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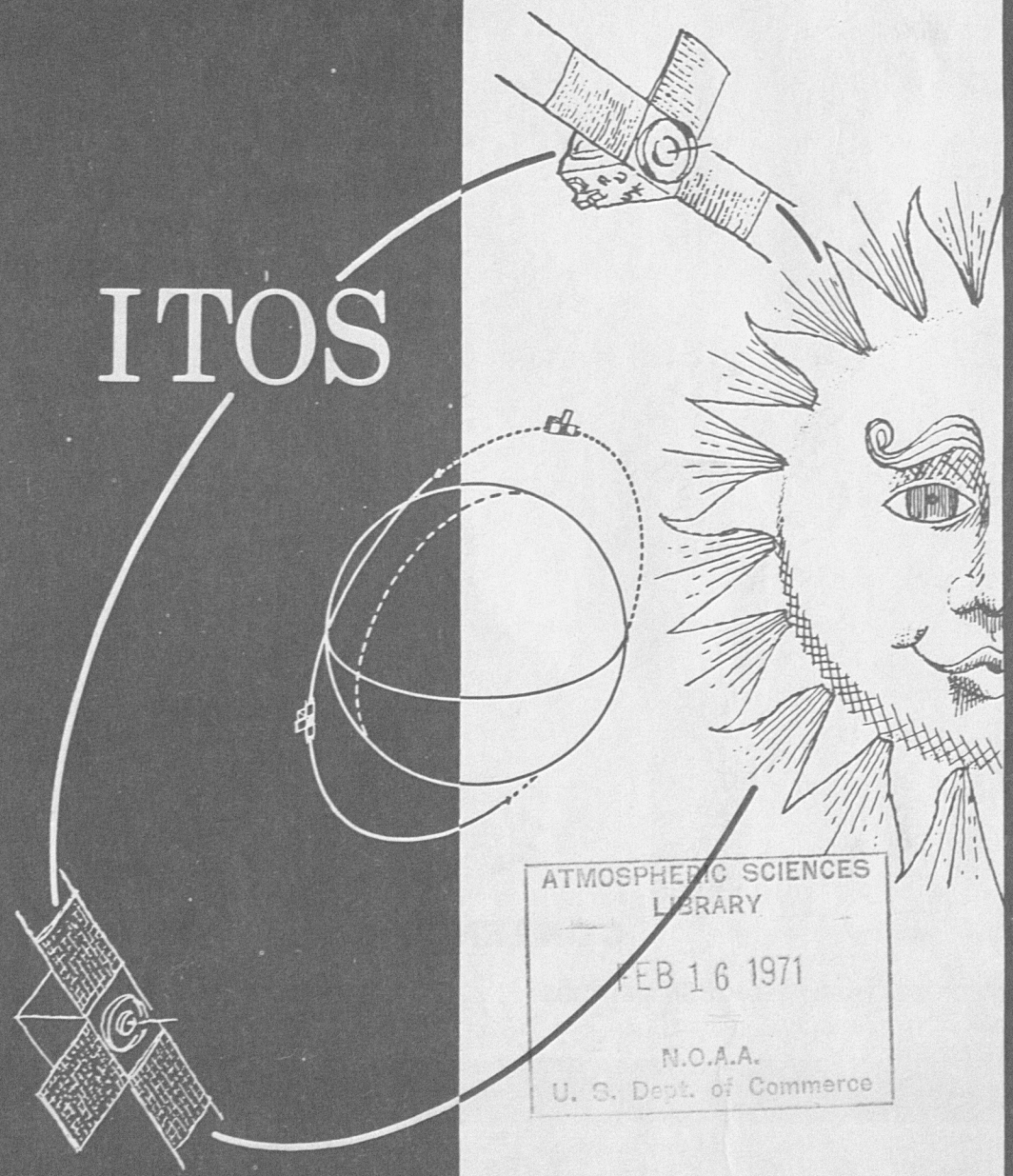
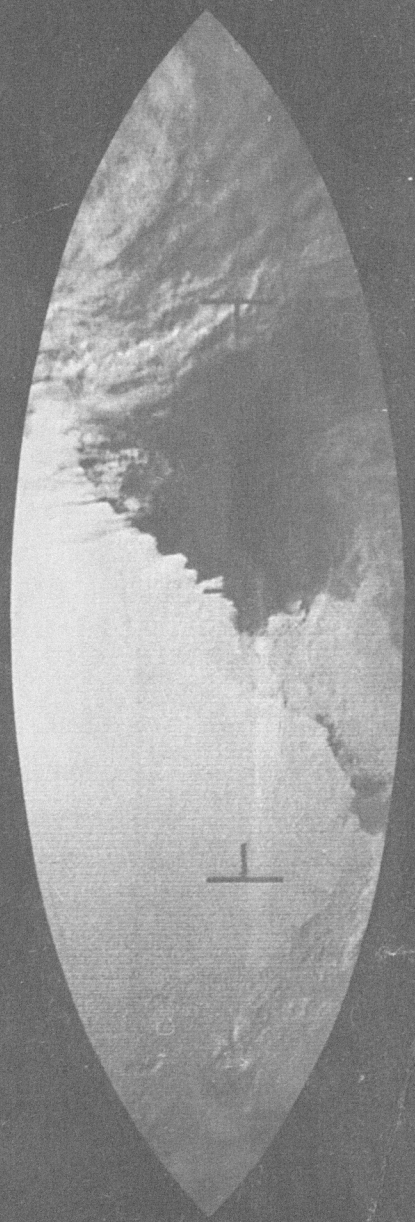
U. S. Goddard Space Flight
Center, Greenbelt, Md.

ITOS





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ITOS

NIGHT - DAY METEOROLOGICAL SATELLITE

ITOS

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National Oceanic and Atmospheric Administration
TIROS Satellites and Satellite Meteorology

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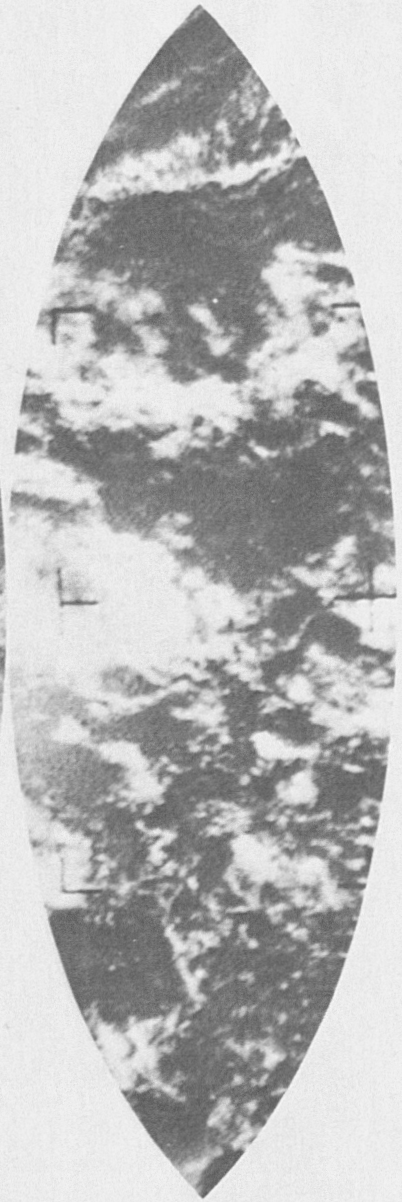

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DEVELOPMENT OF WEATHER PREDICTION METHODS

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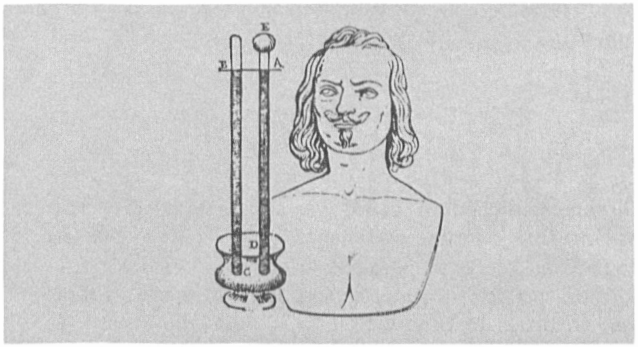
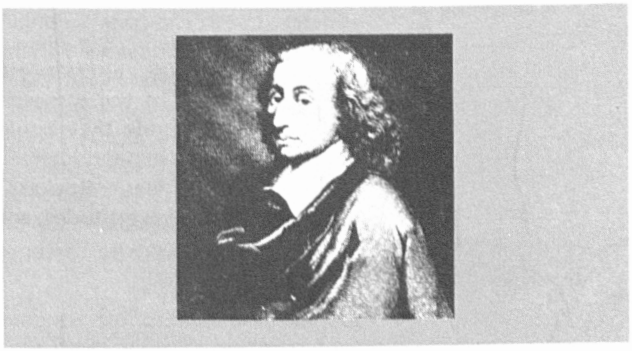


TORRICELLI BAROMETER

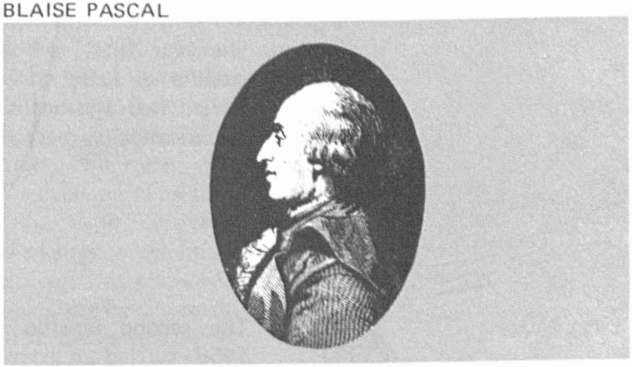
Since 1648, when mathematician Blaise Pascal had his mountain-climbing brother take Torricelli's barometer up an Alp to register the lower atmospheric pressure that prevails at high altitudes, scientists have had proof that characteristics of the air change with height.



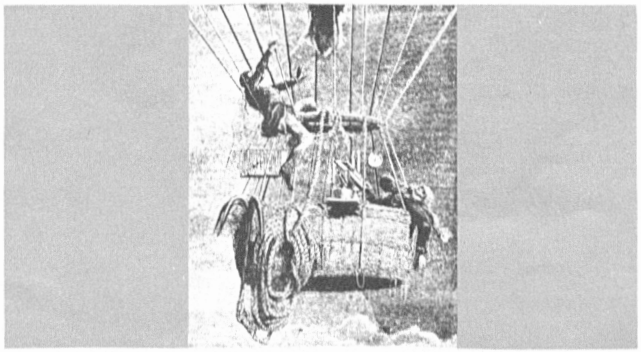
BLAISE PASCAL

MONTGOLFIER BALLOON

But—they could not study these characteristics at locations higher than they could reach by climbing mountains or sending instruments aloft on kites. One answer to their problem came in France in 1783, when the Montgolfier brothers invented the hot-air balloon. In the same year physicist Jacques Charles undertook the first manned balloon flight and carried a barometer along to measure altitude.

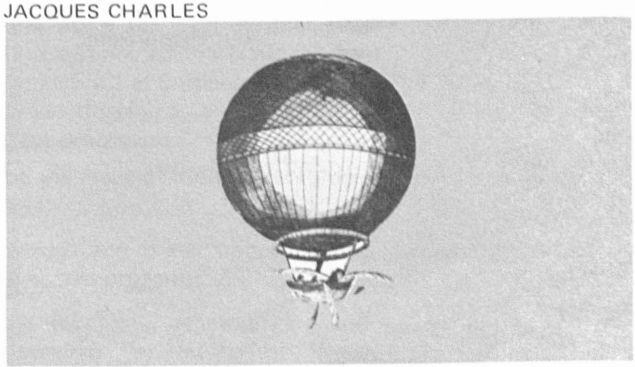


JACQUES CHARLES



GLAISHER BALLOON FLIGHT

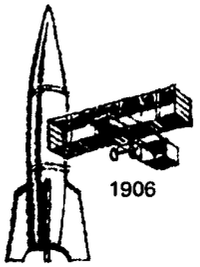
Two years later, in 1785, Dr. John Jeffries performed the first scientific measurements of temperature, humidity, and barometric pressure during a balloon flight at heights up to 9000 feet. Lack of oxygen above 29,000 feet made manned balloon flight risky at those altitudes; James Glaisher, who made 28 balloon ascents between 1862 and 1866, was almost asphyxiated while trying to sample the composition of air at 29,000 feet.



JEFFRIES BALLOON FLIGHT

1893

In 1893, meteorologists sent instruments up in unmanned balloons to register altitudes over 60,000 feet. At about 65,000 feet, the balloons burst and floated back to earth carrying the instruments.



1906

1946

By 1906, aircraft offered greater flexibility in making studies of the atmosphere, but these were still limited in the altitude they could reach. In the mid-1940's, rockets carried meteorological instruments up to altitudes around 80,000 feet. Rockets had two advantages: the ability to reach high altitudes, and the ability to travel speedily.

1958

The year 1958 saw the launch of Vanguard 2, the first satellite designed to register atmospheric conditions. It carried two photocells sensitive to light, but did not carry out its mission because of excessive spacecraft nutation.

1959

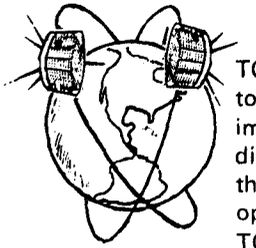
The second weather satellite—Explorer 7, launched in 1959—carried an elementary television system for scanning earth's cloudcover. The pictures it obtained were crude, but encouraging.

1960

The first satellite to be operationally successful in meteorological work was TIROS, the television and infrared observation satellite, launched in 1960. TIROS 1, first of a family of nine, carried television cameras to photograph the earth's cloudcover; the other eight carried infrared sensors in addition to TV cameras, in order to measure the temperatures radiated by the earth's surface. However, the thousands of high-quality pictures taken by the TIROS satellites were only of the sunlit portions of the orbits, and viewing ability was restricted.

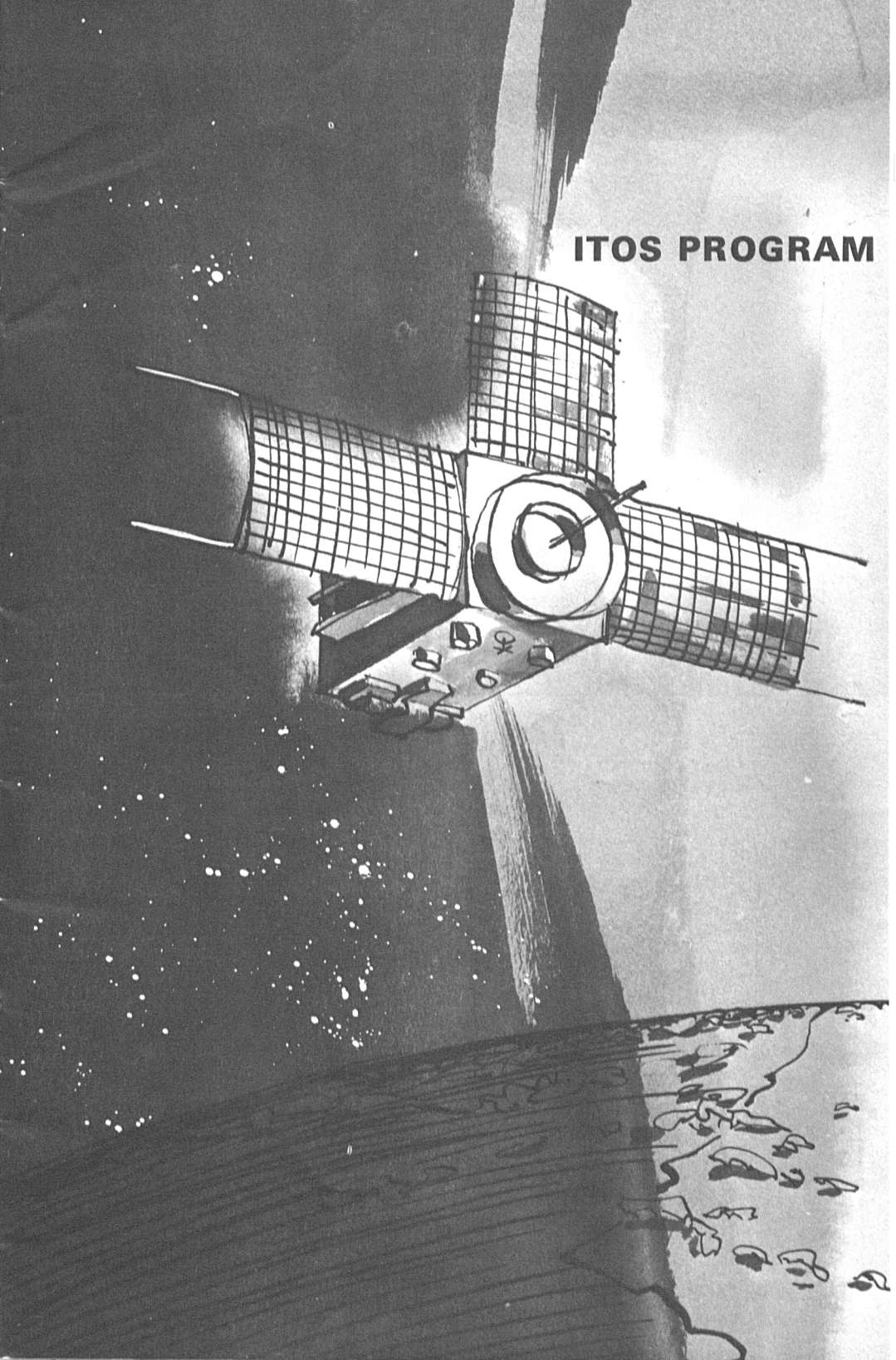
1964

Nimbus, launched in 1964, was the first satellite able to provide both daytime and nighttime coverage of the earth's cloudcover on a daily basis over long periods of time. Nimbus carried TV cameras and infrared scanning radiometers in order to produce pictures of the sunlit and nighttime portions of the orbit respectively. Although not an operational system, Nimbus represented a big step forward in the experimental use of satellites for research and development in meteorology.



