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METEOROLOGICAL SATELLITE DATA SYSTEMS

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METEOROLOGICAL SATELLITE DATA SYSTEMS

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INTRODUCTION

There are many practical factors affecting the design of data systems for meteorological satellites which must be taken into consideration. It is the purpose of this discussion to identify and examine some of the key elements or variables which are a part of the complex matrix that must be solved to produce an effective system design, and to illustrate how such a matrix was solved for one of the forthcoming TIROS satellites.

Figure 1 illustrates the wide variety of shapes and sizes of spacecraft which were used to meet an equally wide variety of functional requirements. For meteorological purposes, these shapes and sizes have been narrowed down to two basic types: one in which the spacecraft or sensor platform is stabilized and controlled by means of an attitude-control system to keep the sensors accurately oriented toward the earth, and the second in which the spacecraft spins at a moderately rapid rate (~ 10 rpm) to provide the stability of a gyroscopic body (Figure 2).

Underlying the design of both types are many common requirements too detailed to be covered in this paper. They include such practical factors as power, data transmission, size and weight, ruggedness and reliability to withstand the rigours of launch and environment of space, and the need for the design to allow adequate ground testing before launch.

OBJECTIVES

The objective of a meteorological satellite system is to provide observations over the entire globe on a daily basis. These observations should include cloud-picture coverage and cloudtop measurements on both the sunlit portion and the nighttime portion of the earth, at least once every day. Because the data is perishable, it should be collected from the satellite and relayed to a central processing point with no more than a two to three hour delay. In addition to processing, preparing, and disseminating global information from a central point, it is desirable to provide direct readout from the satellite to local stations. With such a capability, a user anywhere in the world could receive data from the satellite, when it was in his vicinity, which would cover a significant area surrounding the user.

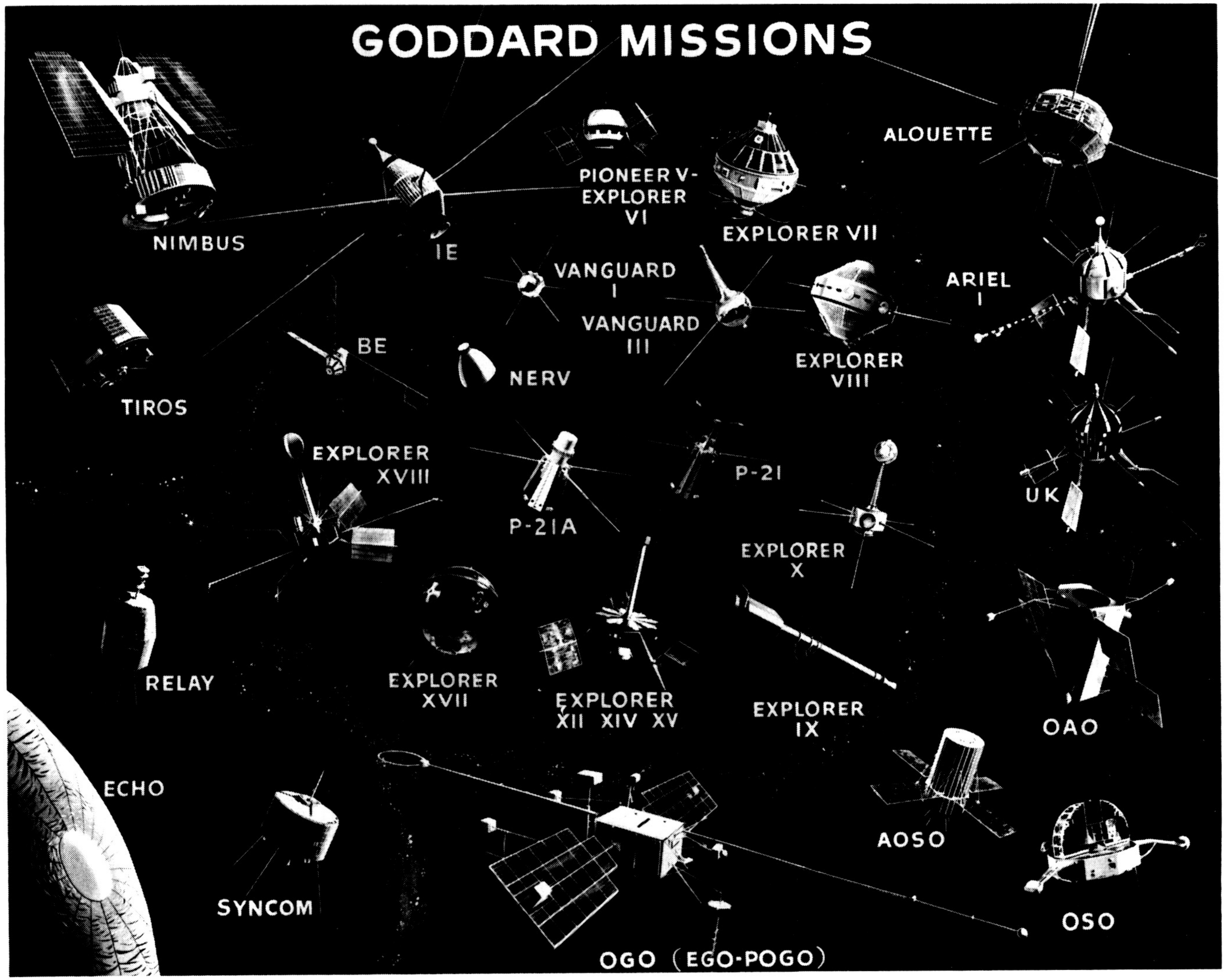


Figure 1–Goddard Missions

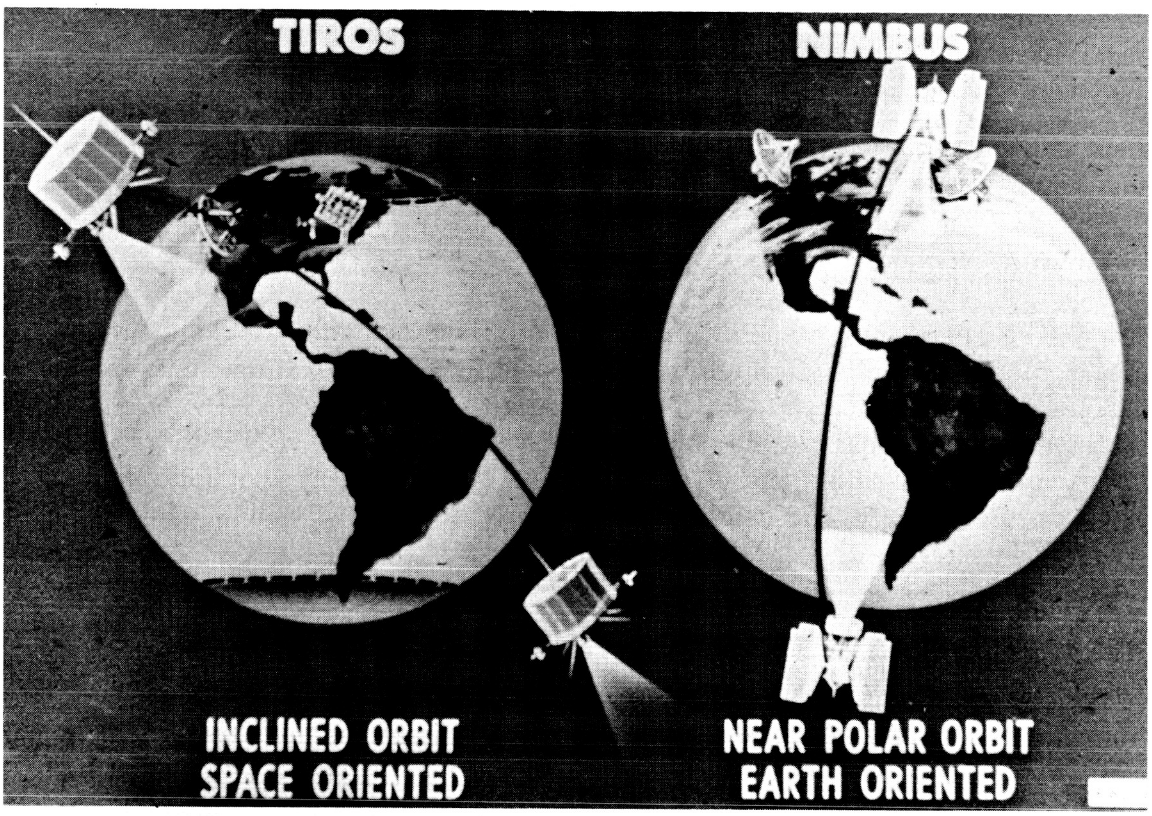


Figure 2-Meteorological Satellite Development

The resolution of the cloud pictures should be in the order of one to two miles at the subsatellite point (Figure 3) and should not exceed four to five miles at the point of contiguity (the point at which pictures from adjacent orbits overlap). At the point of contiguity, the angle between the local vertical and the sensor in the satellite should not exceed 65 degrees (zenith angle).

