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THE ORBITING GEOPHYSICAL OBSERVATORY, A NEW TOOL FOR SPACE RESEARCH

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SUMMARY

In early spacecraft, the systems and experiments were highly integrated assemblies designed to fully utilize the limited weight capabilities of the launching vehicles. This high degree of mechanical and electrical integration required that each satellite or probe be completely redesigned for each new mission. Now, that larger launching vehicles are available, observatory-type spacecraft are being developed which make the integration of large numbers of complex experiments more practical. These spacecraft consist of basic structures, electrical power, thermal control, attitude control, and data handling systems. Typical of these is the Orbiting Geophysical Observatory (OGO) which will carry 150 pounds of experiments to conduct investigations within and immediately outside the earth's magnetosphere and exosphere.

It is being developed with well defined, simple interfaces between the experiments and spacecraft systems so that experiments developed at different laboratories may be integrated into the spacecraft with a minimum of effort. The capabilities of OGO are discussed and the experiments which are being developed for the first OGO launching are listed.

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INTRODUCTION

In the first years of the U.S. space effort, a few simple experiments of a largely preliminary, or probing, nature were built into small satellites and space probes. These were highly integrated mechanically, thermally, and electrically; i.e., they were built as tightly knit, homogeneous structures. In the Explorer I (1958α) and Pioneer IV spacecraft, for example, it was not possible to change components without almost completely disassembling the payloads.

As spacecraft became more complex and the number of experiments carried on each mission increased, the lead times required for their preparation increased. It soon became obvious that the integration and testing programs must be simplified to prevent the build-up of unacceptably long lead-times. One method of accomplishing this was to divide the systems into well defined subassemblies, each capable of being tested separately and each independently removable from the spacecraft. Early examples of this type of spacecraft were the Explorer XII (1961ϵ) and the earlier, partially successful, Pioneer I. These spacecraft, however, still required a fairly high degree of system integration to conserve weight. It was necessary to adjust the detailed characteristics of the circuits in different subassemblies individually to make the system operate reliably as a whole. The spacecraft were one mission systems in that considerable mechanical, electrical, and thermal redesign and rebuilding was necessary to fly a different set of experiments in the same basic spacecraft.

Both of these types of spacecraft will continue to have a place in the space sciences program for a number of years. They will be used to carry small numbers of somewhat specialized experiments into orbits which most precisely meets their need. But a new type of spacecraft — the *Observatory* — will eventually assume a dominant role in the research program. The observatory will include a basic structure on which will be mounted both the experiments and the systems necessary to service them. An attitude control system will orient the experiments in space to permit a determination of the directional distribution of the various phenomena. A thermal control system will keep the experiments and system assemblies at workable temperatures whether the observatory is in sunlight or shadow. The power system will provide electrical power for both the experiments and the systems; and a data handling system will prepare, store, and transmit the experimental data to the ground. A command system will allow the experimenters and systems engineers a limited degree of control over the Observatory.

This Observatory concept is expected to provide many advantages, including the following:

1. It can accommodate relatively large numbers of directly and indirectly related experiments for studying the correlations between different phenomena. For example, it will be possible to study simultaneously the relationships between solar events, the solar plasma, the earth's radiation belt structure, and the earth's atmospheric structure.

2. It results in a greater convenience to the experimenter in designing his instrumentation by providing well defined, standard, mechanical, electrical, and thermal interfaces between the spacecraft and the experiments. This will allow the integration of the experiments with a minimum of effort.

3. The spacecraft is large enough to permit the inclusion of an advanced attitude control system to control the orientations of various experimental detectors with respect to several references simultaneously.

4. Conservatively designed data handling, power, and thermal control systems can be provided to simplify the task of designing the experiment instrumentation.

5. It is possible to include a limited number of relatively "high risk" experiments which may be exploratory in nature or which may be installed late in the program after some spacecraft testing has been completed. The fact that these experiments may have a somewhat smaller probability of a positive return can be accepted, since they represent only a small fraction of the total experiment load.

6. Operational efficiency will be improved by the continuous use and evolution of the ground station network, operating procedures, and data handling and reduction techniques.

7. Data acquisition and reduction will be simplified as there will be fewer satellites to track and fewer satellite orbits to compute.

8. Reliability will be improved by the repeated use and constant stepwise improvement of a basic design.

9. The average cost per experiment will be lower since the development of new spacecraft for each new mission is unnecessary.

A number of observatories are being developed for the NASA scientific research programs. These include the Orbiting Solar Observatory (OSO), the Orbiting Geophysical

Observatory (OGO), and the Orbiting Astronomical Observatory (OAO), which are being built as a part of the Goddard Space Flight Center earth satellite program; and the Ranger and Mariner spacecraft being developed as a part of the Jet Propulsion Laboratory lunar and planetary programs.

THE ORBITING GEOPHYSICAL OBSERVATORIES

This discussion of the OGO will illustrate the design approach to these observatories and the expected manner of using them.