1966

TOS, launched in 1966, used two satellites simultaneously to provide greater weather coverage. Although TOS carried improved sensors and photographed meteorological conditions from a higher altitude than either TIROS or Nimbus, thereby providing full global coverage on a daily basis, its operations were still limited to daytime. After launch the TOS spacecraft were redesignated ESSA 1 through 9.



ITOS PROGRAM

The improved TIROS operational satellite (ITOS) program, an enlargement of TOS program capabilities, is a significant advance in the evolution of operational weather satellites. In comparison to the daytime weather coverage available from TOS, ITOS provides both day and night weather coverage of the entire earth from space. This additional capability will double the amount of weather information from each satellite.

The ITOS program is a joint effort of the National Aeronautics and Space Administration (NASA) and the Department of Commerce (DOC). NASA's Goddard Space Flight Center (GSFC) at Greenbelt, Maryland, is responsible for spacecraft and ground-system design and development, the launch vehicle and launch operations, initial satellite checkout in orbit, and satellite evaluation. Under GSFC technical direction, the ITOS spacecraft was designed and built by RCA's Astro Electronics Division. The DOC's Environmental Science Service Administration (ESSA) at Suitland, Maryland, is responsible for satellite operations, including the ground system, and for acquiring, handling, processing, and distributing the weather data. ESSA is also responsible for recommending satellite replacement as necessary.

To meet ESSA requirements for obtaining systematic worldwide day-and-night weather observations over long periods of time from a single spacecraft, the ITOS program will use a series of spacecraft. TIROS-M, first in the series, is a research and development spacecraft serving as a prototype for the ITOS A, B,* . . . spacecraft. Television cameras proven on the TOS spacecraft will furnish daytime picture coverage of the sunlit portion of the earth; infrared radiometers, sensitive like those proven on Nimbus spacecraft to surface temperatures of the earth, sea, and cloudtops, furnish both daytime and nighttime coverage. ITOS also will furnish secondary data such as measurements of the amount of heat radiated into space by the earth, and proton and electron flux activity near the earth.

The satellites transmit their television and infrared data directly to users around the world for local weather prediction, and through ground stations to the National Environmental Satellite Center (NESC) at Suitland, Maryland, for processing and worldwide dissemination. Secondary data are also sent to NESC for processing.

Equally important is the use made of these meteorological data:

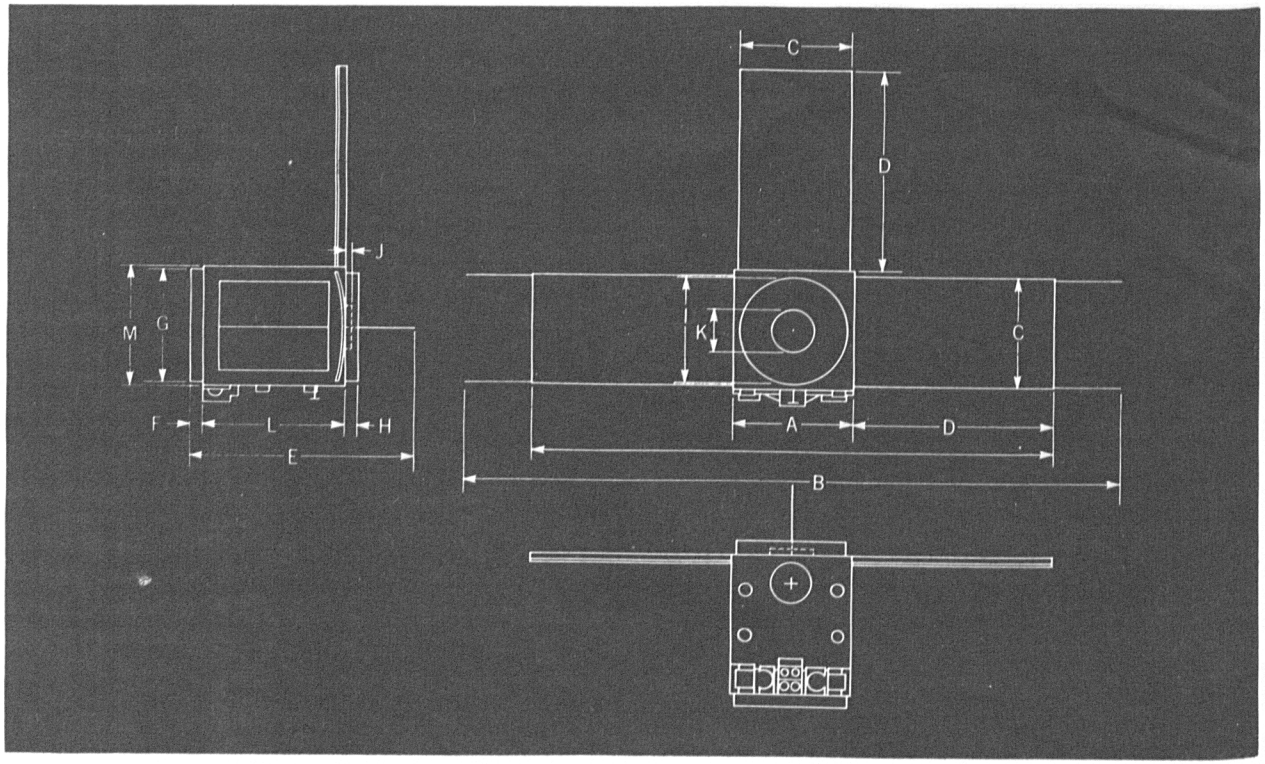
- To provide knowledge and better understanding of the atmosphere and its processes
- To investigate the feasibility of modifying and controlling the weather by means of space technology

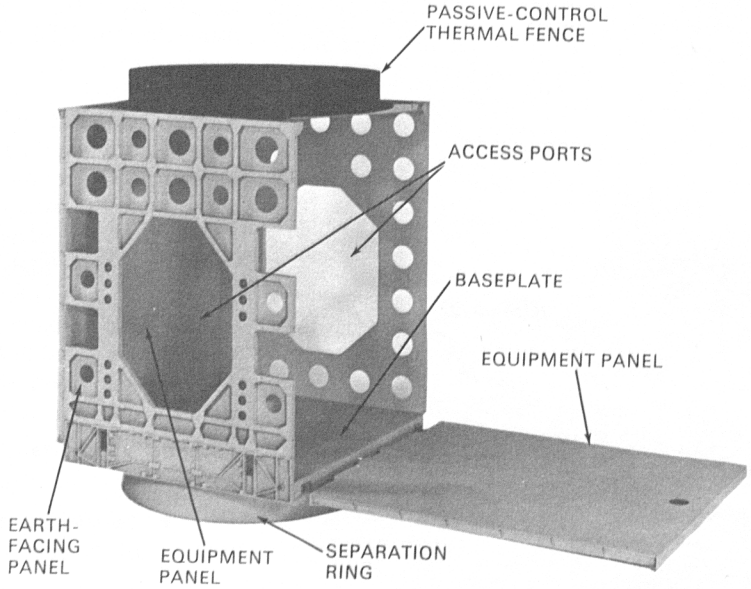
**Redesignated ESSA 10, 11, . . . after launch.*

PRINCIPAL DIMENSIONS

		Inches
Baseplate width	(A) -	40
Width, overall (including solar panels extended and antennas)	(B) -	258.12
Solar panel width	(C) -	36.38
Solar panel length	(D) -	65.15
Length, overall (including command and beacon/telemetry antenna and separation ring)	(E) -	74.54
Separation ring, height	(F) -	5.60
Separation ring, diameter	(G) -	38
Thermal fence outer cup, height	(H) -	4.81
Thermal fence outer cup, diameter	(I) -	36
Thermal fence inner cup, height	(J) -	1.94
Thermal fence inner cup, diameter	(K) -	14.70
Equipment panel length	(L) -	48.6
Equipment panel height	(M) -	40

Weight—678 pounds

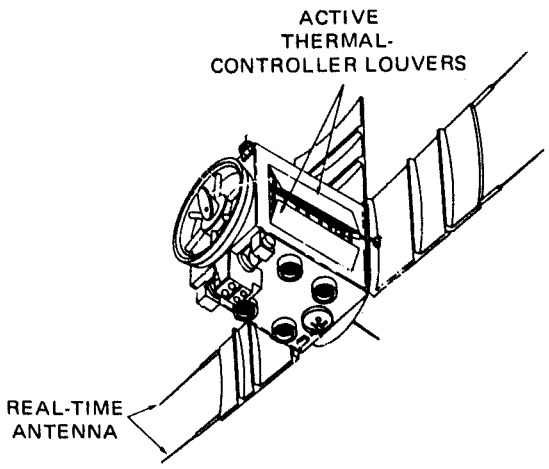


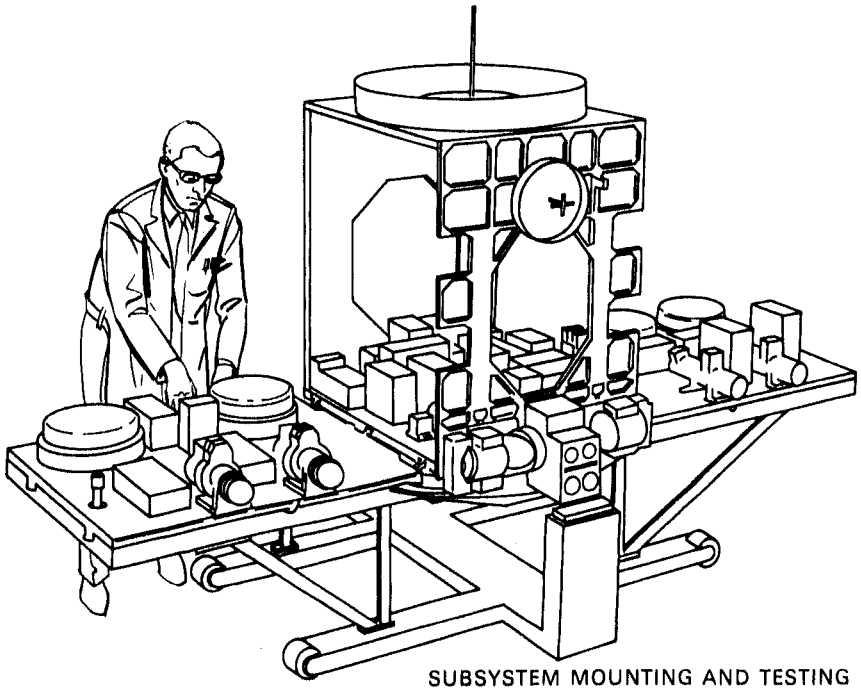


ITOS BASIC STRUCTURE

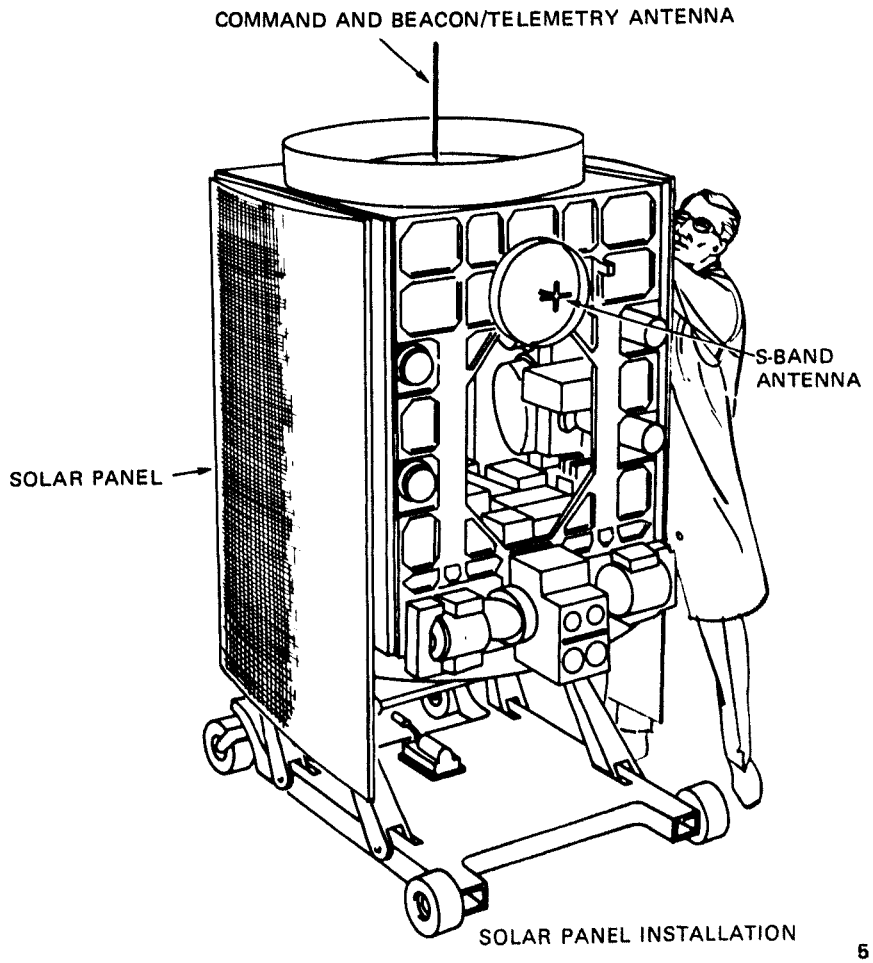
STRUCTURE

The ITOS spacecraft is a rectangular box specifically constructed to withstand the anticipated launch-vibration environment and to allow for future growth with minimum design changes. Three sides of the structure (a baseplate and two equipment panels) support the sensors and electronic equipment. The hinged equipment panels fold down to form a flat work area for installation and testing of components and subsystems. During reassembly, the unfolded equipment panels join to the side and top structures to form the spacecraft. A three-panel solar array hinged to the top edges of the spacecraft is folded at launch and deployed by actuator devices after the satellite has achieved orbit. Two of the solar panels serve as a mounting surface for two pairs of half-wave dipole antennas used to transmit real-time sensor data; these antennas, hinged to the ends of the solar panels, are folded during launch and automatically deployed by springs when the satellite has achieved orbit. The end of the spacecraft continuously exposed to the sun carries a passive-control thermal fence, consisting of two concentric cylindrical fins. A monopole antenna used for command reception and beacon/telemetry transmission projects from the center of the thermal fence. Active thermal-control louvers on the exterior of the two equipment panels operate with the thermal fence to maintain the spacecraft heat balance. The S-band antenna on the earth-facing side of the spacecraft is a crossed dipole above ground plane. A separation ring attached to the baseplate mates the baseplate of spacecraft to the launch vehicle. The design uses redundancy wherever possible to allow for component breakdown that could result in total mission failure.





SUBSYSTEM MOUNTING AND TESTING



SOLAR PANEL INSTALLATION

SPACECRAFT SUBSYSTEMS

The spacecraft consists of two primary sets of systems: the basic spacecraft system, and the sensory system.