ORBITS

Several factors must be taken into consideration when selecting the type of orbit that would most closely satisfy all requirements for a meteorological satellite program. Some of the major factors are cost, reliability, time and area required for proper data coverage, power requirements, equipment parameters, and operating requirements, weight of spacecraft, and location of data-readout stations. The principal advantages and disadvantages of some of the more common orbits are discussed in the following paragraphs.

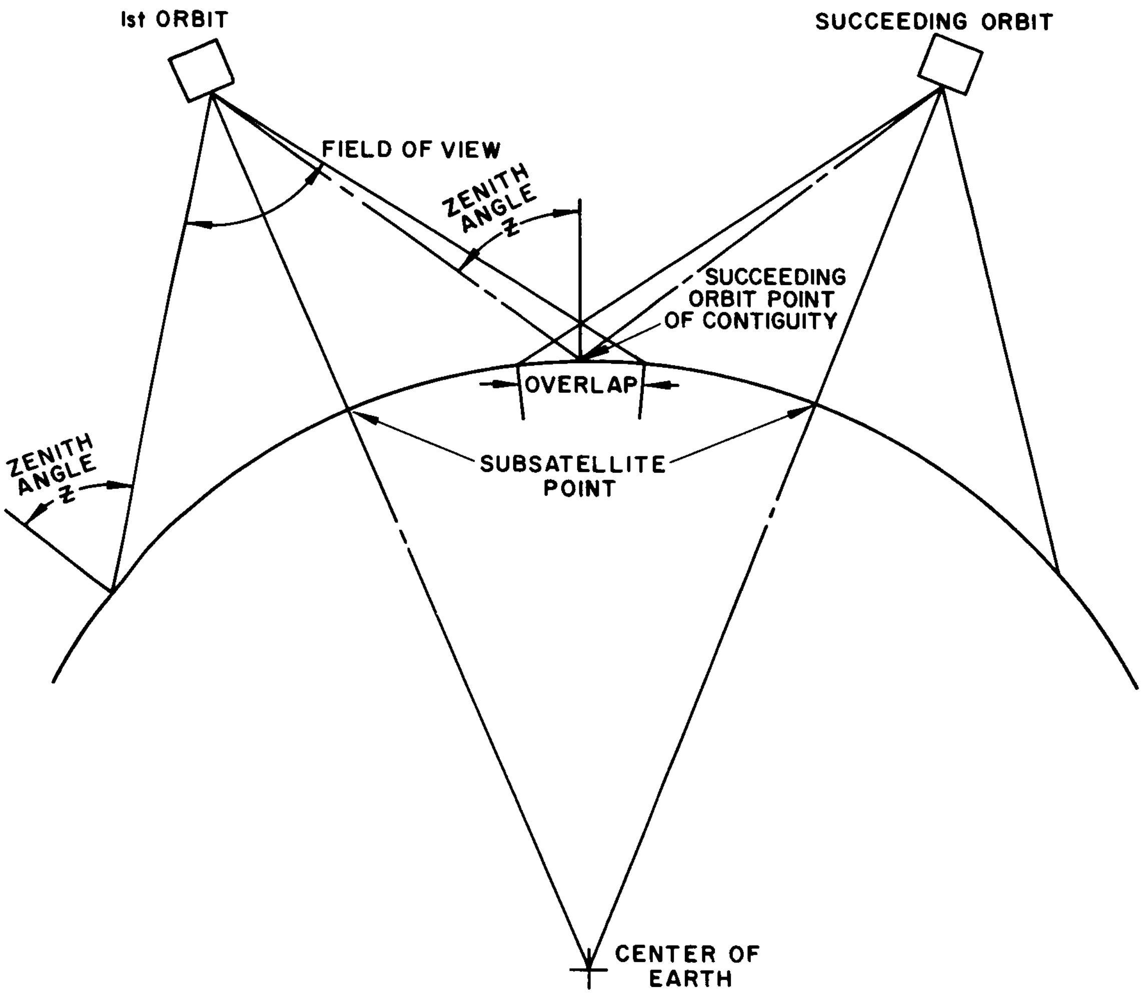


Figure 3-Coverage Geometry

EQUATORIAL ORBITS

Because of launch-vehicle range safety requirements, all U.S. satellites are launched over water. Thus, launches from Cape Kennedy have been restricted to orbits which are equatorial but are inclined to the equator at angles ranging from -28 degrees to +58 degrees. The 58-degree orbit has been quite useful for TIROS. It has provided coverage over the most densely populated areas of the earth, but it cannot provide the much-needed coverage over the polar regions. Further, the orbit plane of this type orbit precesses about the earth at a fairly rapid rate (about 4 degrees per day) so that the relationship between the sun and the orbit plane varies, resulting in a varying daily time of observation and periods of inadequate illumination.

A particularly interesting variation of the nominal equatorial orbit is the pure equatorial, i.e., wherein the satellite is steered into an orbit plane coinciding with the equatorial plane of the earth. At the nominal altitudes used for TIROS (approximately 400 nautical miles), this would provide only a narrow belt of coverage approximately 500 nm above and below the equator. However, if the altitude could be raised to about 2500 nm, the area of observation could be extended to a very useful ±30 degrees of latitude (±1800 nm). The satellite would cover the same area every three and one-half hours and could provide an excellent hurricane "watch" as well as frequent observation of other meteorological phenomena originating in the tropical zone.

A further variation of the pure equatorial orbit is the earth-synchronous or "stationary" orbit. At approximately 22,300 miles, a satellite, like Syncom, will move about the earth at the same angular velocity as the earth and therefore will not move relative to the earth. It can be made to hover above any given point on the equator (Figure 4) and could observe the same area continuously for hours, days, or months. This orbit would be particularly valuable, of course, for the study of the development of a storm area.

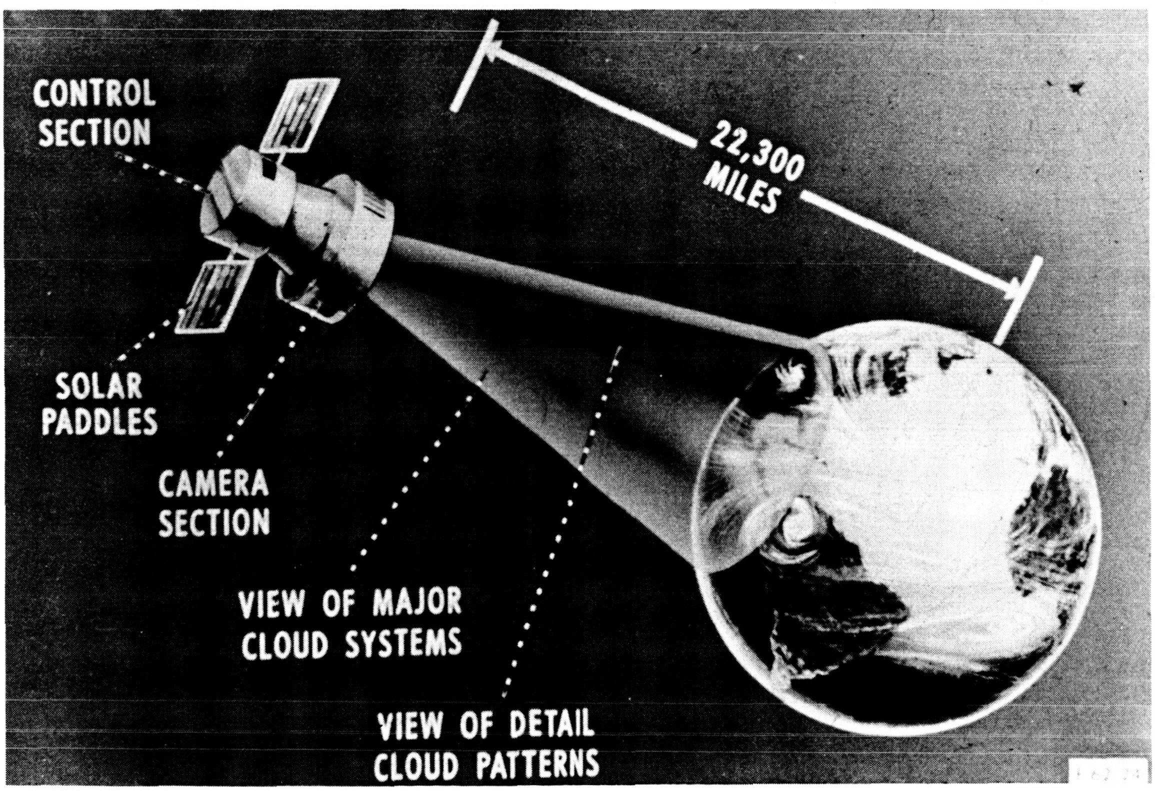


Figure 4-Synchronous Meteorological Satellite

POLAR ORBITS

The minimum orbital requirement for meteorological purposes is global coverage of the entire sunlit portion of the earth at least once every day. A near-polar orbit having an inclination of approximately 80 degrees to the equator (retrograde) permits the plane of the orbit to precess at a rate equivalent to that of the rotation of the earth around its axis so that it is synchronized with the sun, thus maintaining the satellite orbital plane on the earth-sun line. The best conditions for earth viewing are obtained by launching the spacecraft at local noon or local midnight. This launch time yields an orbital plane that contains the earth-sun line. Consequently, the spacecraft will always view the earth at near local noon on the sunlit side and near midnight on the dark side (Figure 5). The sun-synchronous orbit also enables a spacecraft such as Nimbus to require only one axis of paddle rotation for direct sun-pointing.