An artist's conception of OGO is shown in Figure 1. This spacecraft's overall weight will be about 454 kg (1000 lb) of which 68 kg (150 lb) will represent the experiment detectors and their immediately associated signal-conditioning electronics. The basic spacecraft design is intended for repeated use in conducting as many experiments as time and availability permit. The observatories will be assigned to specific orbits required by the experiments, within the capabilities of the available launch vehicles. The first observatory will be launched in mid-1963 from the Atlantic Missile Range, Cape Canaveral, into a highly eccentric orbit by an Atlas-Agena B vehicle, and will be known as an Eccentric Orbiting Geophysical Observatory (EGO). Its orbit will have a nominal inclination of 31 degrees, perigee of 278 km (150 n. mi.) apogee of 111,000 km (60,000 n. mi.), and period of about 43 hours.

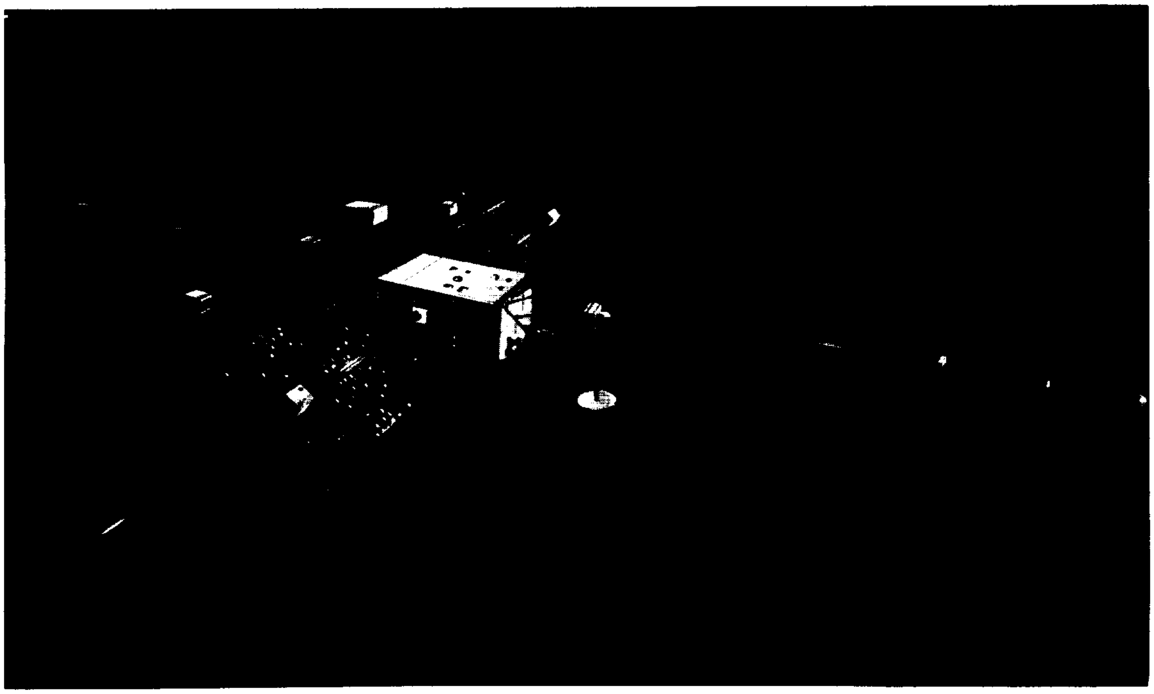


Figure 1—The Orbiting Geophysical Observatory. The distance from tip to tip of the long booms is about 16.5 m (54 ft); the distance between ends of the solar panels is about 6 m (19.5 ft). The experiments for the first flight are shown in the appendages.

The second observatory, to be known as the Polar Orbiting Geophysical Observatory (POGO), will be launched one year later into a polar orbit by a Thor-Agena B vehicle from the Pacific Missile Range. Its orbit will have a nominal inclination of 90 degrees, perigee of 259 km (140 n. mi.), apogee of 926 km (500 n. mi.), and period of about 96 minutes. Later observatories will be launched into orbits having inclinations, apogee heights, and periods between these values, depending on the needs of the experiments. In addition, future missions in the series may include advanced versions of the current spacecraft design with increased weight-carrying capabilities, or may be launched into higher orbits as launch vehicles of increased capability are developed. The present OGO spacecraft is being designed so that it can easily be expanded into a 680 kg (1500 lb) observatory when the Centaur launch vehicle becomes available; most of the weight increase will be available for experiments. This observatory may include a 136 kg (300 lb) pickaback satellite that can be separated from the main spacecraft in orbit to perform experiments requiring an especially pure environment, or experiments needing large separations between two of their parts.

DESCRIPTION OF THE SPACECRAFT

The OGO consists of the spacecraft and the experiments. The spacecraft being developed for NASA by Space Technology Laboratories (STL) consists of a number of systems: the structure; thermal control; power; attitude control; and data handling systems.

The Structure

The main body of the spacecraft is a rectangular parallelepiped, approximately 1.7 m (67 in.) long and 0.81 m (32 in.) across each side. Two opposite faces of the main body are hinged like refrigerator doors to permit easy access to internally mounted equipment (Figure 2). The upper two thirds of each door and the upper quarter of the main body are reserved for experiment instrumentation. System assemblies are located on the lower third of the doors and in the remaining main body volume.

A number of appendages are attached to the main body. The solar arrays are rotated about their line of attachment to keep the solar cells directed toward the sun. Containers at the outer ends of the solar arrays are provided for experiments that must be sun-oriented. Two orbital-plane experiment packages are rotated about an axis normal to the long axis of the spacecraft to direct detectors in the orbital plane.