The basic spacecraft system that enables the sensory system to perform its task includes the following subsystems:

- Dynamics and attitude control
- Power supply
- Thermal control
- Command
- Communications

The sensory system consists of two sets of subsystems:

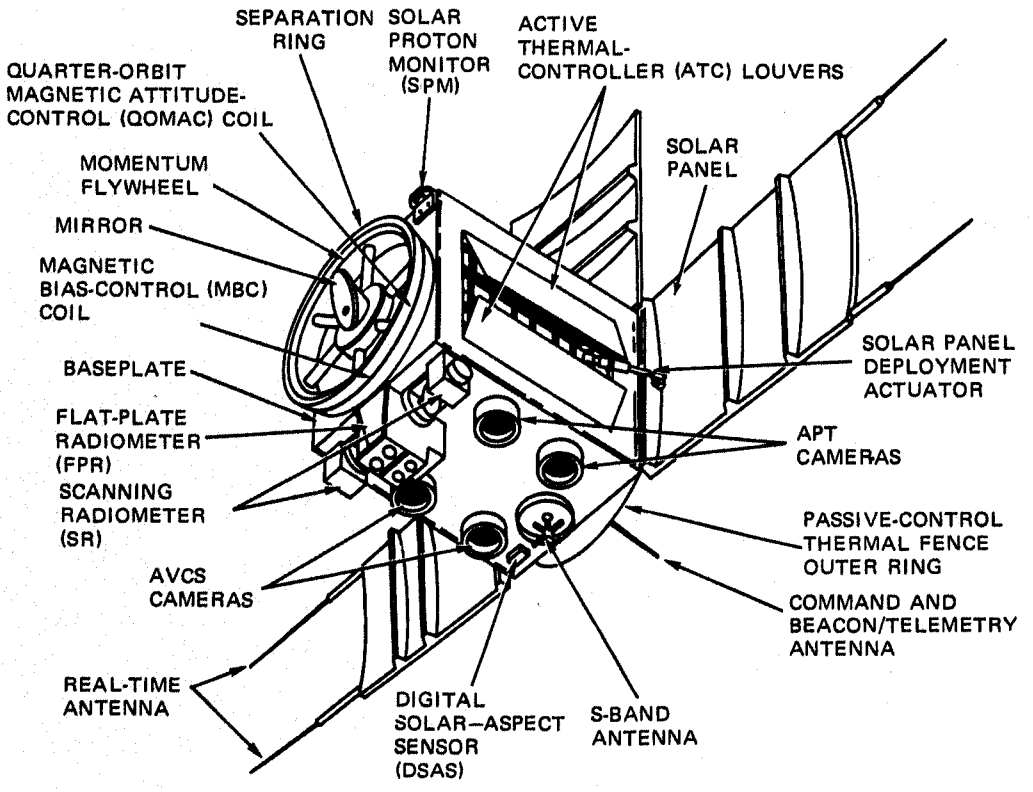
Primary Subsystems

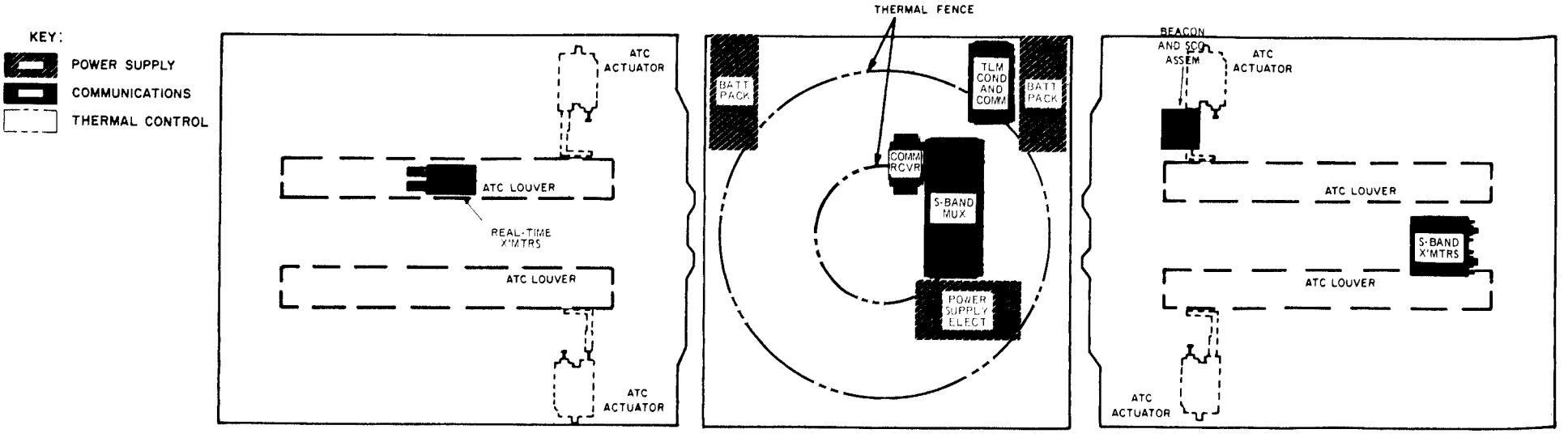
- Advanced vidicon camera subsystem (AVCS)
- Automatic picture transmission (APT)
- Scanning radiometer (SR)

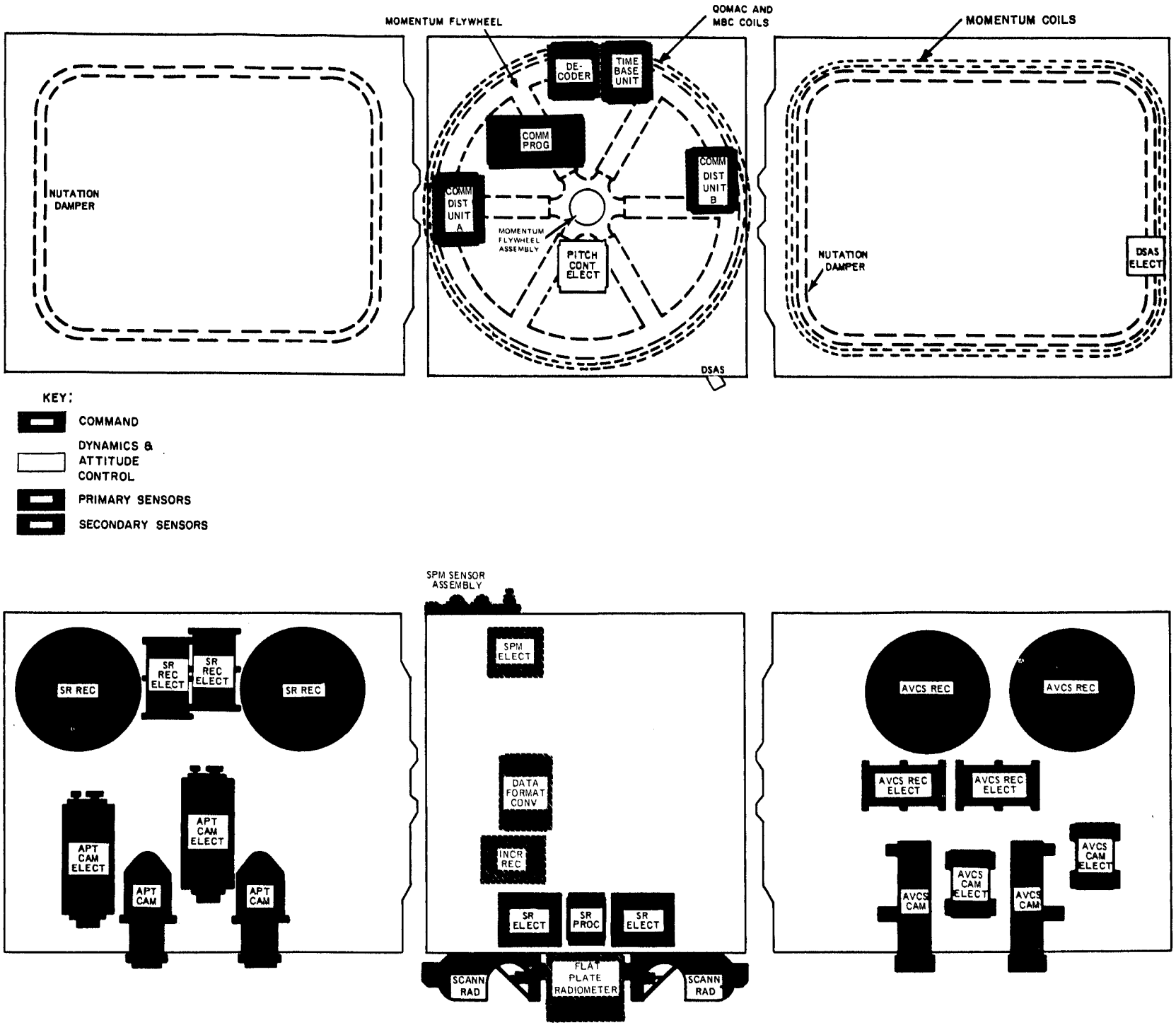
Secondary Subsystems

- Flat-plate radiometer (FPR)
- Solar proton monitor (SPM)
- Data-format converter (DFC)
- Incremental tape recorder (ITR)

All subsystems except the secondary subsystems use redundancy to achieve long satellite life.






MOMENTUM FLYWHEEL
QOMAC AND MBC COILS
MOMENTUM COILS
NUTATION DAMPER
DE-CODER
TIME BASE UNIT
COMM PROG
COMM DIST UNIT A
COMM DIST UNIT B
MOMENTUM FLYWHEEL ASSEMBLY
PITCH CONT ELECT
DSAS
NUTATION DAMPER
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DYNAMICS & ATTITUDE CONTROL
PRIMARY SENSORS
SECONDARY SENSORS
SPM SENSOR ASSEMBLY
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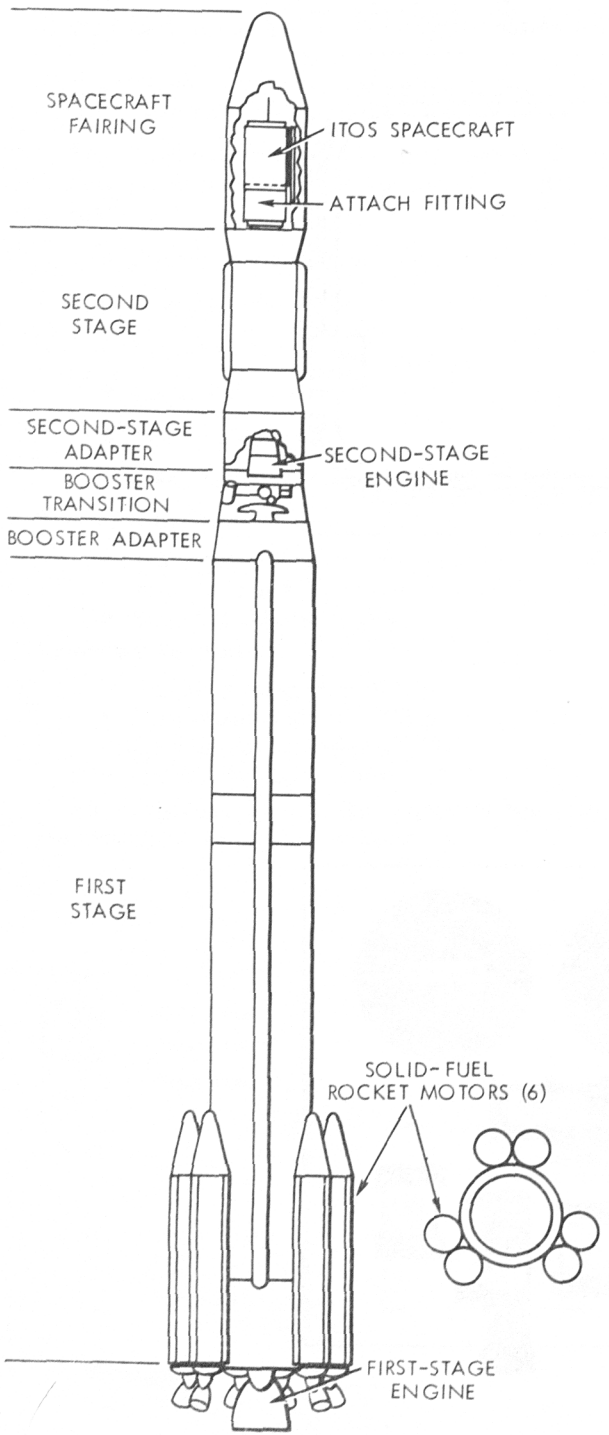


LAUNCH VEHICLE

A Delta N-6 (long-tank two-stage six-solid) launch vehicle designed, built, and launched by the McDonnell-Douglas Astronautics Company (MDAC) under the technical direction of NASA/GSFC, is used to launch the ITOS spacecraft from the Air Force Western Test Range (AFWTR) at Vandenberg Air Force Base, California. The Delta vehicle is a reliable low-cost vehicle that has been 90-percent successful over the past 7 years.

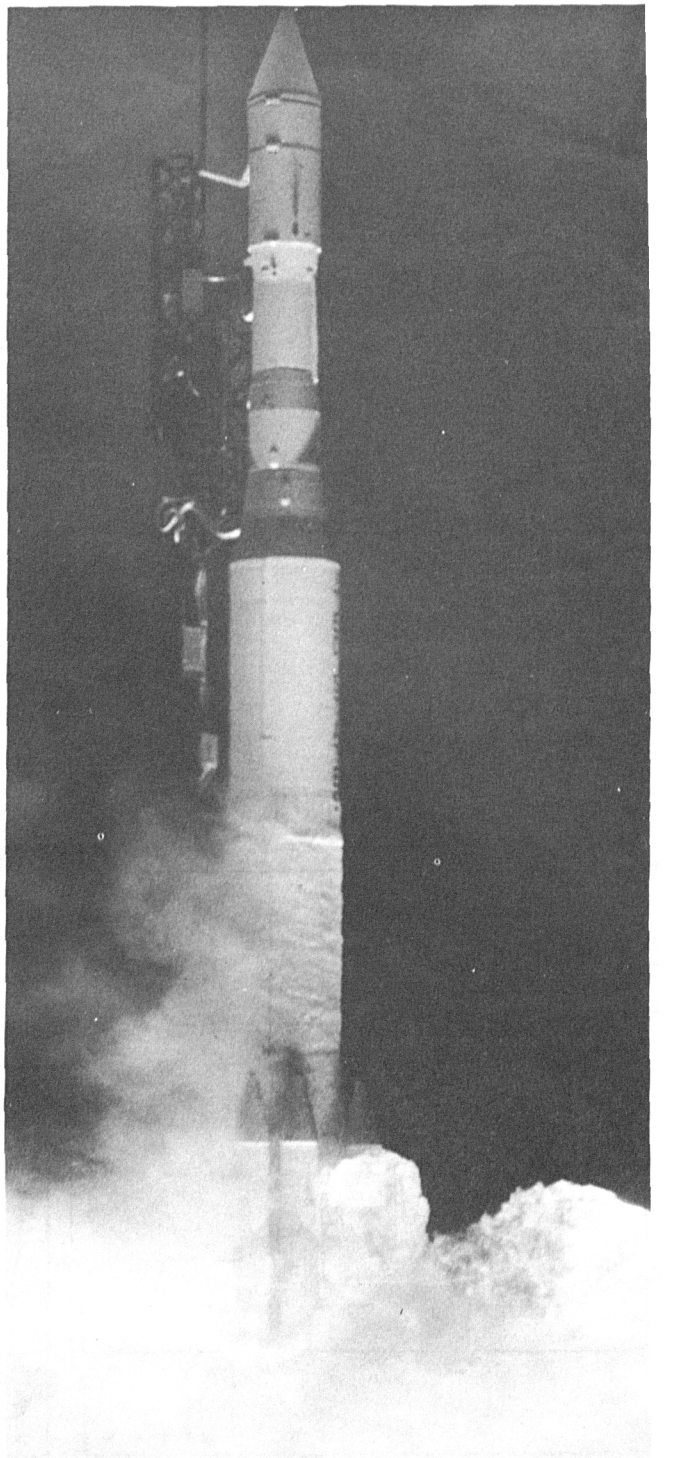
Besides providing the thrust needed to achieve the desired orbit, the launch vehicle before spacecraft separation places the spacecraft in the mission-mode attitude required for operation. The two-stage launch vehicle has an overall length of approximately 106 feet and a maximum body diameter of 8 feet. Nominal launch weight is 222,000 pounds.

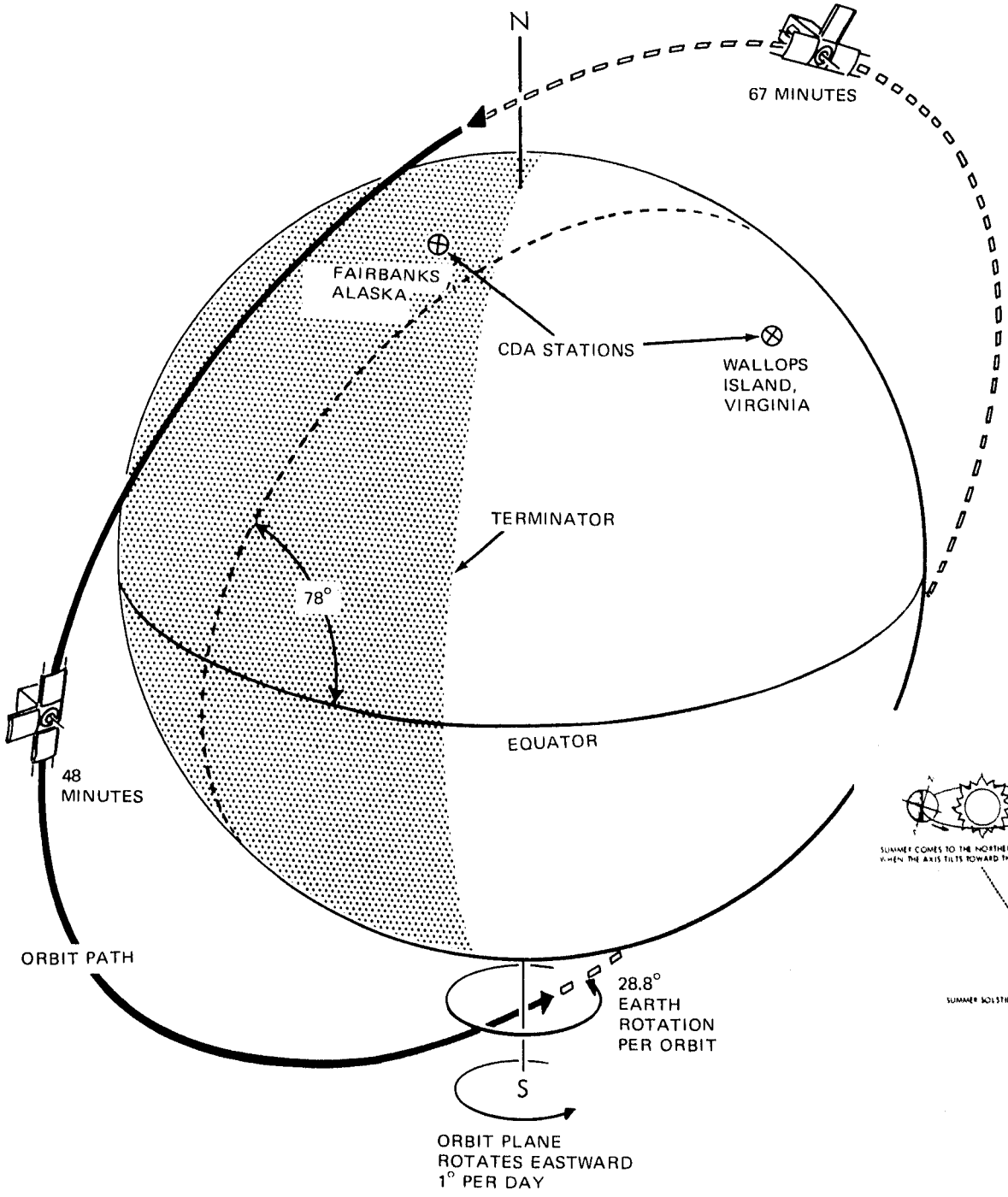
The first stage, a MDAC modified Thor, is powered by a Rocket-dyne engine using liquid hydrocarbon propellants and six strapped-on Thiokol solid-fuel rocket motors.