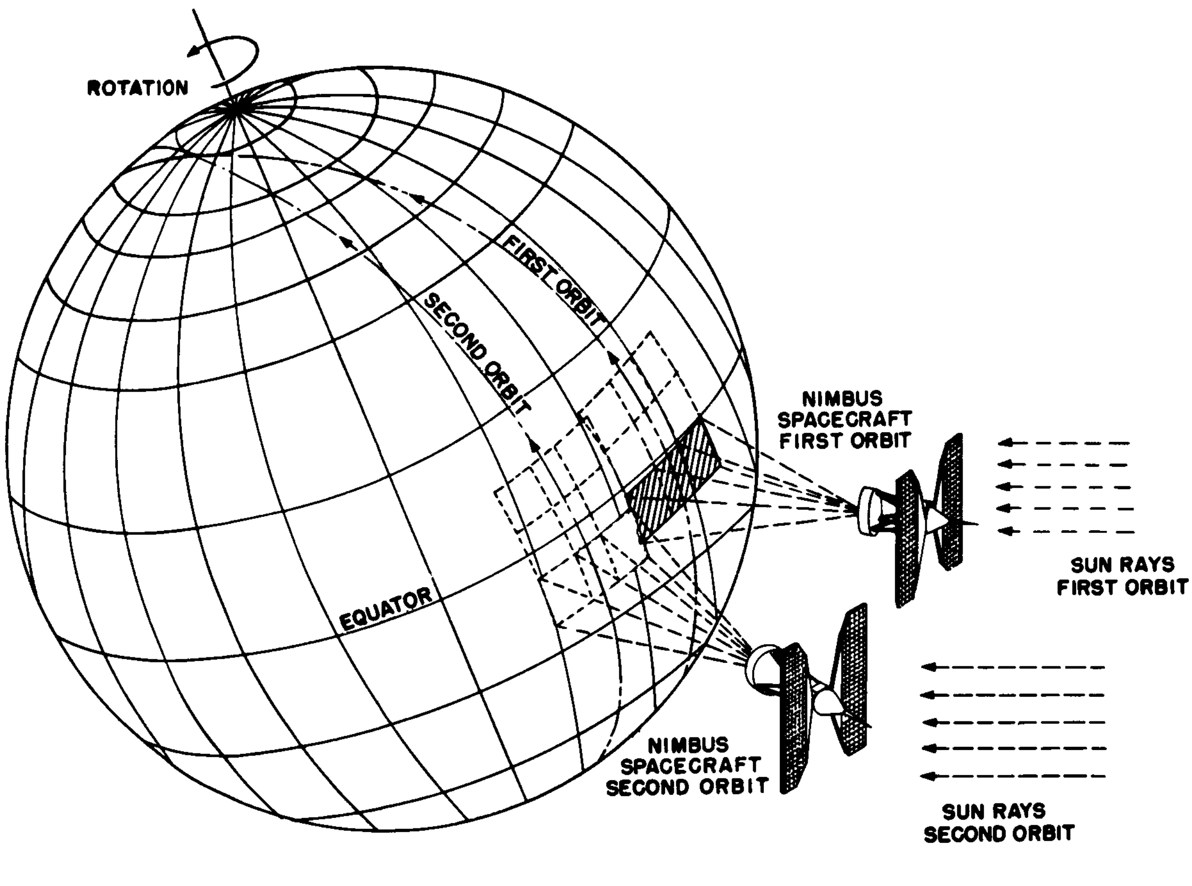


Figure 5-Nimbus Television Coverage

Two practical variations are possible with the sun-synchronous orbit: one, to launch the spacecraft at 9:00 a.m. or 9:00 p.m. to provide observations early in the day; or two, to launch the spacecraft at 3:00 p.m. or 3:00 a.m. to provide late-day observations.

An interesting variation of polar orbit is the pure-polar, or 90 degree inclination, orbit. This orbit would permit complete earth coverage and complete data transmission by using a single station located near one of the polar extremities of the earth. However, there are several distinct disadvantages in the application of a pure-polar orbit. The spacecraft's orbital plane would regress at the rate of 1 degree per day, resulting in a daily change in illumination level. Approximately 30 days of each 180 would be spent in the twilight zone, thus producing severe problems in maintaining adequate thermal control and power. Another disadvantage would be that instead of one axis of paddle rotation required for a near-polar orbit, two such axes would be required for direct sun-pointing.

SENSOR PLATFORMS

Stabilization and Attitude Control

There are several established active and passive methods for stabilizing and controlling the attitude of satellites for meteorological applications. The principal determinants to be considered for selecting the best system depend upon the accuracy necessary for optimum performance of the meteorological sensors to be carried on the satellites. Other factors to be considered are altitude, accuracy, cost, complexity, reliability, control lifetime, redundancy, weight, and power requirements. Another outstanding requirement is that the spacecraft be designed so that the center of gravity is accessible to permit dynamic testing. There are several advantages and disadvantages inherent in each system. Some of the major systems are discussed in the following paragraphs.

Three-Axis Stabilization

The three-axis stabilization control system (Figure 6) has been successfully demonstrated in orbit to be an effective method for controlling the attitude of a satellite. For example, the Nimbus spacecraft functions as a stabilized platform which carries a variety of sensors to view the earth continuously both day and night.