Experiments whose measurements may be affected by disturbances generated in the main body are located on booms. These include magnetic field experiments whose accuracies would be affected by the small amount of ferromagnetic material that must be used in the spacecraft systems and by the magnetic fields produced by incompletely cancelled electric currents. In atmospheric experiments, the small amounts of gas evolved from the assemblies, or carried from one position in space to another by semi-closed trapping

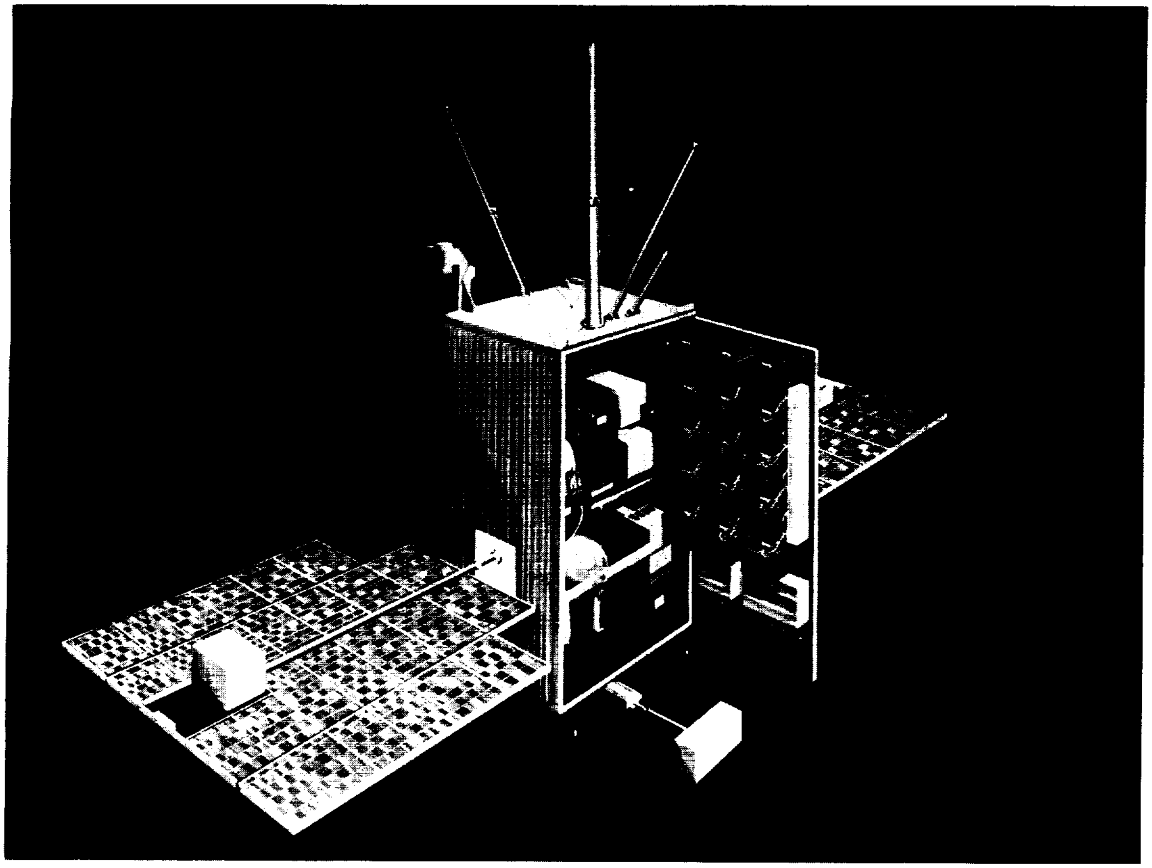


Figure 2—Experiment assemblies for OGO are mounted on the upper two-thirds of the open door and on the corresponding door on the opposite side. Subassemblies for the support systems are mounted inside the main body. Many of the appendages are not shown. The length of the main body is 1.7 m (67 in).

volumes, would affect the validity of the measurements. Experiments to measure ionospheric properties are located in appendages so that the effects of the spacecraft plasma sheath and electrostatic potential buildup can be neutralized. Experiments are also supported away from the massive main body when the results would be influenced by the presence of a nearby large mass. The Observatory will be launched with all appendages folded within the launch vehicle nose fairing. They will be deployed immediately after the observatory is injected into orbit.

Thermal Control

A combination of active and passive thermal control techniques is employed to regulate the temperatures of the electronics system compartments of the observatory. The temperatures of all assemblies within the main body will be kept within the range from 5° to 35° C by sets of radiating panels and temperature-actuated louvers located on two sides of the body (Figures 1 and 2). These panels, owing to the characteristics of the attitude control system, will never be exposed to the sun and will therefore remove thermal energy from the Observatory. Louvers controlled by bimetallic actuating elements regulate the exposure of the radiating panels to space. The loss of thermal energy from the other surfaces of the main body is kept as low as possible by the use of radiation barriers. Thus, the louvers will maintain a balance between the thermal energy input from the sun and earth – including that converted to electrical power and dissipated within the observatory – and the thermal energy lost by radiation from the observatory. Adequate thermal paths are provided between the radiating panels and assemblies within the body, in order to keep the thermal gradients low.