The Delta second stage is powered by an Aerojet General Corporation engine using liquid propellants.

A 37-inch-diameter attach fitting secured to the second stage fastens the ITOS spacecraft to the launch vehicle.

The standard Delta fairing attached to the forward face of the second stage protects the spacecraft from aerodynamic heating during the boost flight.



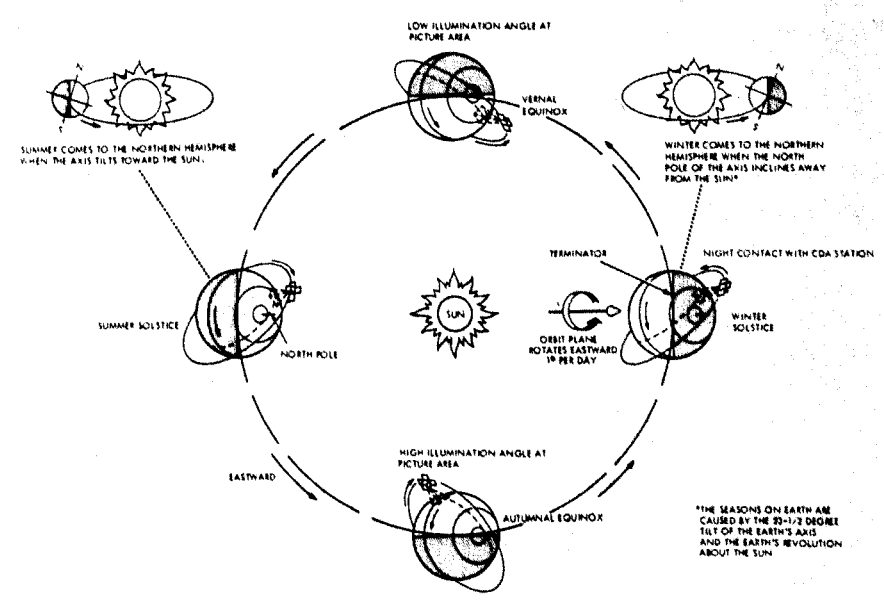


ORBIT SELECTION

ITOS is a three-axis-stabilized earth-oriented spacecraft designed to provide full day and night coverage of the entire surface of the earth on a daily basis. The ITOS orbit is circular at 790 nautical miles altitude, and near-polar with an angle-of-inclination of 78 degrees retrograde to the equator. Total orbital period is approximately 115 minutes (67 minutes in sunlight and 48 minutes in the earth's shadow). The earth rotates beneath the orbit 28.8 degrees during this period, allowing the satellite to observe a different portion of the earth's surface with sufficient overlap from orbit to orbit.

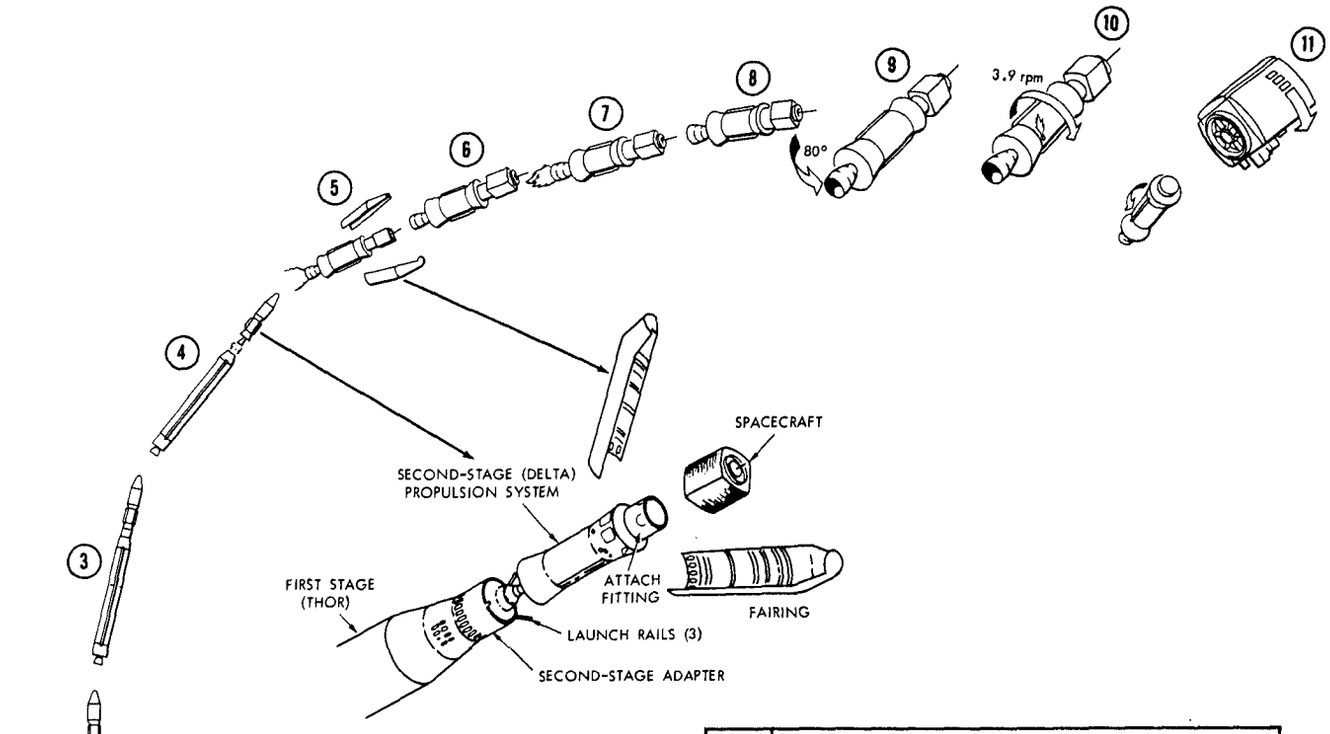
The orbit is sun-synchronous and precesses (rotates) eastward about the earth's polar axis 1 degree per day, or at the same rate and direction as the earth's average annual revolution about the sun. ITOS, launched into an ascending-node orbit, will always cross the equator at 3 p.m. northbound and 3 a.m. southbound local time. Sun-synchronous orbits compensate for seasonal variations by keeping the satellite in a constant position with reference to the sun for consistent illumination throughout the year.

The circular orbit permits uniform data acquisition by the satellite, and efficient command control of the satellite by the command and data-acquisition (CDA) stations located near Fairbanks, Alaska, and Wallops Island, Virginia.



SEASONAL VARIATIONS OF THE ITOS ORBIT

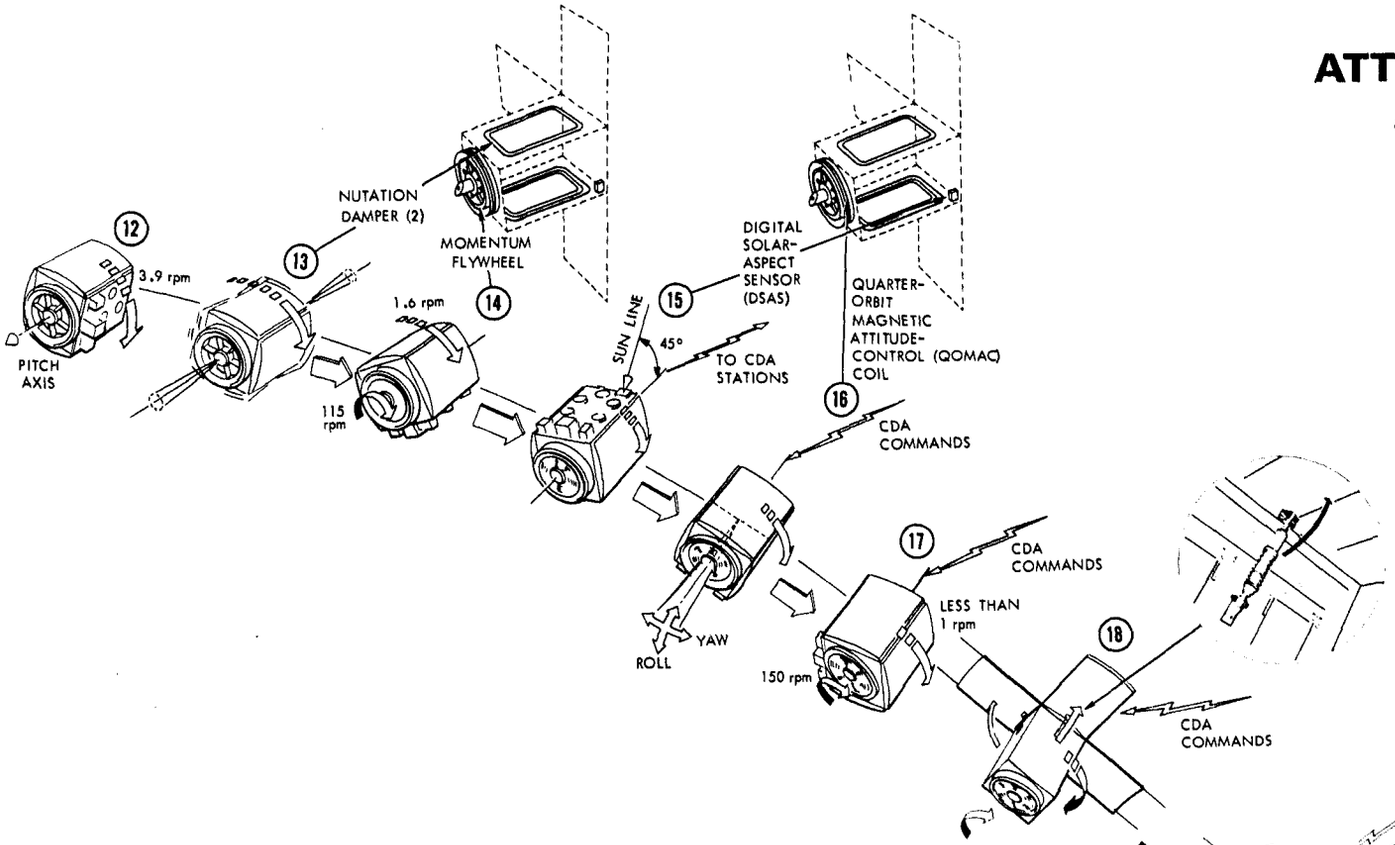
LAUNCH AND INJECTION



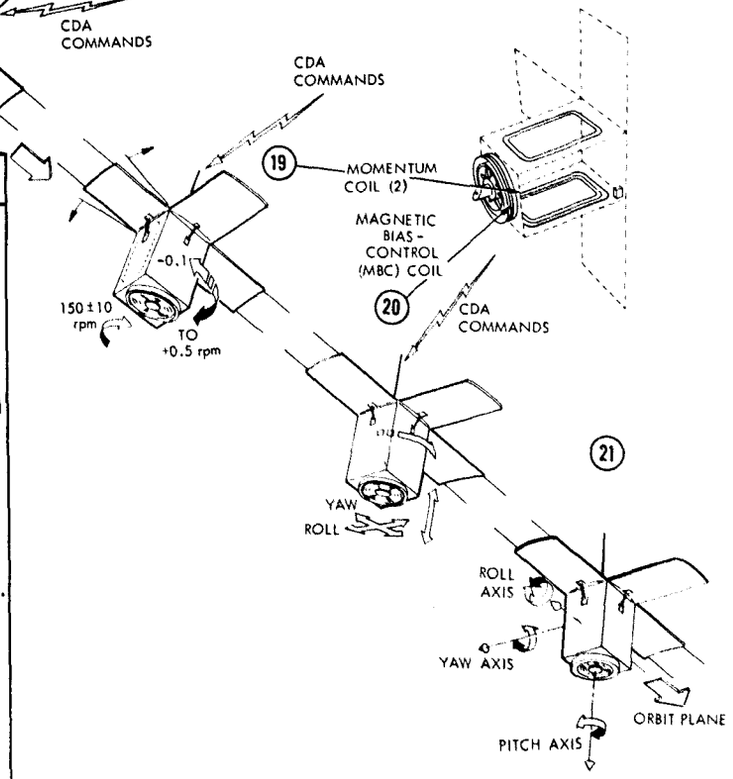
NO.	EVENT	TIME (sec)
1	First-stage ignition and liftoff	T+0
2	Jettison the solid rockets	T+90
3	First-stage cutoff	T+220.548
4	First-to-second stage explosive bolts firing and second-stage ignition	T+224.548
5	Jettison the fairing	T+239.548
6	Second-stage initial cutoff and coast phase	T+589.640
7	Second-stage reignition	T+3662.548
8	Second-stage final cutoff	T+3676.204
9	Begin 80-degree yaw maneuver of second stage	T+3695.548
10	Roll jets operate and spin up second stage and ITOS to about 3.9 rpm	T+3915.548
11	Roll jets cutoff; ITOS separates from second stage and second stage retros to preclude collision with ITOS	T+3926.548

NO.	EVENT
12	Upon separation from the second stage, the satellite spins about its pitch axis at a rate of about 3.9 rpm.
13	Two nutation dampers begin a damping action to reduce satellite wobble (nutation) of its pitch axis to an angle less than ±0.3 degree.
14	At the instant of separation, the pitch-control loop motor, operated by separation switches, accelerates the momentum flywheel to 115 rpm in about 30 seconds. This transfers momentum from the satellite to the flywheel and reduces the satellite's spin rate from 3.9 rpm to about 1.6 rpm.

ATTITUDE ACQUISITION AND STABILIZATION



ITOS carries three solar panels folded along the sides of the satellite during launch and retained by two explosive pin-pullers per panel. After the satellite achieves orbit, CDA-station command actuates the pin-pullers, and hydraulically-damped spring actuators deploy the panels 90 degrees into their operational position. The entire procedure takes about 170 seconds.



NO.	EVENT
15	During the satellite's initial orientation maneuver, the DSAS measures the satellite's spin rate and the angle between the satellite-sun line and pitch axis (nominally 45 degrees). CDA stations use this information transmitted over the 136.77-MHz beacon/telemetry transmitter along with roll-horizon sensor and pitch-index pulse information to correct the spin rate.
16	If the satellite's roll or yaw angles exceed ±3 degrees CDA stations command the QOMAC coil to move the satellite in the direction required to reduce the angle to less than ±1 degree.
17	CDA stations command the pitch-control loop motor to accelerate the momentum flywheel to its normal operating mode of 150 rpm. This reduces the satellite's spin rate from 1.6 rpm to less than 1 rpm.
18	CDA stations command deployment of the three solar panels.

NO.	EVENT
19	If the satellite's spin rate is not within the range of -0.1 and +0.5 rpm, the CDA stations command two momentum coils to move the satellite in the direction required to adjust the spin rate to this range. When this is achieved, and the flywheel is rotating at 150±10 rpm, CDA stations command the pitch-control loop into operation.
20	CDA stations command the MBC coil to continuously correct for minor roll-yaw attitude changes throughout the orbit by moving the satellite in the direction required to maintain the pitch axis perpendicular to the orbit plane. This procedure also keeps the angle between the sun and the solar panels constant.
21	ITOS is completely oriented and stabilized within ±1 degree about the pitch, yaw, and roll axes so that the TV cameras and infrared sensors face the earth continuously as the satellite orbits the earth.