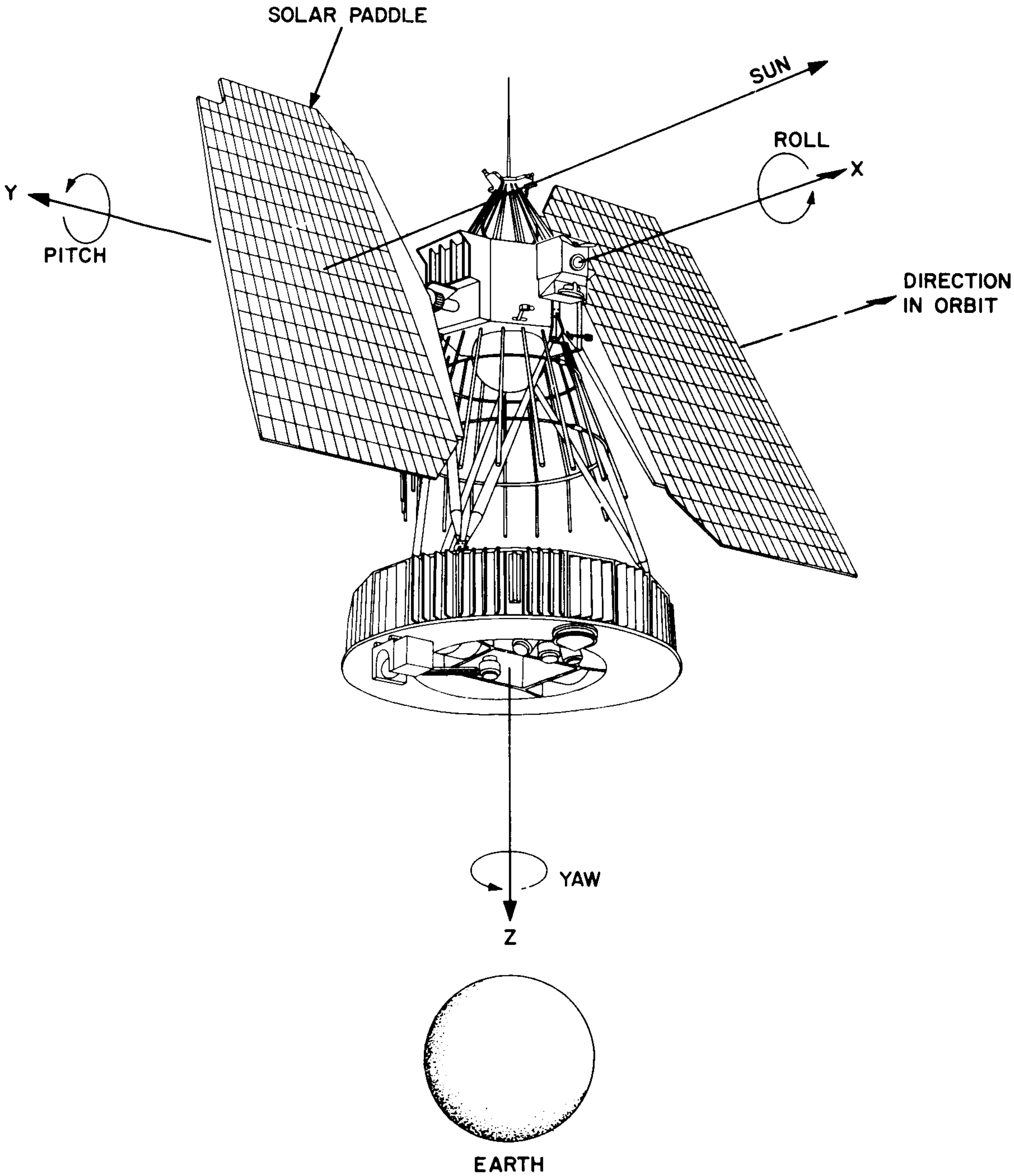


Figure 6–Nimbus Stabilization

The Nimbus attitude control subsystem employs two infrared horizon scanners, two coarse sun sensors and a rate gyro acting as a yaw sensor. Three motor-driven flywheels and eight gas nozzles act as torque generators to provide attitude control. A pneumatic tank contains the gas supply.

The spacecraft coordinate system defined by the location of the optical scanners and inertial devices used for axis orientation is:

- The yaw axis points toward the center of the earth
- The roll axis, perpendicular to the yaw axis, is parallel to the orbital plane
- The pitch axis is perpendicular to both the yaw and roll axes

After separation from the launch vehicle, the horizon scanners located on the roll axis sense the spacecraft's attitude with respect to the earth. The scanners, one looking forward and the other looking to the rear, generate a sky-earth signal which, when applied to the attitude computer logic circuits, produces both pitch and roll error signals, thus operating the pitch and roll flywheels and nozzles to stabilize the spacecraft in pitch and roll.

The position with respect to the sun of the coarse sun sensor provides yaw attitude control during initial stabilization. Error signals from the sensors are amplified to drive a yaw flywheel and gas nozzles to reduce the negative roll axis-sun angle to a minimum.

When the spacecraft passes into the earth's shadow on the first orbit, yaw control is switched to the rate gyro. The gyro produces an error signal proportional to any divergence of the spacecraft roll axis from the spacecraft velocity vector in yaw. This error signal is applied to the yaw reaction wheel to correct the yaw error.

The gas nozzles reduce the large stabilization errors, while the flywheels compensate for small errors. A tachometer monitors the speed of the flywheels to prevent flywheel saturation. When the saturation point is approached, the gas nozzles are activated to reduce the speed of the flywheels back to zero.

Under ideal conditions, it is believed that pointing accuracies in the range of ±1 to ±2 degrees will be achieved. However, depending upon atmospheric conditions in the field of view of the horizon scanners, errors of approximately twice this magnitude could be introduced.

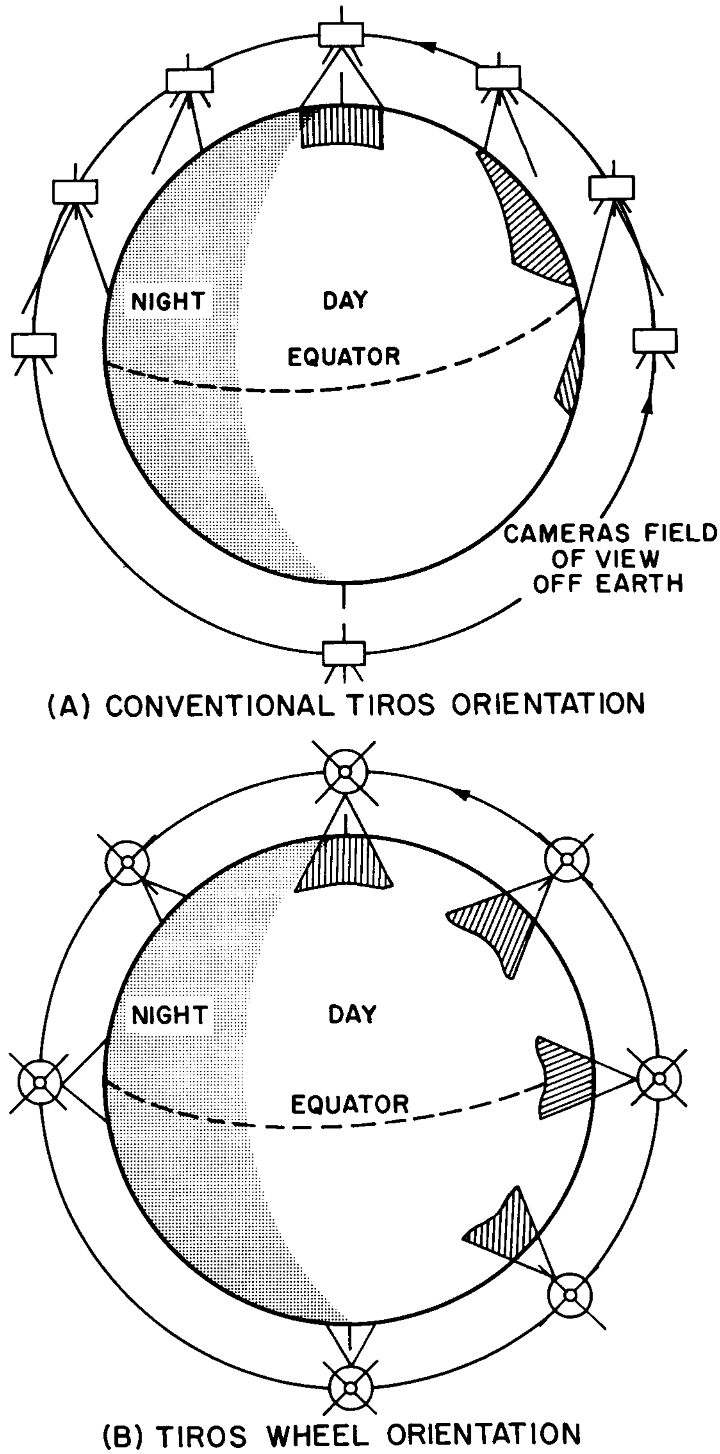


Figure 7-TIROS Picture Coverage Comparison

Spin-Stabilization

A spinning satellite (Figure 7A) normally will not maintain a simple orientation reference with respect to the earth since its spin axis is fixed with respect to space. A reference is derived if the attitude of the spin axis with respect to the earth is known, as well as the angle between the camera and the sun (a "fixed" reference) for each picture taken. Spin-stabilization orients the spacecraft with reference to the earth without wobble or precession about the spin axis by means of a proper selection of the ratio of principal moments of inertia, together with an internal energy absorber. For instance, in the standard TIROS configuration, the spin and camera axes are parallel and space stabilized in the orbit plane. Therefore, the sensors view the earth only during a small portion of each orbit.

The TIROS wheel configuration (Figure 7B) is more efficient in that it provides the advantage of an earth oriented camera system in a spin-stabilized spacecraft so that the cameras look down at the earth from any point in the orbit, thus greatly increasing data coverage capabilities.

The spacecraft spin rate is controlled by three devices after final separation. These spin-control devices consist of the despin mechanism (yo-yo), the spinup rockets, and a magnetic spin-control device.

The yo-yo provides for the initial spindown from the boost-stage stabilization rate ($\sim$120 rpm) to its operational spin-rate ($\sim$10 rpm). This is accomplished by releasing a set of two despin weights which are caged during boost and attached to cables that are wrapped around and hooked to the satellite housing. When released, centrifugal force causes the weights to unwind the cables from the housing. The weights thereby acquire angular momentum from the satellite, which is slowed accordingly.

The spinup rockets (10) are mounted in diametrically opposite pairs under the periphery of the baseplate to provide for coarse increases in the spin rate when commanded to operate by ground command.

The spinup rockets are being replaced by means of a technique wherein the spin rate can be controlled by a magnetic spin-control device similar to a d.c. motor. The magnetic spin-control device permits close, ground-command control of the satellite spin-rate and consists primarily of a coil of wire wound around the periphery of the satellite and a pulse-controlled, solenoid-operated stepping switch. The stepping switch, operating in response to ground-station commands, increases or decreases the amount of current flowing in the coil. Each change in current effects a corresponding change in the magnetic field of the satellite, providing (through the interaction of the magnetic fields of the spacecraft and the earth) the mechanical force necessary for increasing or decreasing the satellite spin rate required for attitude control.