The temperatures of the appendage packages containing experimental instrumentation are controlled by a somewhat similar thermal balance technique, except that louvers are not utilized. Radiation barriers cover the packages except for radiating panels whose areas are chosen to radiate the maximum anticipated thermal power input from the sun and earth and from electrical power dissipation within the packages. Heaters are employed to maintain temperature limits when experiments are turned off. This system will normally keep the temperatures inside the appendage containers within the range 0° to 40° C.

Electrical Power

Electrical power to operate the electronics systems is furnished by a solar energy converter and chemical energy storage batteries. The solar energy converter employs junction silicon solar cells arranged on panels which will be directed toward the sun by the attitude control system. Approximately 32,000 cells, having a total active area of about 6.1 m^2 (66 ft^2) will provide a maximum initial power of 600 w. A number of factors, such as allowance for cell degradation for one year, losses due to non-normal illumination, etc., will reduce the useable power output to 304 w for EGO and 523 w for POGO. Twelve ampere-hour nickel-cadium storage batteries provide electrical power when the observatory is in the earth's shadow and assist in regulating the power-bus voltage. The nominal power bus voltage is 28 v (positive), but it may be anywhere within the range 23.5 to 33.5 v, depending on the state of charge of the chemical batteries and the illumination of the solar panels. The total average power available from the system will depend on the percentage of time spent in the earth's shadow. For the EGO and POGO nominal orbits, this will be about 230 w, of which 50 w will be used by the experiments and the remainder by the spacecraft subsystems.

Attitude Control

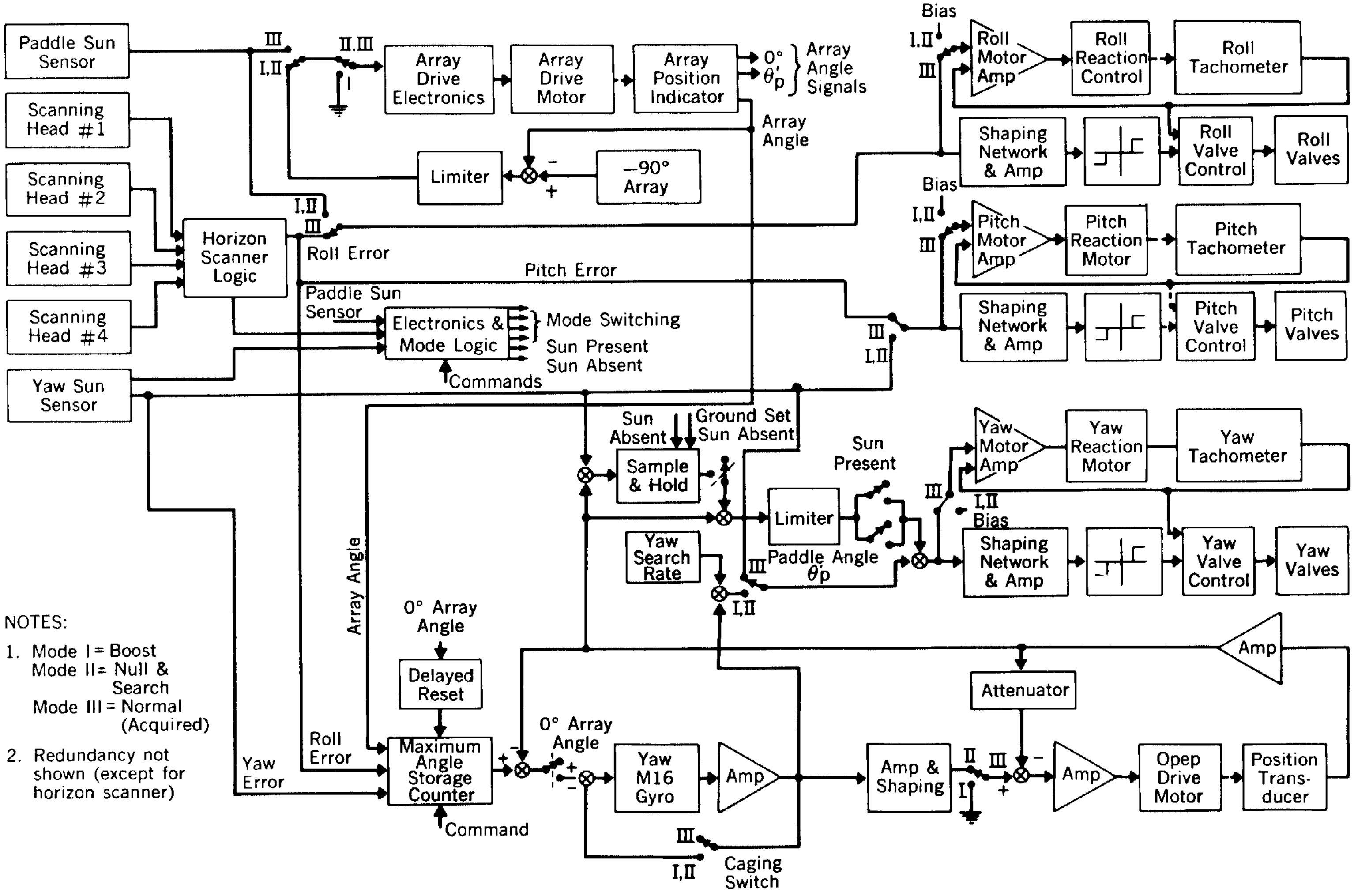
The attitude control system consists of sensors, servos, and torquing components to maintain the proper orientations for the experiments, the directional antennas and the thermal radiating panels. Two of the main body axes are controlled so that one surface of the main body and the directional antennas are always directed toward the center of the earth. The infra-red horizon scanners provide the error signals, and inertia wheels and gas jets provide the torques about these roll and pitch axes (Figure 3). Motion about the third body axis and the rotation of the solar panels about their long axis are controlled by sun sensors located on the ends of the panels. The body yaw torque, produced by a third inertia wheel and set of gas jets, keeps the axis of the solar panels normal to the sun line and the plane of the thermal radiating panels parallel to the sun line. The solar panels are rotated about their long axis so that their surfaces are always normal to the sun line and thus receive the maximum energy from the sun.