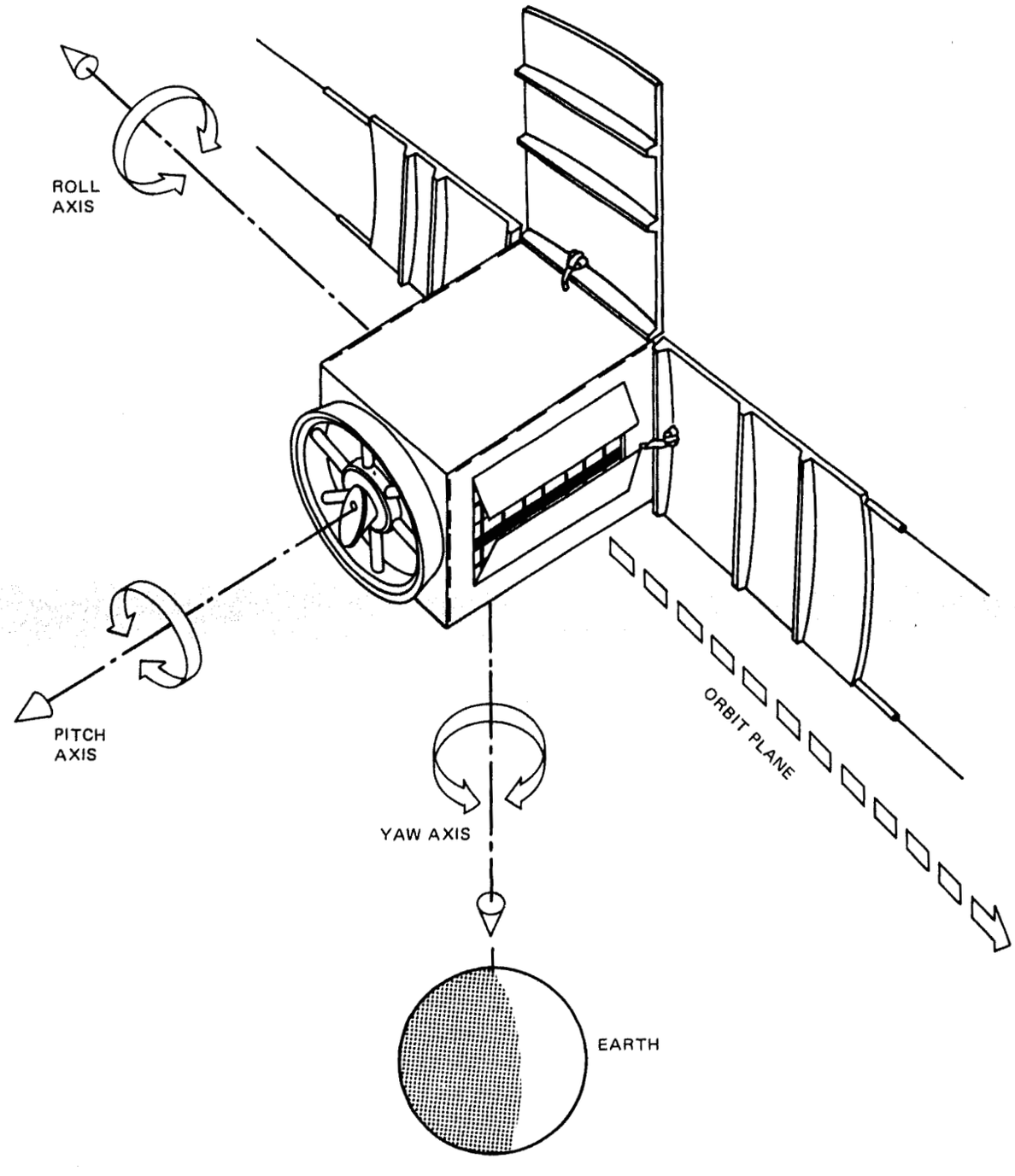
DYNAMICS AND ATTITUDE – CONTROL SUBSYSTEM

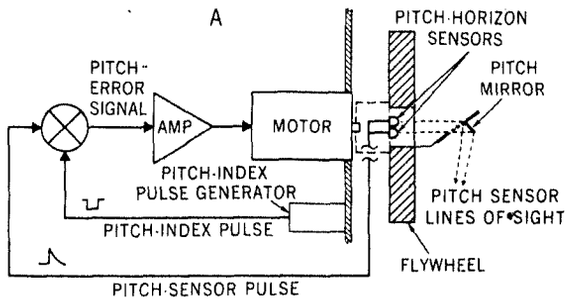
As the satellite moves through space, external forces (solar pressure, magnetic drag, etc.) can induce satellite attitude errors. To eliminate these errors, the ITOS dynamics and attitude-control subsystem orients and stabilizes the satellite with respect to the earth and orbit plane so that the TV cameras and scanning radiometers face the earth continuously as the satellite orbits the earth.

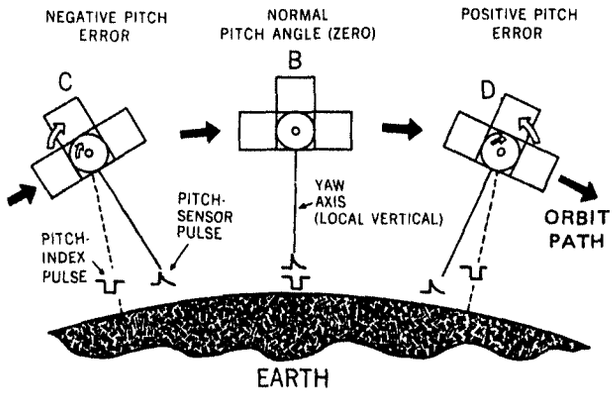
The satellite coordinate system is:

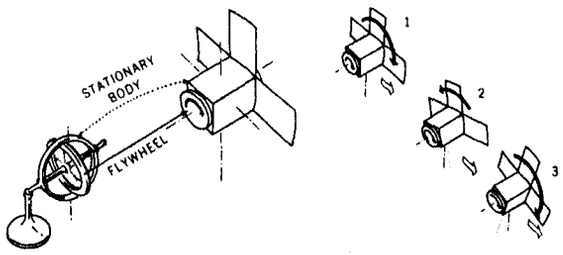
- The yaw axis points toward the center of the earth.
- The roll axis, perpendicular to the yaw axis, is parallel to the orbit plane.
- The pitch axis, perpendicular to both the yaw and roll axes, coincides with the momentum-flywheel spin axis and is perpendicular to the orbit plane.

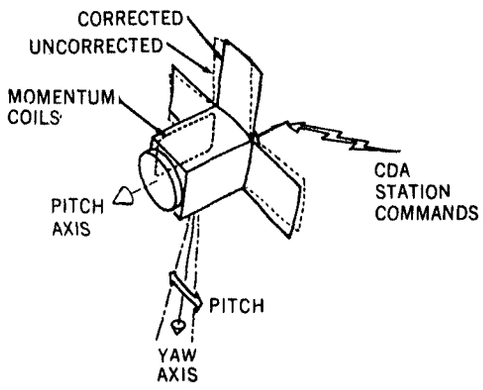
The instrumentation composing the dynamics and attitude-control subsystem is redundant and has two major functions: pitch-attitude control, and roll-yaw attitude control.











PITCH-ATTITUDE CONTROL

An assembly consisting of a pitch-control loop and a pair of momentum coils serves to measure and control the satellite's pitch attitude by keeping the satellite's yaw axis within ±1 degree of the local vertical when the yaw axis is in the orbit plane.

PITCH-CONTROL LOOP

The pitch-control loop consists of a momentum flywheel, a pair of pitch-horizon sensors, a pitch mirror, a pitch-index pulse generator, a servo motor, and associated electronics. The loop corrects satellite pitch-attitude error, independently of CDA station command, by controlling the relative speed between the flywheel and the satellite.

PITCH-ERROR MEASUREMENT AND CORRECTION

A. Either of the redundant pitch-horizon sensors fixed to the satellite structure serves to monitor the satellite's pitch attitude. A mirror attached to the flywheel provides optical scanning for the sensors. A pitch-index pulse generator, fixed to the satellite, generates an index or reference pulse; any difference in time between the index pulse and the scan path's intersection with the earth represents a pitch error, which is converted to an electrical signal that drives the motor to increase or decrease flywheel speed as required to correct the error so that the yaw axis coincides with the local vertical during mission operation.

B. When the satellite's pitch axis is perpendicular to the orbit plane and the yaw axis coincides with the local vertical, the pitch-sensor pulse occurs at the same time as the index pulse to indicate zero pitch error.

C. Should a negative pitch error exist, the pitch-sensor pulse will follow the index pulse, and the resultant signal will decrease motor speed to correct the error.

D. Should a positive error exist, the pitch-sensor pulse will precede the index pulse, and the resultant signal will increase motor speed to correct the error.

MOMENTUM FLYWHEEL

The momentum flywheel, heart of the dynamics and attitude-control subsystem, operates like a gyroscope to transfer momentum between the flywheel and the body of the satellite and thus serves to stabilize the satellite with respect to the earth and orbit plane.

1. During normal mission operation, the flywheel rotates clockwise at 150 rpm and the satellite rotates clockwise once per orbit to keep the yaw axis pointing directly toward the earth.
2. An increase in flywheel rotation above 150 rpm will transfer momentum from the satellite to the flywheel, causing the satellite to move counterclockwise.
3. A decrease in flywheel rotation below 150 rpm will transfer momentum from the flywheel to the satellite, causing the satellite to move clockwise.

MOMENTUM COILS

Two momentum coils, on CDA station command, correct satellite momentum errors by moving the satellite about its pitch axis in the direction required to add or subtract satellite momentum and to keep the yaw axis pointing toward the earth.

The coils operate on the principle of a dc motor: the armature is represented by the coils mounted on one side of the satellite in a plane parallel to the pitch axis, and the permanent-magnet field is represented by the earth's magnetic field. Interaction between the magnetic fields of the satellite and the earth provides the force necessary to increase or decrease the satellite's momentum. CDA stations control the direction of current in the coils and thus the direction of movement about the satellite's pitch axis.

ROLL-YAW ATTITUDE CONTROL

Devices used to measure and control the satellite's roll-yaw attitude, by maintaining the satellite's pitch axis perpendicular to within ±1 degree of the orbit plane, include a pair of roll-horizon sensors, a quarter-orbit magnetic attitude-control (QOMAC) coil, a magnetic bias-control (MBC) coil, and a pair of liquid nutation dampers.

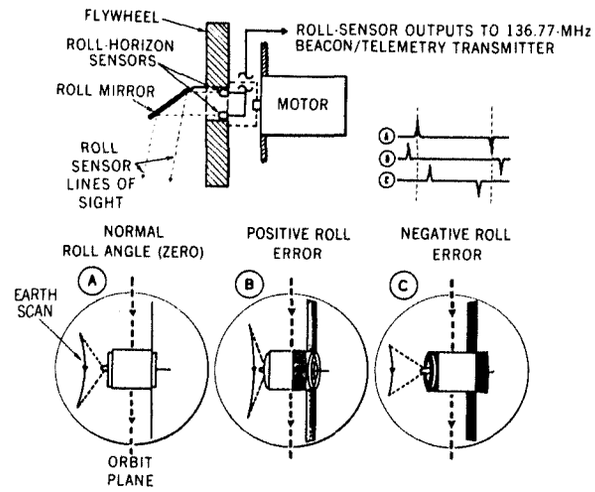
ROLL-YAW ERROR MEASUREMENT

A. Either of the redundant roll-horizon sensors fixed to the satellite structure serves to monitor the satellite's roll-yaw attitude. A mirror attached to the flywheel provides optical scanning for the sensors; rotation of the flywheel generates a conical scan pattern which intersects the earth. The CDA stations receive the roll-sensor outputs over the 136.77-MHz beacon/telemetry transmitter for analysis.

When the pitch axis is perpendicular to the orbit plane, the duration of the sensors' earth scan is normal, indicating that the roll angle is zero.

B. If a positive roll error exists, the duration of the earth scan is greater than normal. If the attitude error exceeds the mission-mode limit of ±1 degree, the CDA stations transmit programmed commands to the satellite for corrective action by the QOMAC and MBC coils.

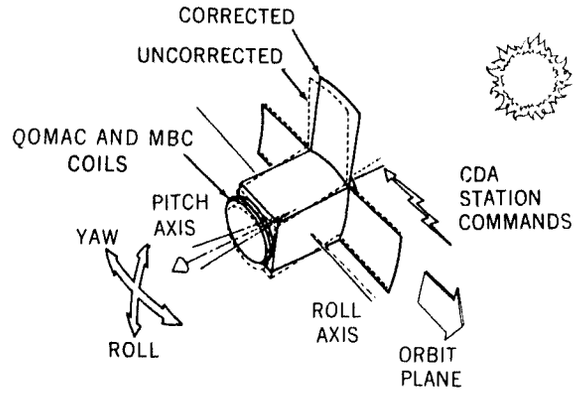
C. If a negative roll error exists, the duration of the earth scan is less than normal. Whenever the attitude error exceeds the mission-mode limit of ±1 degree, the CDA stations transmit programmed commands to the satellite for corrective action by the QOMAC and MBC coils.



ROLL-YAW ERROR CORRECTION

QUARTER-ORBIT MAGNETIC ATTITUDE-CONTROL (QOMAC) COIL

The QOMAC coil, programmed by CDA-station command, corrects for major roll and yaw attitude errors and solar pressure effects by moving the satellite in the direction required to keep the pitch axis perpendicular to the orbit plane. Current in the coil, which is wound around the periphery of the separation ring in a plane parallel to the roll and yaw axes, interacts with the earth's magnetic field to produce force for moving the satellite. Commands from the CDA stations control the magnitude and direction of current in the coil to set the direction and rate of the satellite's rotation.

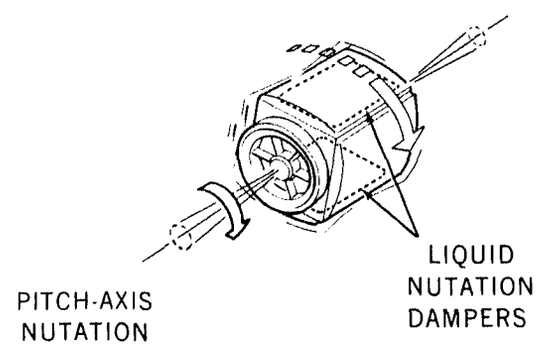


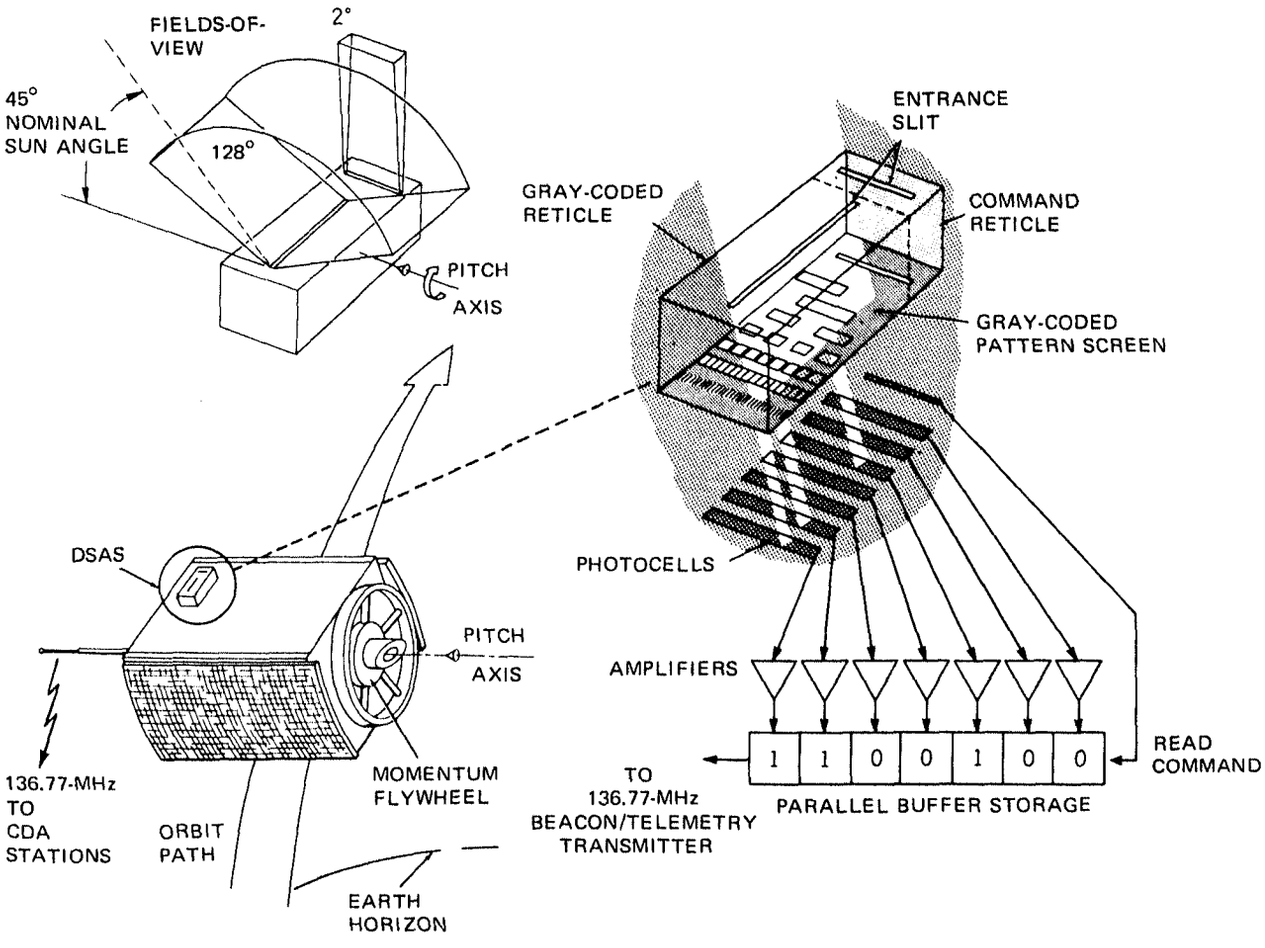
MAGNETIC BIAS-CONTROL (MBC) COIL

The MBC coil, programmed by CDA-station command, continuously corrects for minor roll and yaw attitude errors. Interaction of the MBC coil current with the earth's magnetic field sets up a continuous dipole that offsets any undesirable shift in the residual magnetic dipole of the satellite arising from operation of the subsystems, external magnetic forces, or orbital regression. By moving the satellite in the direction required to keep the pitch axis perpendicular to the orbit plane, the coil serves to keep the angle between the sun and the solar panels constant. The coil, wound around the periphery of the separation ring in a plane parallel to the roll and yaw axes, operates at the command of a CDA station as the QOMAC coil does.