For TIROS, it has been possible to control the attitude of the spacecraft to within a few degrees and, to determine the attitude, after the fact by analysis of the data, to approximately one degree. This is achieved by using both attitude telemetry data from sun and horizon sensors and by geographical referencing from the pictures.

Gyromagnetic Stabilization

Gyromagnetic stabilization (Figure 8) is a simple, three axis, attitude-control system utilizing the principle of magnetic torquing for controlling either spinning or non-spinning earth-orbiting satellites by means of ground-station commands. This system has many desirable features: simplicity, reliability, a potential for long operational life, low weight and power requirements, and adaptability to satellite systems of any size or weight.

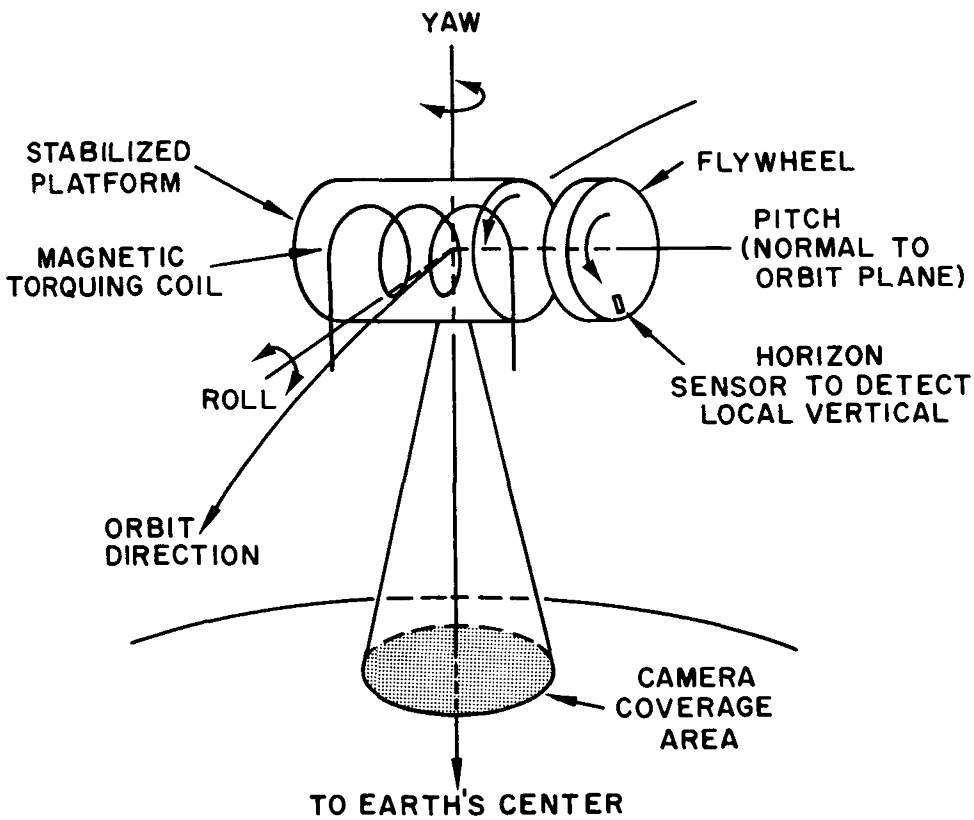


Figure 8-Gyromagnetic Stabilization

The satellite may be thought of as being divided into two parts, one part containing a rapidly spinning unit (the "flywheel"), and the other part, the payload (the "stabilized platform"). The flywheel spins at various rates and is controllable. Its spin can be made to cause the stabilized platform (payload) to rotate through precisely one revolution per orbit. Thus, one portion of the payload structure can be made to face the earth at all times.

The magnetic torquing principle may be compared to the operation of a d.c. motor. In a spinning satellite such as TIROS, the armature may be represented by the coil of wire wound around the periphery of the spacecraft and the permanent magnetic field represented by the earth's magnetic field. By controlling the magnitude and direction of the current in the armature, the interaction of the fields of the armature and the magnet generates a maximum usable torque in one direction (i.e., the fields continually tend to align themselves).

The magnetic torquing principle can be applied to an orbiting, non-spinning satellite such as Nimbus. The interaction between the magnetic coil on the payload and the earth's magnetic field similarly produces a torque which tends to align the payload with the earth's field.

Gravity-Gradient Stabilization

The three-axis passive gravity-gradient system (Figure 9) should be the most reliable of all the attitude-control systems as it requires no power after deployment and operates with the smallest number of moving mechanical parts.

The gravity-gradient torquing system consists of extendible gravity gradient rods that are stored during the launch phase. They are deployed either automatically or by ground command when orbit has been achieved. At the present state-of-the-art these rods, which are very long ($\sim$100 feet), represent a serious problem in mechanical design since they must be flexible enough to store but must not flex under temperature change when extended which would introduce disturbing torques.

The gravity-gradient system causes a satellite to orient itself with the axis of minimum moment of inertia along the vertical, and with the axis of maximum moments of inertia perpendicular to the orbit plane. This principle causes the three moments of inertia to be as much different as possible to provide larger restoring torques, and thus to permit attitude control within a short time.

Damping control is required to reduce perturbing forces caused by solar radiation pressure, atmospheric drag, interactions with the geomagnetic field,

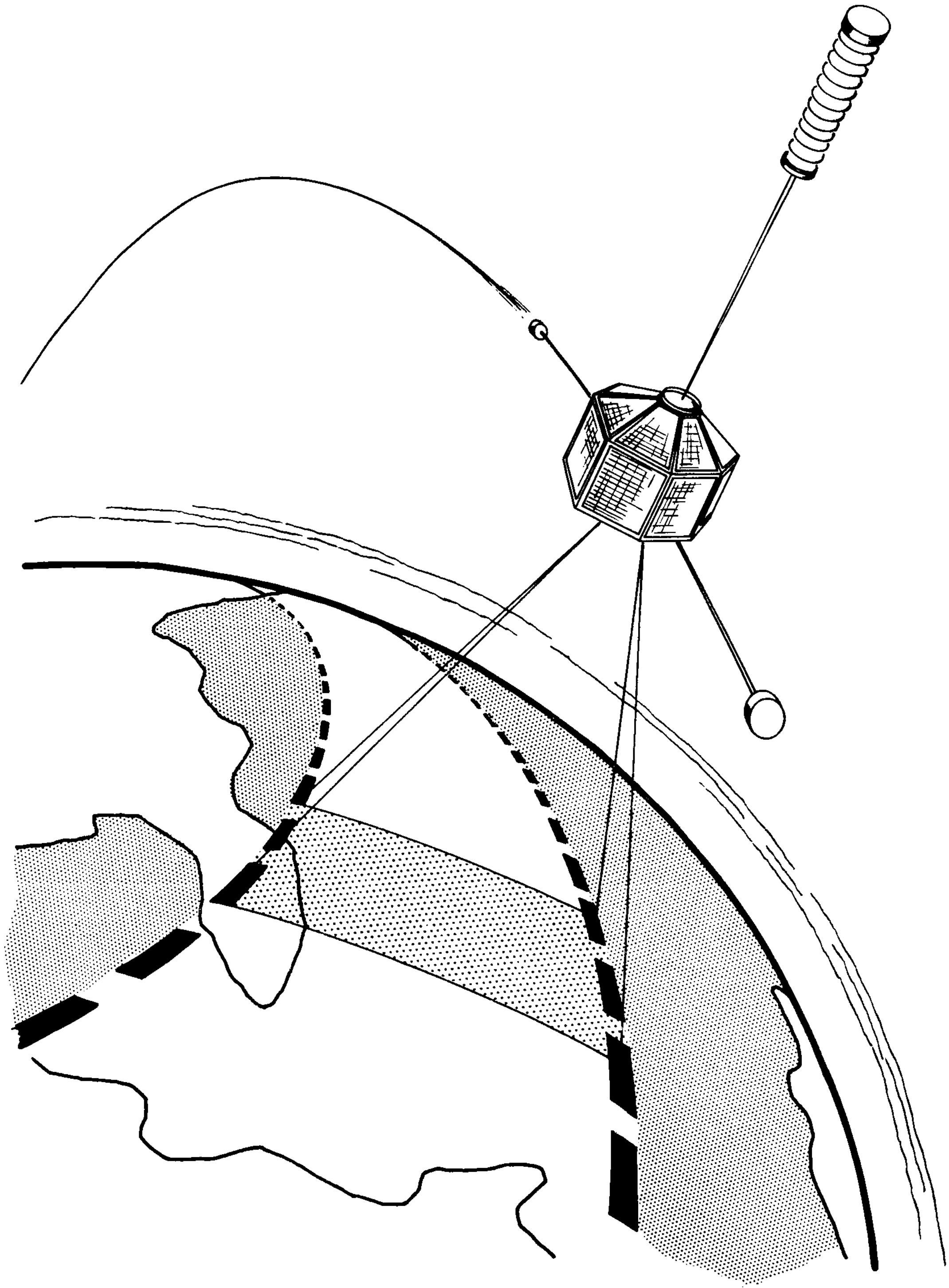


Figure 9–Gravity-Gradient Configuration

mechanical displacement, and rotation of satellite parts. Damping control is provided by using a lossy spring or hysteresis bars.

