special characters.



Ionosphere Explorer IE-A



OGO

ORBITING GEOPHYSICAL OBSERVATORIES

The observatories are the first of a series of large satellites designed to accommodate a variety of scientific space experiments. Because of their size, complexity, and number of experiments aboard (20 in the first OGO-A), the satellite projects demand a fresh look at the problems of telemetering to earth vast quantities of data, and of processing this data into forms suitable for utilization by the experimenters. (Data has been received from the first OGO-A, reduced, and is still being evaluated for analysis.)

A total of about 10^{11} bits of data is acquired from these satellites every six months. The Data Processing Branch has the responsibility to process this large volume of data on data processing systems consisting of signal conditioning and formatting units, plus a large scale digital computer. These processing systems extract the telemetry and ground station time signals from the station tapes, write the raw data on digital tape in computer format, fan out the data to produce a digital tape for each experiment (containing the data for the experiment plus supporting spacecraft data), generate an orbit-attitude digital tape, and convert spacecraft time to universal time.

The telemetry tapes received from the data acquisition stations are logged and the contents of the tapes are examined to determine their quality, whether or not the signals were recorded on the proper track, the presence of usable time signals, and whether there may be an equipment malfunction at the data acquisition station. The tape evaluation provides feedback to the station in addition to separating tapes which cannot be processed in the automatic system.

The processing of the pulse code modulation data on the acceptable station tapes occurs in four phases. Phase one uses specially designed processing equipment, while the other three phases use a 1107 digital computer. In addition, the rubidium magnetometer data transmitted by the spacecraft special purpose telemetry is prepared for analysis by a specially designed processing line.