NUTATION DAMPERS

After the satellite separates from the second stage of the launch vehicle, two liquid nutation-damping tubes begin acting to reduce satellite wobble (nutation) of its pitch axis to an angle less than ±0.3 degree. The tubes, filled with silicon oil and mounted on two opposite sides of the satellite, keep the plane of the dampers parallel to the pitch axis because the oil moves relative to the damper-tube walls as a result of satellite wobble. As the fluid moves, the viscous drag of the fluid converts the wobbling, or kinetic energy, into heat; when all the kinetic energy has been dissipated as heat, the fluid comes to rest in the tubes and the nutation has been reduced to a minimum.



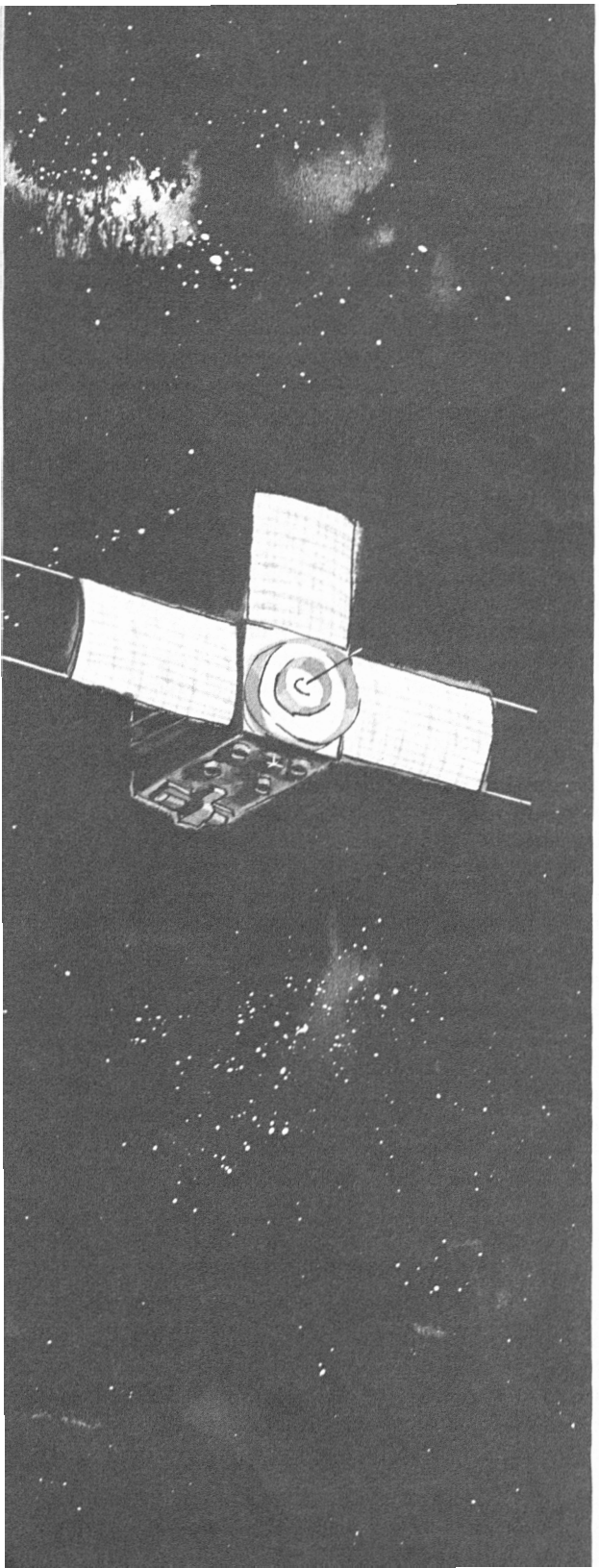


DIGITAL SOLAR-ASPECT SENSOR (DSAS)

The DSAS uses a dual reticle arrangement to measure the angle between the satellite-sun line and pitch axis (nominally 45 degrees), and the satellite's spin rate about the pitch axis during the satellite's initial orientation maneuver. It derives its scanning from the rotation of the satellite. The two types of reticles are gray-coded and command.

The gray-coded reticle, with an entrance slit perpendicular to the satellite pitch axis, has a field-of-view of 128 degrees, a resolution of 1 degree, and an accuracy of ±0.5 degree. This reticle encodes sun angles as digital numbers by quantizing the field-of-view into 128 combinations of "zero" and "one"; this represents a coverage of 128 degrees in 1-degree increments. As the satellite rotates, light passing through the slit forms an illuminated image of the slit on a 7-bit gray-coded pattern screen. The image's position depends upon the angle of the sun's rays. Behind each column of the code pattern is a photocell. If the light falls on a clear portion of the pattern in a particular column, the photocell behind is illuminated producing an output "one"; if it falls on an opaque segment, the photocell is not illuminated, and the output is "zero." The DSAS electronics amplifies the outputs of the photocells and stores them in digital form for serial readout.

The command reticle has two slits parallel to the pitch axis; the entrance slit has a field-of-view of only 2 degrees. As the satellite rotates, light passes once per revolution through the slits to a single photocell which generates a "read" command that causes the stored digital data representing the sun angle to be read out serially for transmission to the CDA stations over a 136.77-MHz beacon/telemetry transmitter.



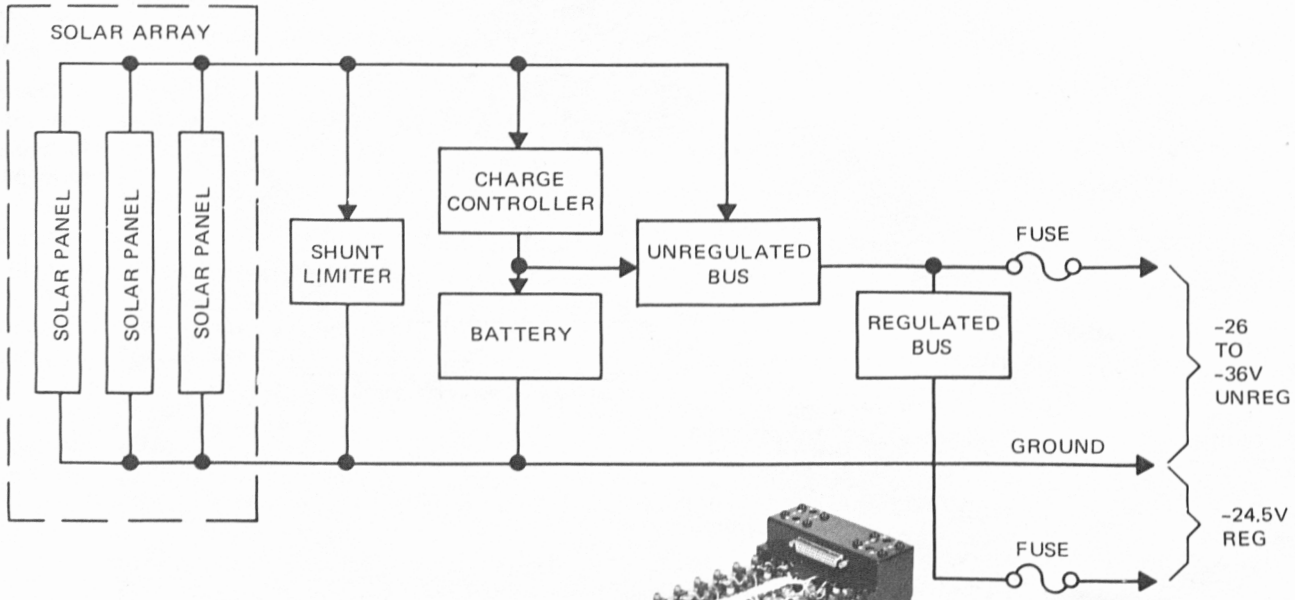
POWER SUPPLY

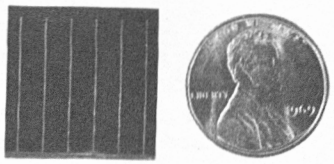
The power supply for ITOS consists of a solar array of approximately 10,260 n-on-p 2 X 2-cm silicon solar cells, plus two redundant sets of shunt limiters, charge controllers, rechargeable nickel-cadmium storage batteries, voltage regulators, and protective devices.

One side of each of the three deployable panels folded along the sides of the satellite at launch contains 3420 solar cells. After the satellite achieves orbit, the panels deploy into a position perpendicular to the satellite sides for maximum exposure to the sun. During the daytime portion of the orbit, these cells convert solar energy to electrical energy for both satellite operation and battery charging.

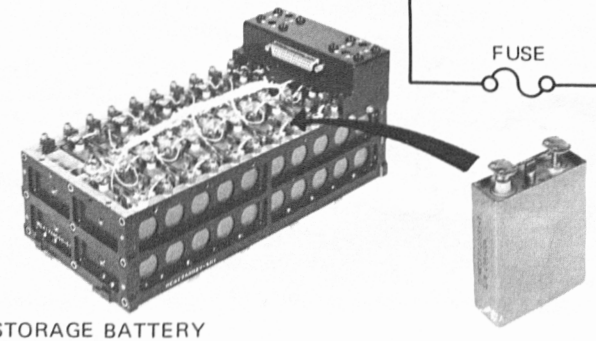
Two storage batteries of 23 cells each supply power during nighttime operation, or during periods when the satellite power requirements exceed the solar array capability. Shunt limiters prevent the solar-array output voltage from exceeding the required operating limit. Charge controllers protect the batteries during charge and overcharge periods by keeping the charging currents at safe limits.

The supply uses series regulators to deliver -24.5 volts dc regulated (±1 percent) to the regulated bus. The supply also delivers an unregulated bus voltage of -26 to -36 volts dc. Nominal average power output of the supply is 70 watts. The power supply design includes fuses to isolate parts of the subsystem whose failure might cause total power loss.





N-ON-P SILICON
SOLAR CELL (ACTUAL SIZE)



STORAGE BATTERY
23 CELLS

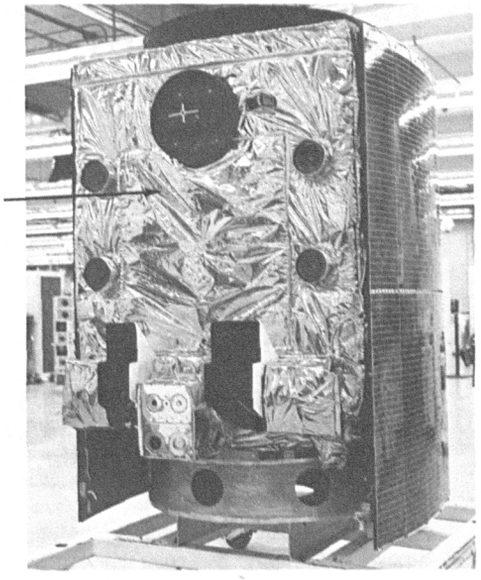
THERMAL CONTROL

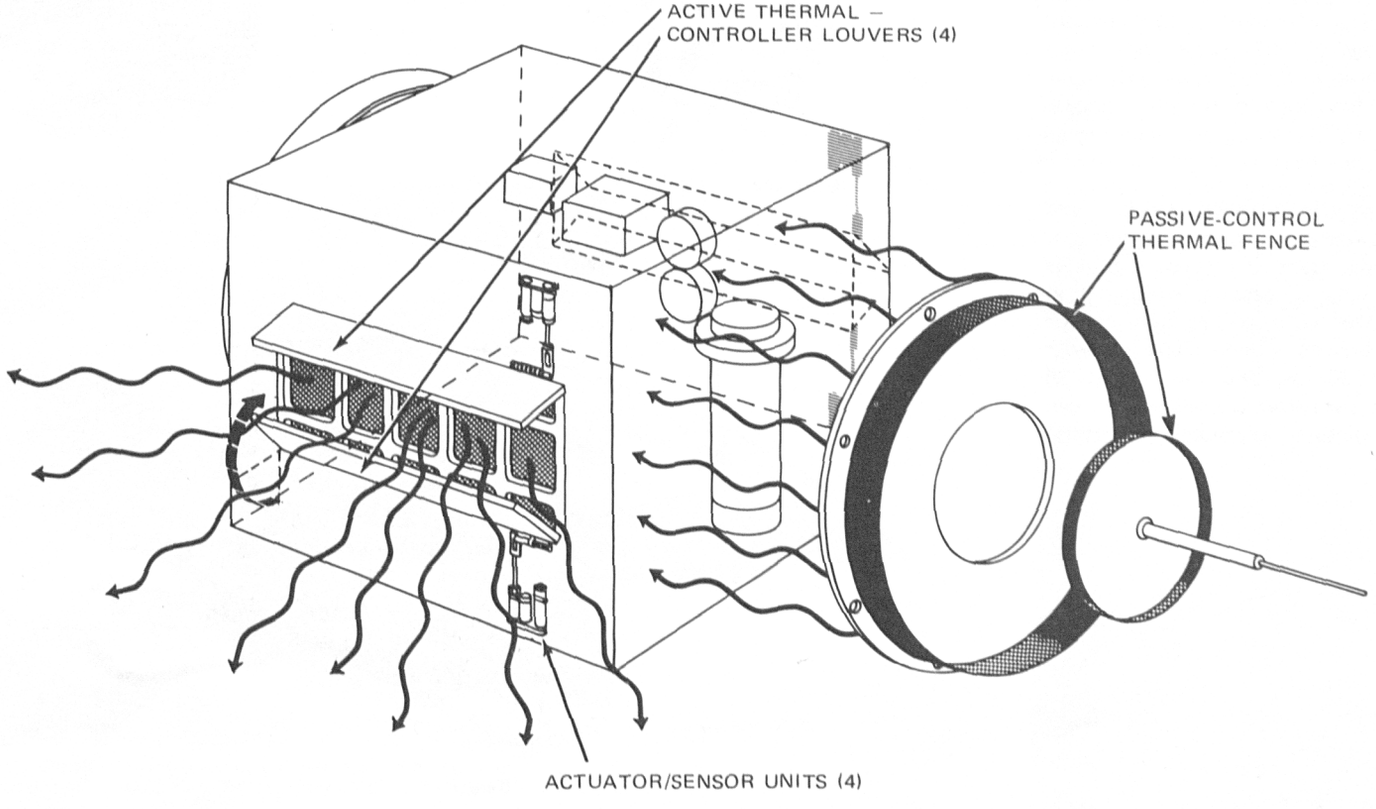
The ITOS thermal-control subsystem uses both active and passive methods to maintain a temperature range of 5 to 35°C inside the spacecraft.

Active thermal control comes from louvers on two sides of the spacecraft operated by four independent actuator/sensor units, two per side, each connected to a single vertically hinged louver by mechanical linkage. Expansion of fluid in the actuator/sensor, responding to temperature changes on the mounting surface, moves the louvers to the position required to prevent overheating in the spacecraft. The active controllers operate only when the solar panels are deployed. The louvers remain fixed in a fully open (180-degree) position during launch and injection, and their maximum open position during normal operation is 90 degrees.

Passive thermal control consists of two sheet-metal cylinders concentrically riveted to form a thermal fence plate on the end of the spacecraft continually exposed to the sun. The fence, thermally insulated to prevent conduction of heat to the spacecraft structure, and designed to absorb more solar energy at higher sun angles, compensates for the reduction in electric-power level and corresponding heat dissipation in the spacecraft caused by the increasing sun angle on the solar panels. Increase of the sun angle exposes more thermal fence area to the sun, which means more solar-energy absorption; the resulting temperatures control the spacecraft temperatures by heat radiation. Passive thermal-control compensation combines with the active-control portion to maintain heat balance in the spacecraft.

Multifoil-layer insulation blankets cover the remaining surfaces of the spacecraft, and suitable thermal finishes provide thermal control of components mounted on the outside of the spacecraft.