The best pointing accuracy achieved to date has been in the order of ±5 to 10 degrees with no moving parts (not even camera shutters or relays) on board. However, because of the attractiveness of this technique from the viewpoint of long life and reliability, considerable effort is being expended to improve the stability.

SENSORS

The most useful meteorological function performed by satellites to date has been to provide observations of the cloud cover of the earth, and to demonstrate that regular and continuous observations of the cloud cover can be effectively integrated into a meteorological system. Both TV-picture and infrared-radiometric sensing systems have been employed, and both techniques have demonstrated that the data can be used to gain a better understanding of the earth's atmosphere. The TV pictures, used operationally for more than two years, have been limited to the sunlit portion of the earth because of inherent sensitivity limitations in the simple vidicon television system presently employed. The infrared systems have demonstrated the ability to provide observations of the nighttime cloud cover and information leading to the determination of cloud heights.

TV Systems

The primary characteristic of the vidicon camera tube which has made it exceptionally well-suited to satellite application is the image-storage capability of the vidicon target surface. The photosensitive target material can store an image projected on its surface for several seconds after an exposure of only a few milliseconds. This allows time for a slow-scan readout of the image and results in a frequency-bandwidth compression of the video signal. Thus, a narrower radio frequency bandwidth (compared to conventional television bandwidths) can be employed to transmit the data to ground or to accumulate the data on a relatively simple tape recorder before its transmission to ground.

In the TIROS satellites, a half-inch diameter vidicon tube has been employed, providing a 500 scan-line image. The exposure time is 1.5 milliseconds with a readout time of 2.0 seconds. Thirty-two pictures can be stored on the tape recorder and played back to the ground station in less than two minutes over a channel less than 1/2-megacycle wide. When the satellite is in range of the ground station, the pictures can be transmitted directly, bypassing the tape recorder. The cameras have been used in pairs for redundancy and are operated as shown in the functional block diagram (Figure 10).

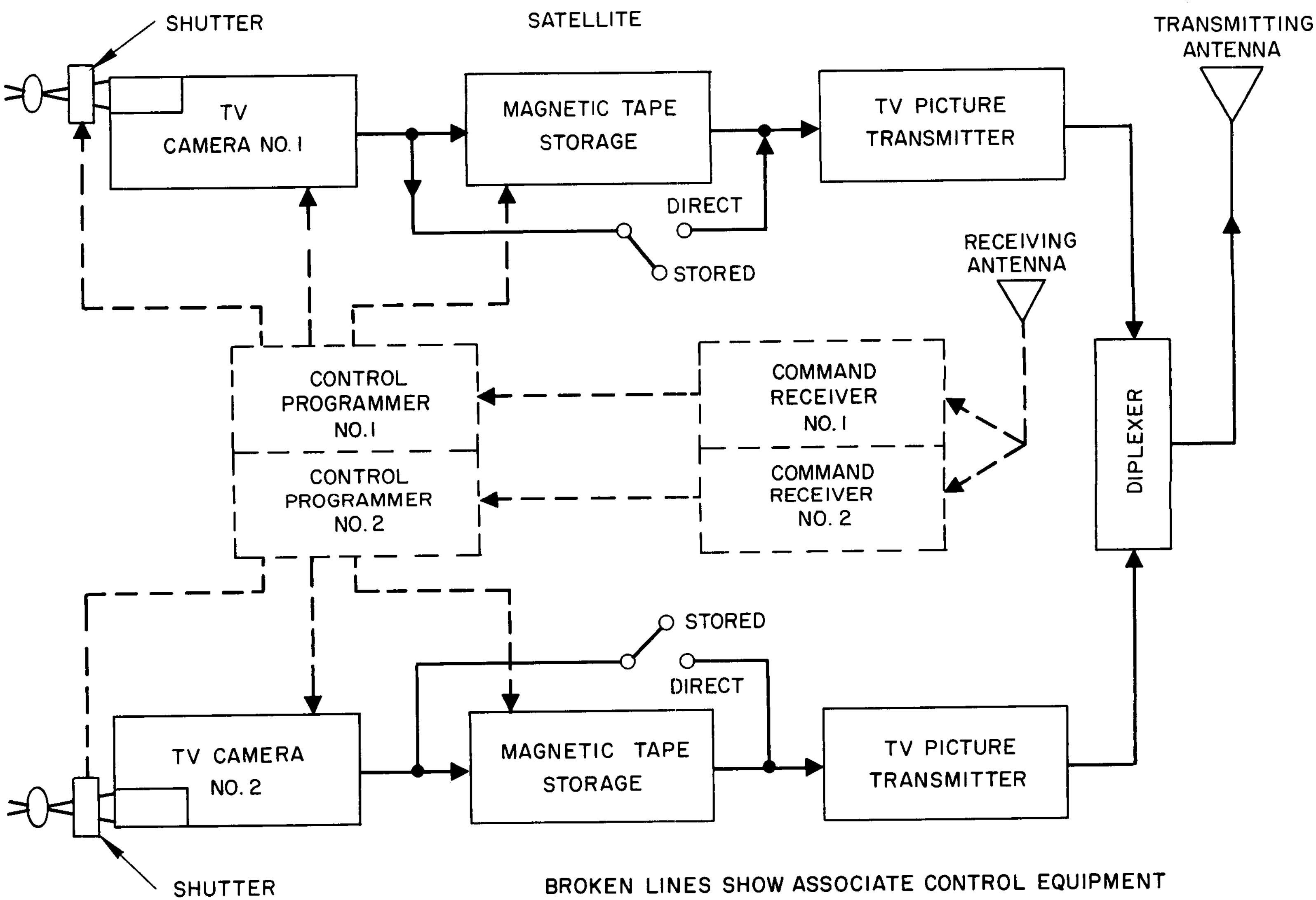
In the advanced vidicon camera system designed for Nimbus, three identical cameras are mounted in a trimetregon arrangement with overlapping fields of view. The three adjacent pictures are aligned across the direction of the orbit and provide television coverage of a 420 by 1400 nautical-mile area from an altitude of 500 nautical miles. Each camera employs a one-inch vidicon camera tube providing an 800-scan-line image; each camera is equipped with a variable iris which permits the exposure to be optimized for solar elevation angles ranging from 90 degrees down to approximately 4 degrees. The three cameras are exposed simultaneously for 40 milliseconds, which is practical only on a three-axis stabilized platform, and are readout in parallel in 6.25 seconds resulting in a bandwidth compression similar to that described earlier. The three pictures can be simultaneously transmitted or recorded on a four-track tape recorder together with reference tones and timing signals. Each of the video tracks can store 57 pictures. Each camera is equipped with built-in calibration facilities for both sweep and gray-scale linearity.

Table 1 shows the relationship of orbit altitude to area coverage and resolution for three different lens/camera combinations and typical coverage for the Nimbus trimetregon arrangement.

Automatic Picture Transmission (APT)

The APT system is designed to provide wide-angle cloud-cover pictures in real time to local ground stations for immediate use. The equipment employs the same basic principles as the TV cameras described above and is capable of taking pictures continuously throughout the sunlit portion of each orbit.