A third attitude control subsystem controls an Orbit Plane Experiment Package (OPEO), which permits the study of particles whose velocities are not great compared with that of the observatory. These experiments are directed forward in the plane of the orbit and normal to the observatory-earth line; thus they are directed along the observatory velocity vector at perigee and apogee, and at a small but known angle to the velocity vector at all other orbital positions. The sensor for this orientation is a gyroscope operated in a gyrocompass mode; its error voltage controls a drive which rotates the OPEP with respect to the body. This system operates when the body angle rates are high (throughout the entire POGO orbit, and near perigee of the EGO orbit).

Figure 3 outlines the complete attitude control system. A number of switches are shown to indicate schematically the manner in which the system operates in each of its three modes. In the boost mode the system is caged. In the null-and-search, or acquisition mode, the system goes through a sequence in which, first, the solar panels are directed toward the sun; then the horizon scanners are activiated to establish earth orientation; and finally the OPEP system is actuated. The system then switches automatically into the normal mode of operation. If attitude control about any of the five degrees of freedom is lost, the system switches back into the required phase of the acquisition mode.

Data Handling and Communications

The data handling and communication system consists of four main subsystems shown in Figure 4. The wide-band data system is a high capacity digital data system designed to condition, store, and transmit most of the experiment and spacecraft data to the ground receiving stations. Each of the two identical data handling units includes a set of time multiplexers, or commutators, and an analog-to-digital converter. A large number of high and low speed input channels are provided in each data handling unit. Either analog or digital data can be accepted, depending on the basic nature of the data source. The output of one of the two data handling units is recorded by one of two redundant magnetic-tape data storage units. Each recorder contains sufficient tape to store data at a rate of about 1 measurement per second per experiment for 12 hours. These tapes will be periodically read out at high



NOTES:

1. Mode I = Boost
   Mode II = Null & Search
   Mode III = Normal (Acquired)
2. Redundancy not shown (except for horizon scanner)

Figure 3—Block diagram of the OGO attitude control system.

speed by the ground stations. For the POGO orbits, the recording rate will be increased by a factor of 4; thus each recorder will have a 3 hour capacity. The second data handling unit will be used at a higher rate to telemeter data to the ground stations in real time. It is capable of making approximately 8 to 64 measurements per second per experiment upon command from the ground. One of two redundant 400 Mc transmitters will telemeter the data from the real-time data handling unit or from the data storage unit as directed by ground command. Normally the transmitter feeding the directional antenna will be used. In the event that the transmitter fails or the attitude control system no longer points the directional antenna at the earth, the other transmitter and its omnidirectional antenna will be used.

The second major data handling and communications subsystem is the special purpose transmitter system. It will telemeter data from experiments that are incompatible with the time-sharing feature of the wide-band system, or whose signals need to be telemetered in a completely unprocessed form.

The command system is provided to permit operational control of the data system; to permit operational control, calibration, and scale factor changing in experiments; to control the power to the experiments and spacecraft subsystems; to back up the initial sequencing of the spacecraft; and to permit limited troubleshooting by substitution of redundant subassemblies in the event of partial failure. The ground commands are received by two parallel redundant receivers. Most of the commands (256 in number) are digital in nature and are decoded by the two redundant digital decoders. A few of the most important commands can also be sent as tone commands and would be decoded by a simple, highly reliable tone decoder.

A set of transmitters is included in the Observatory to provide signals suitable for tracking the satellite. The goal of the tracking program is to be able to supply the experimenter with the satellite position at any time within a radius of uncertainty of 1 km or less at 1000 km, 100 km or less at 5 earth radii, and 1000 km or less at 10 earth radii. This will require the use of three beacon transmitters on the observatory for angle and angle rate measurements. Two of these are redundant low power transmitters, one of which will be on continuously. The third is a high power transmitter (10 w output) which will be turned on for short periods by command to provide highly accurate measurements near EGO apogee.

In the observatory data system a clock will synchronize the entire system and will generate a time code which will be recorded and telemetered to provide an easily used unambiguous time correlation for all data. The clock will also provide accurate timing signals to assist in programming the experiments.