PRIMARY SENSORS

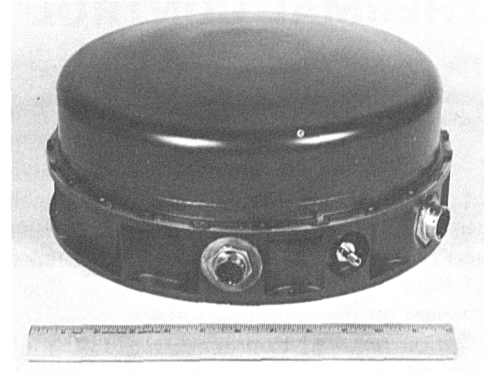
The primary sensor subsystems provide both direct readout and remote recording of pictures of the earth and its cloudcover during daytime and nighttime operations. The primary sensors consist of the following redundant subsystems:

ADVANCED VIDICON CAMERA SUBSYSTEM (AVCS)

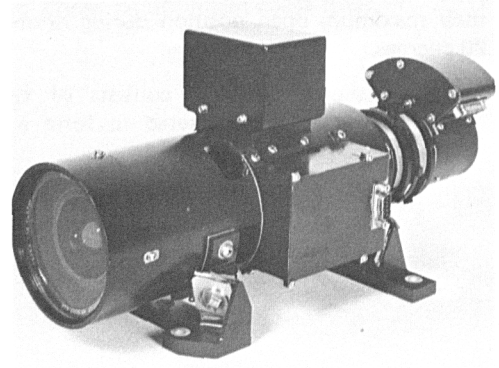
The AVCS takes a series of wide-angle high-resolution daytime pictures of the earth and its cloudcover, stores them on a tape recorder, and, on command, plays them back for transmission to the CDA stations. The AVCS consists of two redundant units composed of a TV camera, a magnetic tape recorder, and associated electronics.

The TV tube is a 1-inch-diameter vidicon with 800 scan lines. The lens, a Tegea Kinoptic 89-degree wide-angle f/1.8 lens with a focal length of 5.7 mm, works with an electromagnetically controlled shutter. The storage property of the vidicon allows a nominal 6.5-second frame-scan time. Concurrent with shutter actuation, a 15-increment gray scale appears at the edge of each picture frame as a contrast check of the photo against the known gray scale. The faceplate of the vidicon has reticle marks which appear on each picture frame as an aid in relating the picture to an actual position on the earth's surface.

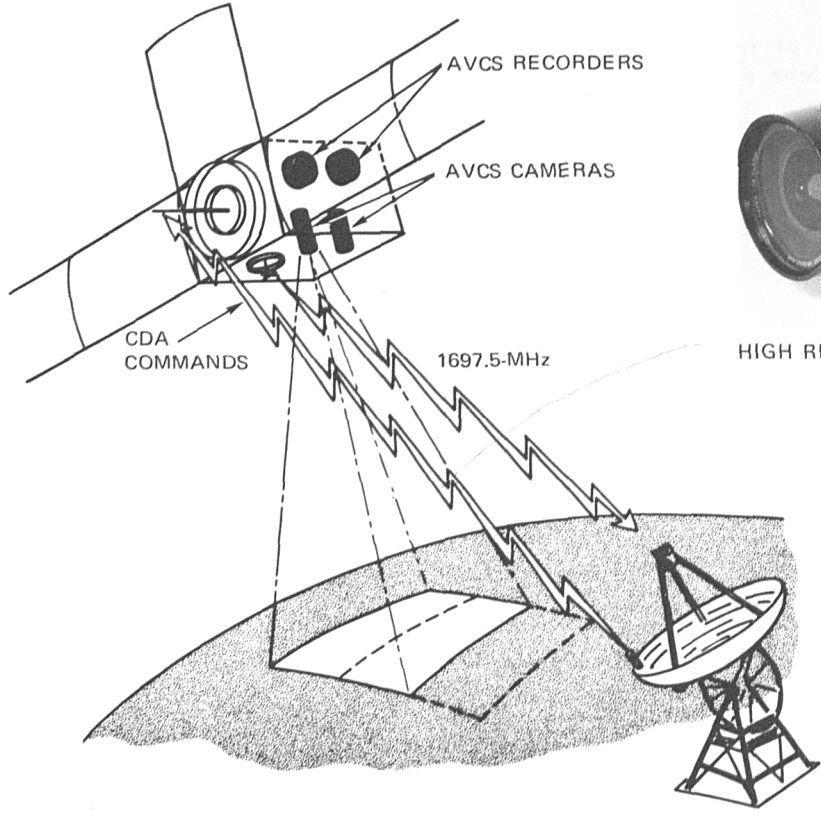
Each tape recorder contains three tracks: tracks 1 and 3 record and play back camera video, one camera per track, and picture time code; track 2 records a 50-kHz flutter and wow tone used by processing equipment at NESC to detect recorder-speed variations so they can be compensated for in the received video. The recorder records and plays back at 30 ips, and can record 38 pictures on one track in a start-stop operation. It can store up to 3 complete picture sequences (3 orbits) before playback.

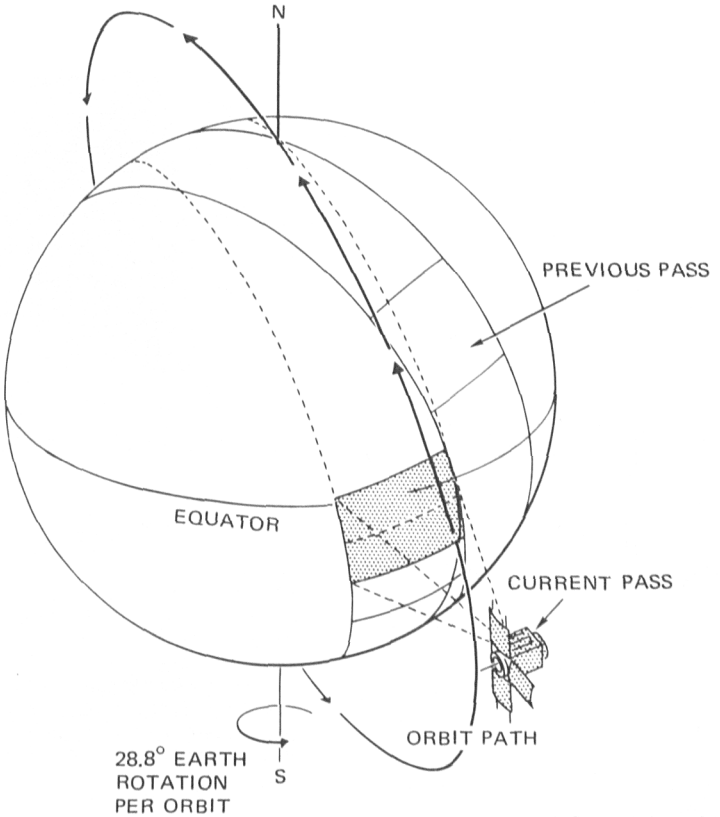


THREE-TRACK MAGNETIC TAPE RECORDER

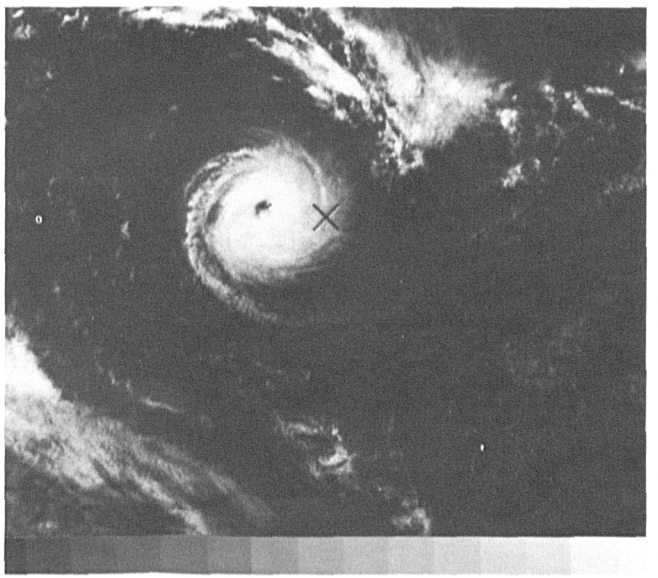


HIGH RESOLUTION TV CAMERA





AVCS DAYTIME COVERAGE



GRAY SCALE

AVCS photo showing a tropical cyclone off the east coast of Madagascar, taken Feb. 19, 1970 by ITOS 1 (TIROS-M)

The APT subsystem transmits daily television pictures of the cloudcover below the satellite in real time to meteorologists throughout the world for local weather forecasting. The scanning radiometer (SR) subsystem also transmits nighttime or daytime picture data on command to the APT stations in real time on the same frequency used to transmit APT pictures during daylight hours. The significant features of this subsystem are:

The AVCS operates in three modes:

- Record mode—A program of commands from the CDA stations directs the AVCS to start taking and recording pictures just after the satellite crosses the earth's terminator into the daylight portion of the orbit. A complete sequence lasts 44.2 minutes, during which AVCS automatically takes 11 pictures at 260-second intervals. Each picture covers an area of 1700 by 1700 nm with a 50-percent frame overlap; pictures on successive orbits are contiguous at the equator. The picture information is stored on the recorder, and, when the last picture in the sequence is recorded, the the AVCS is commanded "OFF."
- Playback mode—The recorder plays back on CDA station command and transmits the pictures over the 1697.5-MHz S-band transmitter to the CDA stations. It takes less than 2 minutes to play back the 11 pictures taken during a single orbit.
- Direct-readout mode—While a picture-taking sequence is in progress, the CDA stations command transmission of TV pictures and the 50-kHz flutter and wow tone over the S-band transmitter to the ground in real time, as they are being recorded on tape. This procedure does not interrupt any previously programmed picture-taking operation.

AUTOMATIC PICTURE TRANSMISSION (APT) SUBSYSTEM

The APT subsystem transmits daily television pictures of the cloudcover below the satellite in real time to meteorologists throughout the world for local weather forecasting. The scanning radiometer (SR) subsystem also transmits nighttime or daytime picture data on command to the APT stations in real time on the same frequency used to transmit APT pictures during daylight hours. The significant features of this subsystem are:

- Pictures will be transmitted as soon as taken.
- Pictures received during nighttime or daytime at any ground station will be of the local area.
- Relatively simple and inexpensive ground station equipment can produce high-quality pictures.

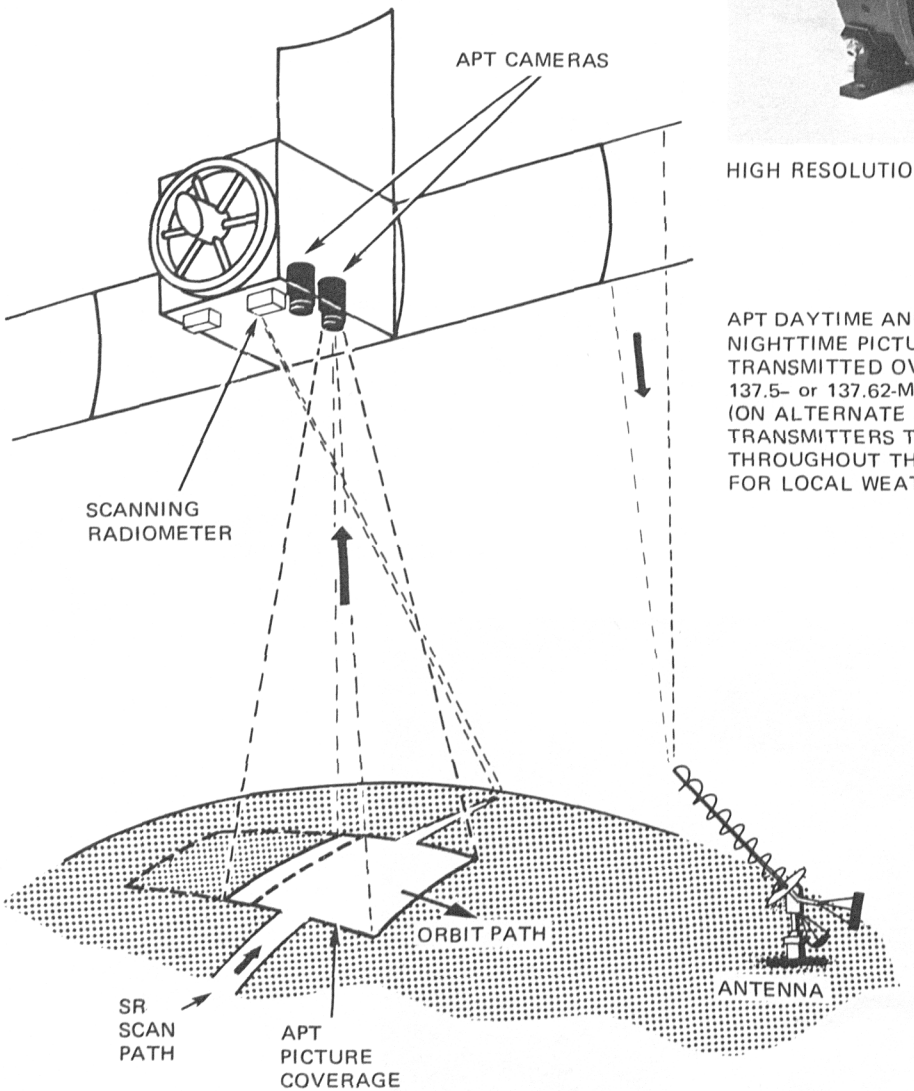
The instrumentation composing the APT subsystem is of two kinds: satellite-borne equipment, and ground-station equipment.

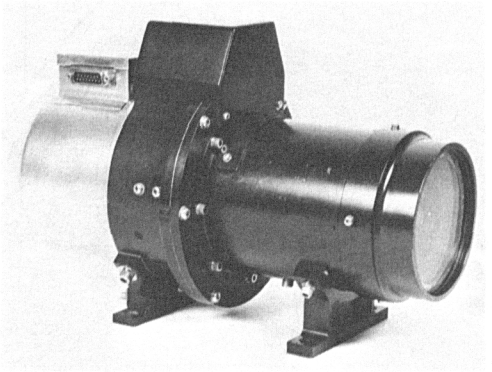
SATELLITE-BORNE EQUIPMENT

The satellite-borne equipment consists of two redundant units composed of a TV camera and associated electronics. The TV tube is a 1-inch-diameter vidicon with 600 scan lines. The lens, a Tegea Kinoptic 108-degree wide-angle f/1.8 lens with a focal length of 5.7 mm, works with an electromagnetically controlled shutter. The storage property of the vidicon and method of readout permit a nominal 150-second frame-scan time.

During each orbit, the camera takes pictures of the sunlit portion of the earth; at a nominal altitude of 790 nm, each picture will cover a ground area of 1700 by 1300 nm, with a 30-percent overlap between pictures. The wide-angle lens focuses the camera's field-of-view on the vidicon.

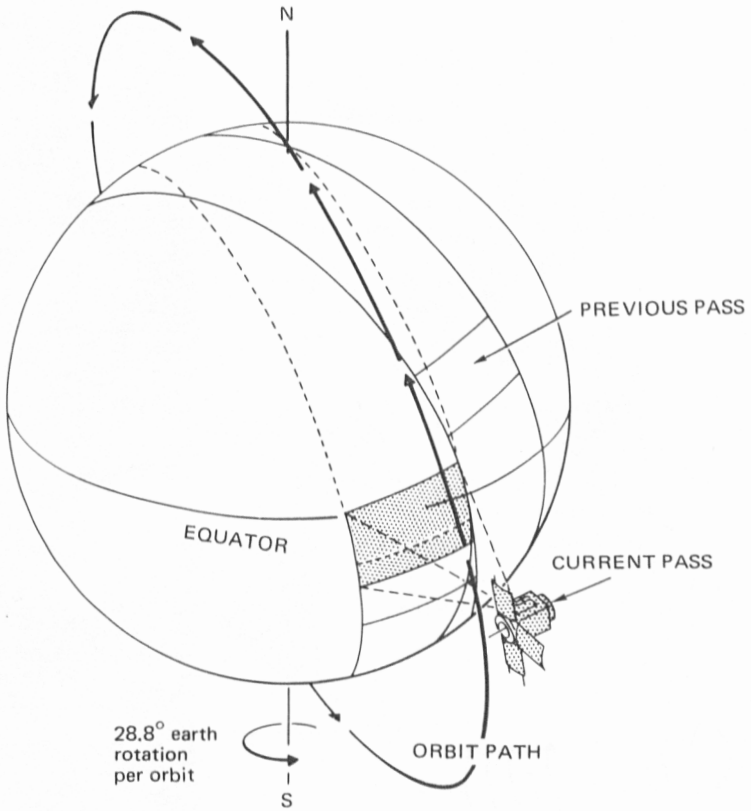
The faceplate of the vidicon has reticle marks that appear in the video format and aid in relating the picture to an actual position on the earth's surface. Total readout time for one picture is 158 seconds: during the first 8 seconds, the vidicon is conditioned and a new picture is stored electrically in the vidicon; during the next 150 seconds, the picture information is read out line by line at a scanning rate of 4 lines per second. The APT ground stations receive a 600-line picture with scan lines perpendicular to the orbit track. The stations also receive start and phasing signals at the beginning of each picture to synchronize the facsimile recorders in the ground stations with the vidicon scanning beam. The video circuitry amplitude-modulates a 2400-Hz subcarrier whose signal frequency-modulates the 137.5- or 137.62-MHz transmitters for transmission to the ground stations.