The APT system consists of an 800-scan-line vidicon, an FM transmitter, and associated electronics. The vidicon is similar to other 800-scan-line vidicons except for the addition of a polystyrene layer to provide extended image-storage capability. The tube is operated through the prepare, expose, and readout phases by varying the mesh potential with respect to the target potential; i.e., the image is projected on a prepared photoconductive layer, then transferred (developed) by potential change to the storage layer for readout. The prepare, expose, and develop operations are accomplished during the first eight seconds of each 208-second picture cycle. During the next 200 seconds, the picture information is read out line by line at a scanning rate of four lines per second and transmitted to the APT ground stations. Start and phasing signals are transmitted to the ground stations at the beginning of each picture to synchronize the ground



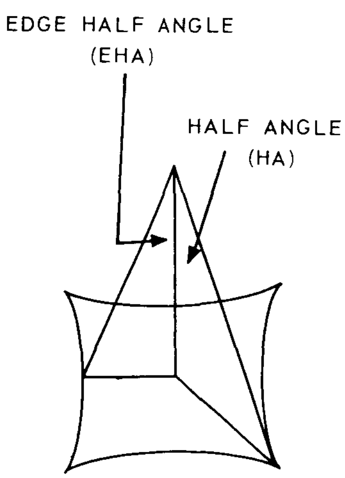
BROKEN LINES SHOW ASSOCIATE CONTROL EQUIPMENT

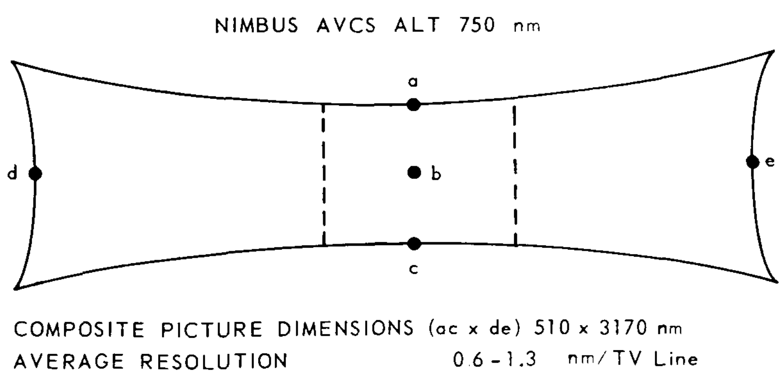
Figure 10-TV Picture System, Block Diagram

Table 1
Picture Coverage Resolution and Viewing Angle for Different Sensor Lenses and Spacecraft Altitudes

Altitude	375 nm			500 nm			750 nm		
Lens	A	B	C	A	B	C	A	B	C
Picture size-diameter in nm inscribed in circle	440	720	770	600	960	1050	900	1500	1600
Resolution in nm/TV line at Z = 0°	0.9	1.4	0.9	1.15	1.8	1.2	1.7	2.7	1.8
Resolution in nm/TV line at Z = 65°	2.1	3.2	2.1	2.7	4.3	2.9	4.1	6.4	4.3
Z at center edge	34°	48°	50°	35°	50°	53°	38°	55°	58°
Z at corner	46°	61°	64°	46°	64°	68°	50°	74°	80°

A = HA = 39°, EHA = 30°, W/500 line vidicon
B = HA = 52°, EHA = 42°, W/500 line vidicon
C = HA = 54°, EHA = 44°, W/800 line vidicon
nm = nautical miles





station facsimile recorders with the vidicon scanning beam. The system has been so designed that only relatively simple and inexpensive ground station equipment is required.

Infrared Sensors

A number of infrared radiometric experiments have been flown on TIROS satellites which have utilized the combination of the spinning motion of the satellite and its motion along the orbit to provide a means of scanning the earth's surface. These measurements have provided some very useful information on the earth's albedo (0.2 to 6 micron), on the water vapor emission band (5.9 to 7.0 micron), on the thermal emission from the earth (7.5 to 35 micron), and on the near-visible portion of the spectrum (0.5 to 0.75 micron) for reference and comparison with the TV systems. The most promising observations have been made in the 8- to 12-micron "window." In this window, the radiation patterns have provided a remarkably good description of the earth's cloud cover in both daylight and nighttime areas, thereby indicating a potential for full global coverage with a single sensing system.

A typical radiometer consists of an optical system, a photoconductive detector, associated electronics, and a mechanical drive-all enclosed in a suitable housing. In contrast to television the radiometer forms no image, but instead integrates the energy received from the target. Composition of a picture is achieved by a scanning mirror technique. The mirror, located in the radiometer, scans the earth as the satellite advances in its orbit. The mirror reflects the received energy and focuses it on a mechanical chopper, which provides the necessary modulation of the energy signal. The modulated signal actuates the detector which produces an electrical output signal corresponding to the energy-signal intensity. The output is recorded on a tape recorder designed to store the data taken for the full duration of an orbit or for multiples thereof.

The data are recorded at the ground station and converted from analog to digital form to permit computer processing. Data are then re-recorded on multichannel tape which carries the data as well as all pertinent reference data such as time and location coordinates; this multichannel tape is ready for machine processing to produce meteorological information.

Plans for two improved infrared radiometers for the TIROS wheel satellite are presently being investigated. One of these is a modified Nimbus five-channel medium-resolution radiometer (MRIR) to yield a one or two channel instrument operating in the 10-11 micron window. The present design concept of the Nimbus MRIR would be retained; however, the size of the radiometer casting, scanning mirror, and electronics module would be reduced to reflect the reduction in the number of channels. Also, the nominal scanning rate, field of view, and information bandwidth would be changed to be compatible with the satellite's orbital parameters and the data gathering requirements of the mission. The rotation of the scanning mirror would be phase-synchronized with the spin of the wheel satellite, resulting in a scan pattern having a diagonal orientation with respect to the satellite velocity vector and passing through the subsatellite point.

The other infrared system which is being actively investigated is a multi-sensor medium-resolution instrument. This design consists of 16 individual small reflective optics and thermopile detectors mounted in a stepped fashion around the cylindrical surface of the spinning wheel. The optical axes of the sensors are inclined at different angles to a plane normal to the spin axis. The sensors are sequentially sampled as the axis of each instantaneously lies in a plane passing through the spin axis and subsatellite point, resulting in a transverse row of scan spots which make up a swath extending about 1,000 miles over the surface of the earth centered about the subsatellite point.

GROUND STATIONS

The location of ground stations to read out data and to control the operation of the satellite is a complex problem of geography, logistics, and communications, and is a major element in the design of a satellite system. Locating stations is particularly difficult for a polar orbiting satellite because the ground station for this system should be located either at the North or South Poles in order to "see" and communicate with the satellite at least once per orbit or else the data will be delayed by some multiple of an orbital period. However, the requirement for continuous wideband communications (approximately 50 to 100 kc) to transmit the data to a central processing point makes it almost impossible, or at least impractical, to locate fulltime operational facilities within the Arctic Zones. This in turn makes it necessary to use at least two ground stations widely separated in longitude to provide data recording facilities capable of storing at least two orbits of data on board the satellite.

TIROS I

The TIROS I satellite system is an experiment to obtain cloud-picture coverage of the entire sunlit part of the earth on a daily basis using a spin-stabilized satellite.

To satisfy the global coverage requirement, a polar or near-polar orbit was indicated; because of its special advantages for a meteorological satellite, a sun-synchronous orbit was selected. Advantages of a sun-synchronous orbit are constant ground illumination and relatively constant satellite/sun angle which facilitates picture interpretation and simplifies the thermal and power supply designs of the spacecraft. Also considered to be an advantage by many meteorologists is the fact that all cloud pictures will be taken at the same local time; i.e., if the satellite is launched at 10:00 a.m., then the cloud pictures for every orbit will be taken at 10:00 a.m. The time recommended for this experiment is 3:00 p.m. in order to provide the meteorologists with late-day observations.

In the standard TIROS configuration, the spin axis and the camera axis are parallel. Since the spin axis is fixed in space and is stabilized in the orbit plane, the cameras view the earth for only a small part of the orbit as shown in Figure 7A. If a satellite of this configuration was to be launched in a sun-synchronous orbit and the spin axis steered to a position in the orbit such that it was vertical midway in its useful area, then it could provide about 50 degrees of latitudinal coverage.

However, as indicated earlier, TIROS has a wheel configuration in which the cameras are positioned radially instead of parallel to the spin axis, which is much more efficient. The cameras can observe the entire sunlit part of the orbit, nominally about 120 degrees. A further advantage in the system as designed for TIROS I is that, by means of a fairly simple horizon sensor triggering arrangement for the camera shutter, all of the pictures are taken straight down. Taking the pictures straight down will provide a much more uniform product for the meteorologist to analyze and will require a minimum amount of rectification to correct for picture distortion.

TIROS I will use two ground stations which together will intercept nearly all of the orbital passes (80 percent). The polar station, located near Fairbanks, Alaska, is not quite far enough north to see all of the passes (Figure 11). Even the addition of an East Coast station at Wallops Island, Virginia, did not quite solve the problem. A compromise was made by providing tape-recorder storage capacity on board the spacecraft to accommodate at least four orbits of picture data. The problem of intercepting all the passes is of considerable concern since the orbits that cannot be seen from either station generally occur out over ocean areas where information on the weather is at a premium.