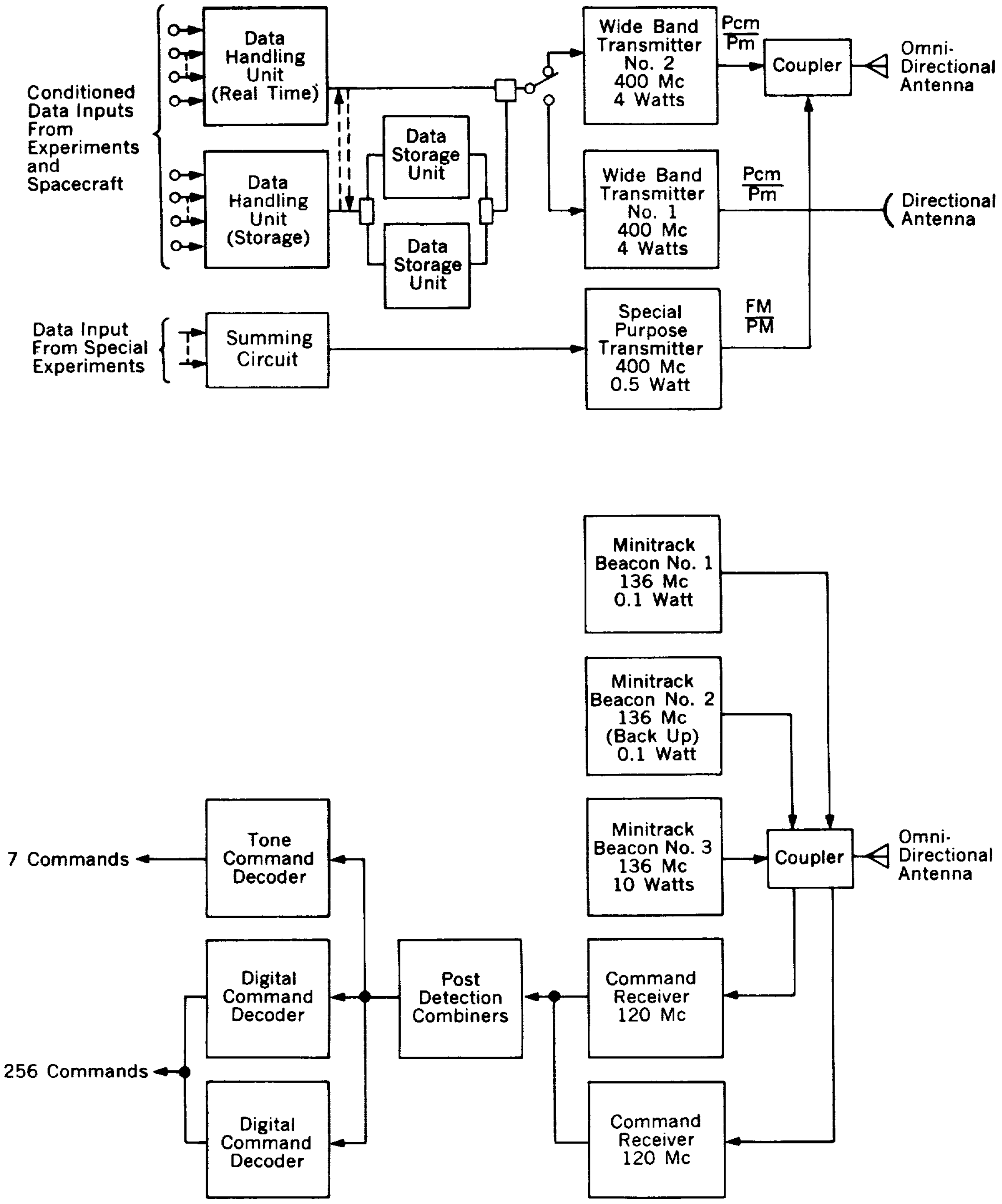


Figure 4—Block diagram of the OGO data and communications system

EXPERIMENTS FOR OGO

The foregoing general characteristics of the Orbiting Geophysical Observatory systems constitute the framework within which the experiments must fit. The process of conducting experiments in this general purpose, large capability spacecraft involves a series of steps:

1. Initial development of experimental techniques to determine their suitability for use in the space program.

2. Selection of experiments for each particular mission.

3. Development and fabrication of the prototype and flight instrumentation.

4. Testing of the ability of the experiments to operate on the spacecraft under the conditions imposed by the launch and orbit environments.

5. Integration of the experiments into the spacecraft, including testing of the performance of the observatory as a complete system and calibration of the experiments.

6. Launching of the observatory.

7. Operation of the observatory, including the determination of its orbit and the recovery of the data.

8. Processing of the data into a form suitable for analysis.

9. Analysis of the data and publication of the results.

10. Feedback of information obtained during each of these steps and from other programs into the initial phases of the preparation for the next observatory.

Development

Experiments proposed for inclusion in the NASA Space Science Program are first submitted to the Director of the Office of Space Sciences, NASA Headquarters, Washington 25, D. C. Normally, this office supports the initial development of meritorious experimental techniques to determine their suitability for inclusion in the flight program. At the appropriate time, it selects the experiments and experimenters for particular flight programs. This process has been completed for the first OGO (code name S-49). These experiments, experimenters and their institutions are listed in Table 1.

When the experiments were selected and preparation of the prototype and flight instrumentation commenced, the support of the experiments was assumed by Goddard Space Flight Center. The experimenters and the OGO project staff work directly together to ensure that the experimental objectives are met. In designing the spacecraft, the mechanical, electrical

Table 1
Experiments for the First OGO

Experiment Title	Principal Experimenter	Phenomena to be Measured
Solar Cosmic Rays	K. A. Anderson, University of California	Solar proton and x-ray flux, energy and variations
Plasma, Electrostatic Analyzer	M. Bader, Ames Research Center	Solar plasma flux, energy and direction
Plasma, Faraday Cup	H. J. Bridge, Massachusetts Institute of Technology	Solar plasma flux, energy and direction
Positron Search and Gamma Ray Spectrum	T. L. Cline and E.W.Hones, Goddard Space Flight Center and Institute for Defense Analysis	Search for positrons and solar gamma ray flux and spectrum
Trapped Radiation Scintillation Counter	L. R. Davis, Goddard Space Flight Center	Geomagnetically trapped electron & proton flux, energy and direction
Cosmic Ray Nuclear Abundance	F. B. McDonald, Goddard Space Flight Center	Primary and solar cosmic ray flux, charge and energy
Cosmic Ray Spectra and Fluxes	J. A. Simpson, University of Chicago	Primary and solar cosmic ray flux, charge and energy
Trapped Radiation, Omnidirectional Counters	J. A. Van Allen, State University of Iowa	Geomagnetically trapped electron and proton flux and energy
Trapped Radiation, Electron Spectrometer and Ion Chamber	J. R. Winckler and R. L. Arnoldy University of Minnesota	Geomagnetically trapped electron energy and flux, and total ionization
Rubidium-Vapor and Flux Gate	J. P. Heppner, Goddard Space Flight Center	Magnetic field strength and direction
Triaxial Search Coil Magnetometer	E. J. Smith, Jet Propulsion Laboratory	Magnetic field low frequency variations
Spherical Ion and Electron Trap	R. Sagalyn, A. F. Cambridge Research Laboratory	Thermal charged particle density, energy, and composition.
Planar Ion and Electron Trap	E. C. Whipple, Goddard Space Flight Center	Thermal charged particle density, energy, and composition
Radio Propagation	R. S. Lawrence, National Bureau of Standards	Electron density
Atmospheric Mass Spectrum	H. A. Taylor, Goddard Space Flight Center	Atmospheric composition
Interplanetary Dust Particles	W. M. Alexander, Goddard Space Flight Center	Micron dust particle velocity and mass
VLF Noise and Propagation	R. A. Helliwell, Stanford University	VLF terrestrial noise, solar particle emissions, and cosmic noise frequency distribution and strength
Radio Astronomy	F. T. Haddock, University of Michigan	Solar radio-noise burst frequency spectrum
Geocoronal Lyman-Alpha Scattering	P. Mange, Naval Research Laboratories	Lyman-Alpha intensity
Gegenschein Photometry	C. L. Wolff and K.L. Hallam, Goddard Space Flight Center	Gegenschein intensity and location

and thermal interfaces between the experiments and spacecraft were kept as simple and well defined as possible to make the task of designing the experiments straightforward. Detailed specifications of these interfaces were distributed early in the program. No spacecraft, however, is completely universal, and prospective incompatibilities must be detected as early as possible and resolved. In addition, extreme care must be taken to ensure that interference between individual experiments, and between the spacecraft and experiments, does not excessively lower the significance of the individual measurements.

Integration and Testing

The prototype and flight instruments will be brought to the Goddard Space Flight Center approximately nine and six months before the flight respectively. All prototype and flight units will be subjected to an extensive series of checks and tests; the first is a check of the electrical interface, in which the experiment will be operated by a spacecraft data and power system simulator. Many of the parameters, such as voltages, pulse widths, and temperatures, will be varied to determine the experiment's operating tolerances. Then a sequence of environmental tests will be made to ensure that the experiments will have a high probability of operation in the pre-launch, launch, and orbital environments. These include vibration, shock, acceleration, temperature, leak (for sealed assemblies), thermal vacuum, and magnetic field tests.

Following these tests, the experiments will be delivered to the spacecraft for integration and will be physically mounted on the spacecraft. The necessary thermal paths will be established to allow the proper heat exchange. The experiments will be connected one at a time to the power and data systems, first through protective devices to prevent any possible damage to the spacecraft due to improper cabling, and finally by direct connections. Following the integration of each small group of experiments, system checks will be performed to ensure that the experiments operate properly together and with the spacecraft. A more thorough interference test will be made when all experiments are installed. Next, the complete Observatory will enter another testing sequence. Environmental tests will be run to ensure that the complete Observatory will have a high probability of proper operation under the launch and orbital conditions. By this time, a large fraction of the early failures and interface incompatibilities should have been detected as a result of the assembly level testing and interface checks; and it is expected that most of the failures occuring during the Observatory level testing will be structural failures of the mountings, and random parts failures. This two-step testing philosophy is necessary to obtain a reasonably short testing period since the Observatory is extremely complex.