The most serious problem was encountered in the design of the camera system to provide continuous coverage with no gaps at the nominal TIROS orbit altitude of 380 nautical miles. With the standard TIROS one-half inch vidicon and the widest angle lens (104 degrees) practical for these applications, a gap of approximately 900 nm would exist at the equator between succeeding orbits; this

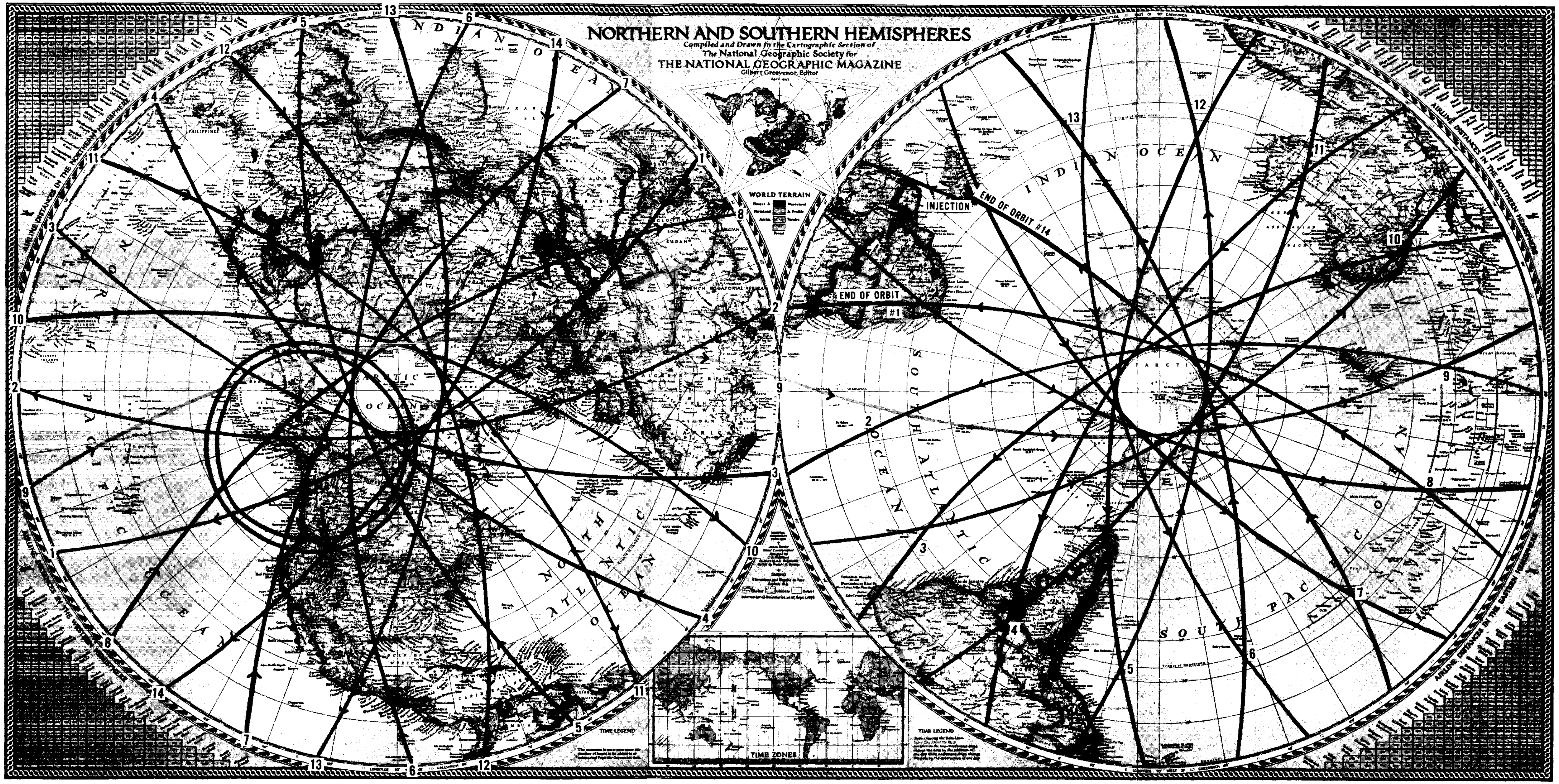


Figure 11-Orbital Coverage from Fairbanks, Alaska

gap would narrow down away from the equator until contiguity is achieved at a latitude of approximately 68 degrees. It is obvious that even the use of one-inch vidicon cameras would not close the gap.

The solution to the problem was to cant the cameras. The optic axes, instead of being parallel to the spin axis as in previous TIROS satellites or at right angles to the spin axis as originally conceived for the wheel configuration, will be canted approximately 26.5 degrees to each side of the plane of rotation. Figure 12 shows the area covered by a single frame of one of the cameras. When

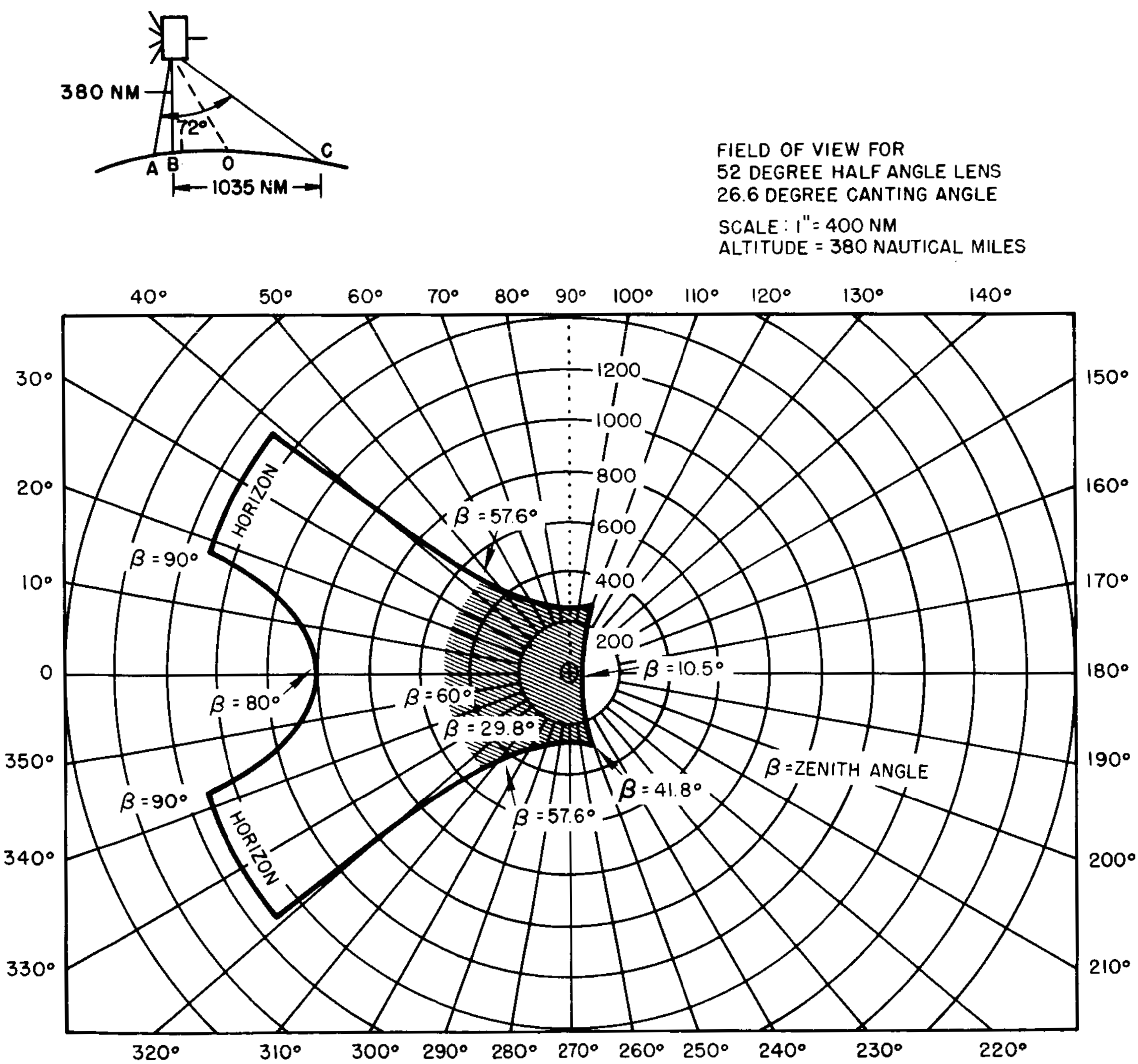


Figure 12-TIROS I Camera Field of View for 380-Nautical-Mile-Orbit

combined with the mirror image provided by the second camera, a "butterfly" pattern is created that extends approximately 1000 nm to either side of the satellite track and provides adequate overlap at the equator.

Some compromise was necessary in zenith angle which exceeded design objectives by a few degrees. Specifically, the zenith angle at the point of contiguity at the equator is 68 degrees although 65 degrees is the preferred maximum value. One other limitation of the canted camera design is that some of the redundancy afforded by the use of two camera systems is lost since both camera systems are required to provide full global coverage.

Regretably, it was not practical to include in this spacecraft either an infrared sensor system or a further test of the APT camera system. However, it is believed that the experiment to obtain global picture data will provide valuable information leading toward the development of an operational meteorological satellite system.