At various points in the testing sequence, experimenters will be able to perform detailed calibrations while their experiments are mounted on the Observatory and operating as a part of the complete system. Following this testing, the flight Observatories will be shipped to the launch site. There they will be completely checked; simple experiment calibration checks will be made to ensure that no changes have occurred; and the Observatory will be mounted on the launch vehicle. Only simple checks of the experiments will be possible once the Observatory is aboard the launch vehicle, owing to the difficulty of injecting many stimulating signals into the detectors in this configuration. The final commitment of the experiments will be made early in the launch countdown.

OPERATION OF OGO IN ORBIT

The successful operation of the Observatory in orbit will require the close coordination of a large number of facilities. Many of these are indicated in the operational diagram of Figure 5. A worldwide network of radio-interferometer stations will obtain fixes on the satellite and forward them to Goddard Space Flight Center, where the orbital elements will be computed. From these, orbit predictions will be computed to provide receiving stations with antenna pointing information which will permit initial antenna acquisition at the beginning of each pass. The telemetry receivers at six receiving stations distributed

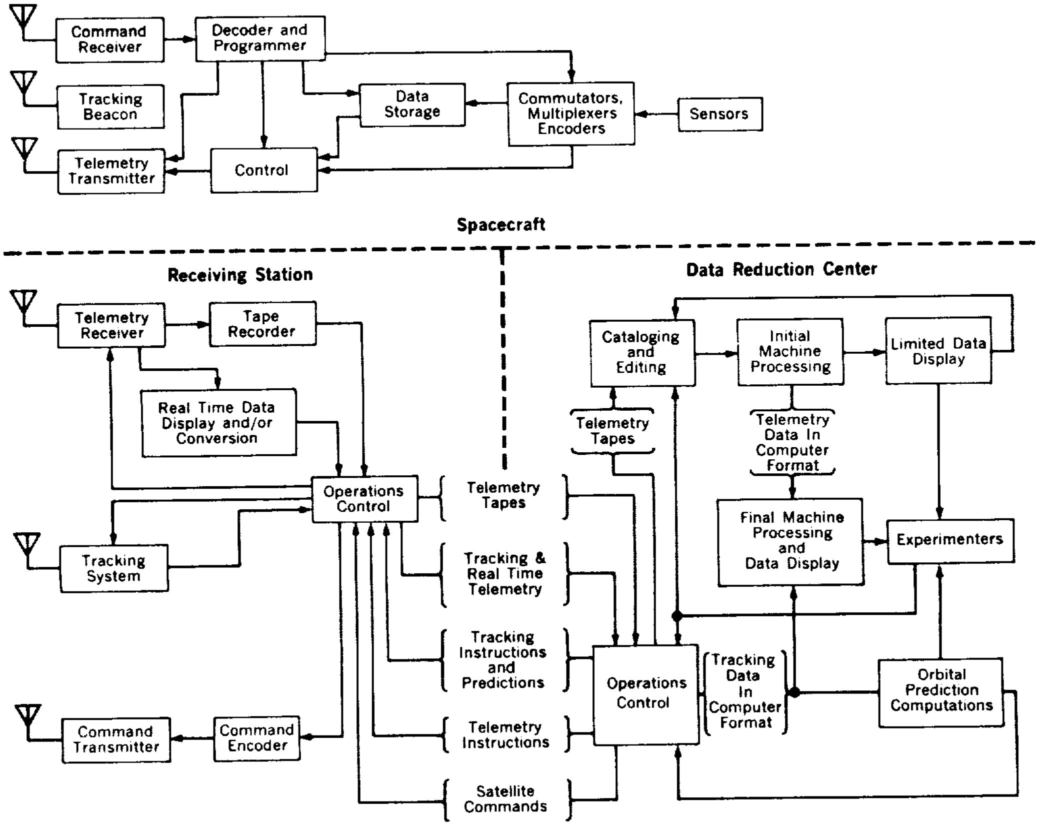


Figure 5—Flow diagram for operation of the OGO.

over the earth will receive the data when the appropriate telemetry modes are commanded by the encoders and command transmitters. The tape-recorded telemetry signals will be forwarded to Goddard Space Flight Center for further processing. In addition, selected spacecraft performance parameters and experiment data will be observed at three of the stations to permit immediate correction of discrepancies in the spacecraft and to command different modes of operation.

At Goddard Space Flight Center the telemetry tapes will be cataloged and processed. The general procedure will be to produce noise-free master computer tapes containing all raw experimental data and the orbit data. Individual computer magnetic tapes will be produced for each experimenter, containing the data from his experiment, spacecraft performance parameters, spacecraft orientation, orbital elements, and universal time. These will be forwarded to the experimenter for further processing and analysis. The primary means for disseminating the new information to the scientific and space technology communities will be publication in the open literature.

CONCLUDING REMARKS

The Orbiting Geophysical Observatories will permit the simultaneous performance of many experiments in space. They will be of the greatest possible use only if the program inspires the confidence of the experimenters and receives their full support. Therefore, the OGO philosophy allows the scientist to conduct the experiment in the classical manner. It places primary responsibility for the development and preparation of the instruments and the checkout and calibration of the detectors on the experimenter, who will also have sole responsibility for analyzing and reporting the data. This combination — a standard, flexible space laboratory and experiments developed by expert space scientists — should answer many existing questions about the physical universe, and in turn, raise many new questions to which answers must be sought.

NASA-Langley, 1962 G-264