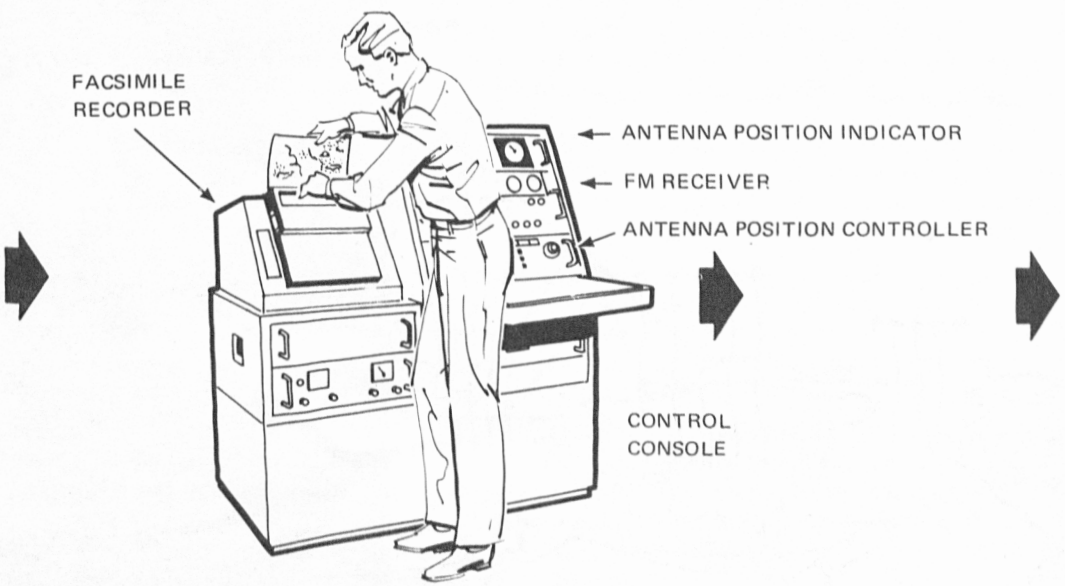


HIGH RESOLUTION TV CAMERA

APT DAYTIME AND SR DAYTIME OR NIGHTTIME PICTURES ARE TRANSMITTED OVER 137.5- or 137.62-MHz (ON ALTERNATE SATELLITES) TRANSMITTERS TO STATIONS THROUGHOUT THE WORLD FOR LOCAL WEATHER FORECASTING



APT DAYTIME COVERAGE



GROUND-STATION EQUIPMENT

The relatively simple and inexpensive ground stations are suited to wide use by the Environmental Science Services Administration (ESSA), military, individual corporations, universities, and other meteorological groups throughout the world. The APT ground station consists of four basic components:

Antenna—an 8-turn helix mounted on a pedestal, capable of 360-degree rotation from the center point in azimuth and 180-degree rotation in elevation. A preamplifier mounted on the pedestal compensates for losses in the RF cable (up to 1000 feet) between the antenna and control console.

Control console—includes a position-control and indicator unit for independent rate control of both azimuth and elevation and for continuous display of antenna position. The console also includes an FM receiver equipped with both aural and visual means of determining the presence and condition of the input signals.

Facsimile recorder—operating at 250 rpm with a resolution of 100 lines per inch forms a picture, line by line. The unit will produce ten shades of gray, varying from black to white. The picture has an aspect ratio of one on an 8-inch by 6-inch format.

The recorder will start and phase automatically upon receipt of start and phasing signals from the spacecraft, or it can be started and phased manually.

Direct-readout infrared (DRIR) adapter—converts APT-station equipment to receive and process infrared nighttime-cloudcover picture data by changing the APT picture-format scan rate of 250 rpm to the infrared-format scan rate of 48 rpm.

APT photo of eastern coast of United States showing a heavy snow storm moving out to sea, taken Feb. 13, 1970 by ITOS 1 (TIROS-M)

SCANNING RADIOMETER (SR)

The SR subsystem, a versatile meteorological instrument built especially for use on ITOS, continuously measures and records surface temperatures of the earth, sea, and cloudtops in daylight as well as at night for subsequent playback to CDA and APT stations. With the pictures taken by the AVCS and APT (which operate only during sunlit hours) the SR offers complete 24-hour data coverage, and can also serve as an operational replacement for both AVCS and APT subsystems if they fail.

The two-channel SR takes measurements in two spectral regions: visible radiation reflected from the earth in the 0.52- to 0.73-micron region during daytime, and infrared radiation emitted from the earth in the 10.5- to 12.5-micron region during day and night.

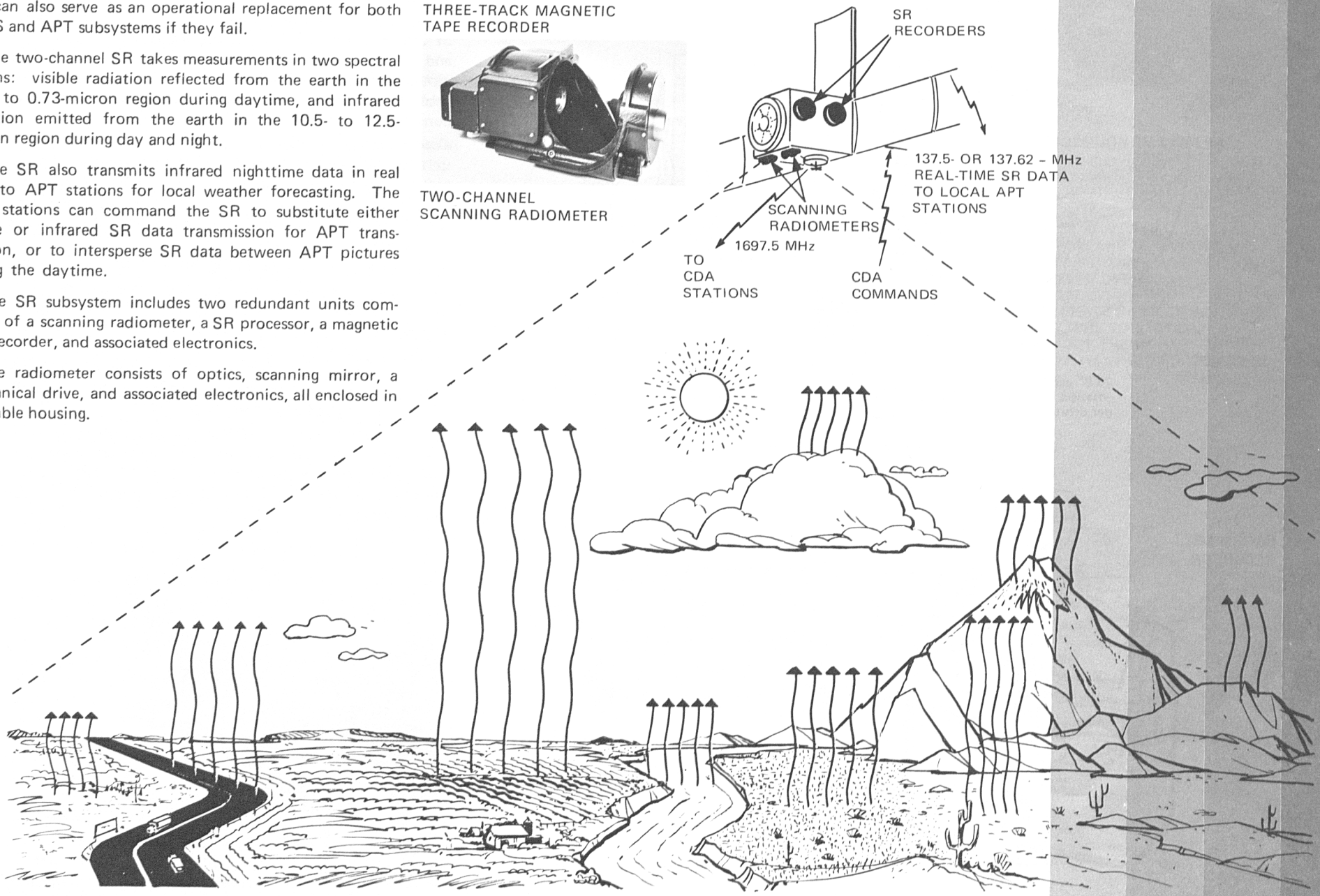
The SR also transmits infrared nighttime data in real time to APT stations for local weather forecasting. The CDA stations can command the SR to substitute either visible or infrared SR data transmission for APT transmission, or to intersperse SR data between APT pictures during the daytime.

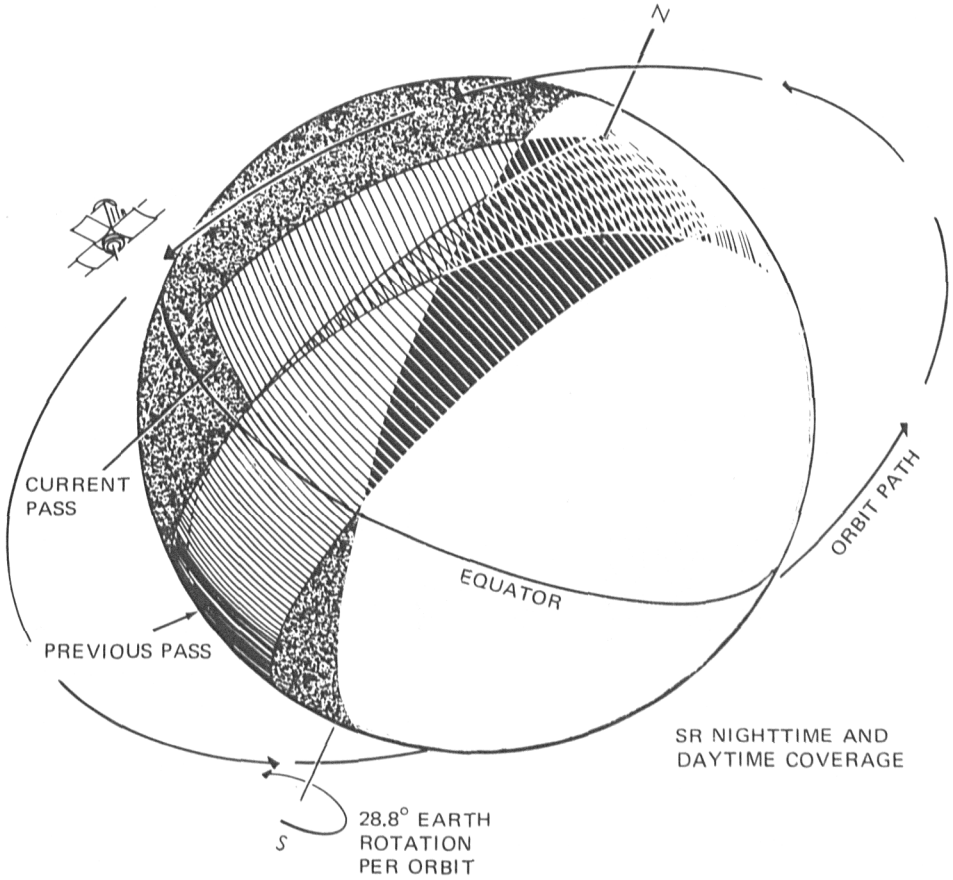
The SR subsystem includes two redundant units composed of a scanning radiometer, a SR processor, a magnetic tape recorder, and associated electronics.

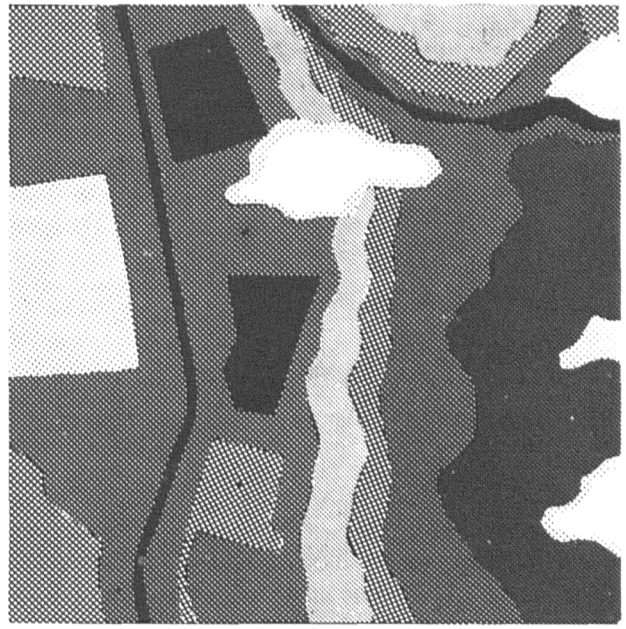
The radiometer consists of optics, scanning mirror, a mechanical drive, and associated electronics, all enclosed in a suitable housing.

THREE-TRACK MAGNETIC TAPE RECORDER

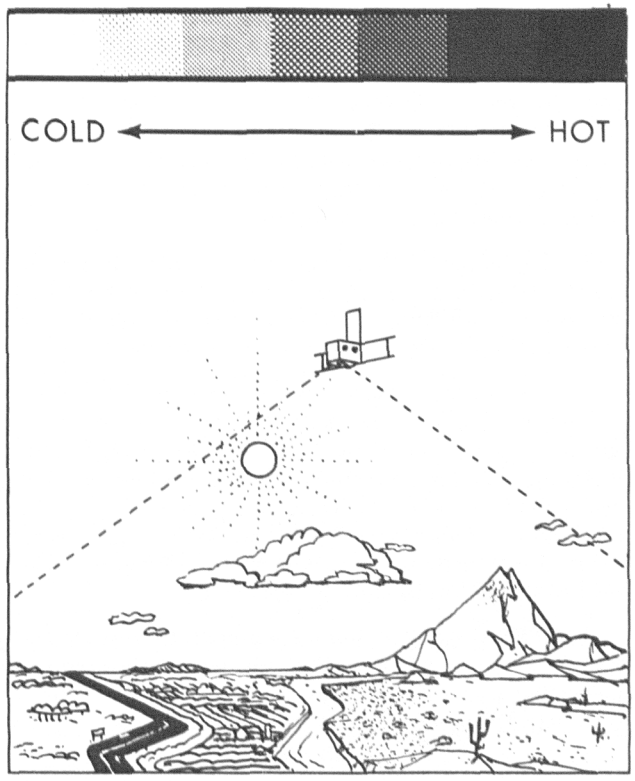
TWO-CHANNEL SCANNING RADIOMETER







SR data are displayed so that cold areas such as clouds appear as white and warm areas (oceans) black. Temperatures of other areas appear as varying shades of gray.



Each tape recorder contains three tracks: tracks 1 and 3 respectively record and play back infrared and visible radiation data; track 2 records a 3.125-kHz flutter and wow tone used by processing equipment at NESC to detect recorder-speed variations so they can be compensated for in the received data. The recorders record at 1.875 ips and play back at 30 ips (16 times the record speed) and can store 2 orbits of data; each track has a total recording capability of 145 minutes.

A program of commands from the CDA stations control the operations of the SR subsystem, and select the SR and tape recorder to be used during picture-taking operations. Each half of the SR processor is associated with one radiometer and is powered when the radiometer is powered. Spacecraft time-base and command-distribution units perform major timing and control functions of the SR.

Unlike a camera, the SR does not "take a picture" but rather forms an image using a scanning-mirror technique. The mirror, located in the SR, scans the earth's surface perpendicular to the satellite's orbit path at a rate of 48 rpm. Mirror rotation causes a transverse scan across the earth; during the time required for one complete mirror rotation, the satellite progresses approximately 5 nm along the orbital track. This procedure is repeated throughout the orbit, each rotation of the mirror providing one scan line of a picture. Ground stations reconstitute the picture by means of a facsimile recorder whose scan, to form a continuous picture, must advance the equivalent of the satellite's forward motion during each scan of the mirror.

The SR processor combines SR time-code and scanning-radiometer telemetry data with the infrared and visible radiation signals, for recording on tape. Time-code and telemetry data are not included in the real-time transmitted data.

Transmission of these data is programmed by CDA station command for playback over a 1697.5-MHz S-band transmitter to the CDA stations. These data are also programmed for direct readout over the 137.5- or 137.62 MHz real-time transmitters to local APT stations.

SECONDARY SENSORS

During daytime and nighttime operations, the secondary sensor subsystems offer remote recording and playback of additional environmental data that supplement the data provided by the AVCS, APT, and SR subsystems. Secondary subsystems are not redundant.

The secondary sensors and equipment required to support their operation are as follows.

FLAT-PLATE RADIOMETER (FPR)

The FPR subsystem, designed and built by the University of Wisconsin, measures the amount of heat being radiated into space by the earth. Comparison of this measurement with the known solar input to the earth permits defining the amount of heat absorbed by the earth. Observations of long-term heat changes will indicate whether the earth is getting warmer or cooler.

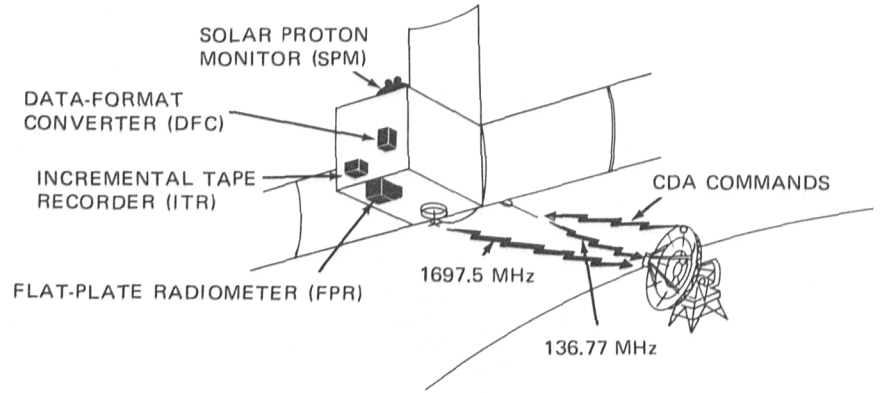
The FPR consists of two sections: the sensor head, and the associated electronics unit.

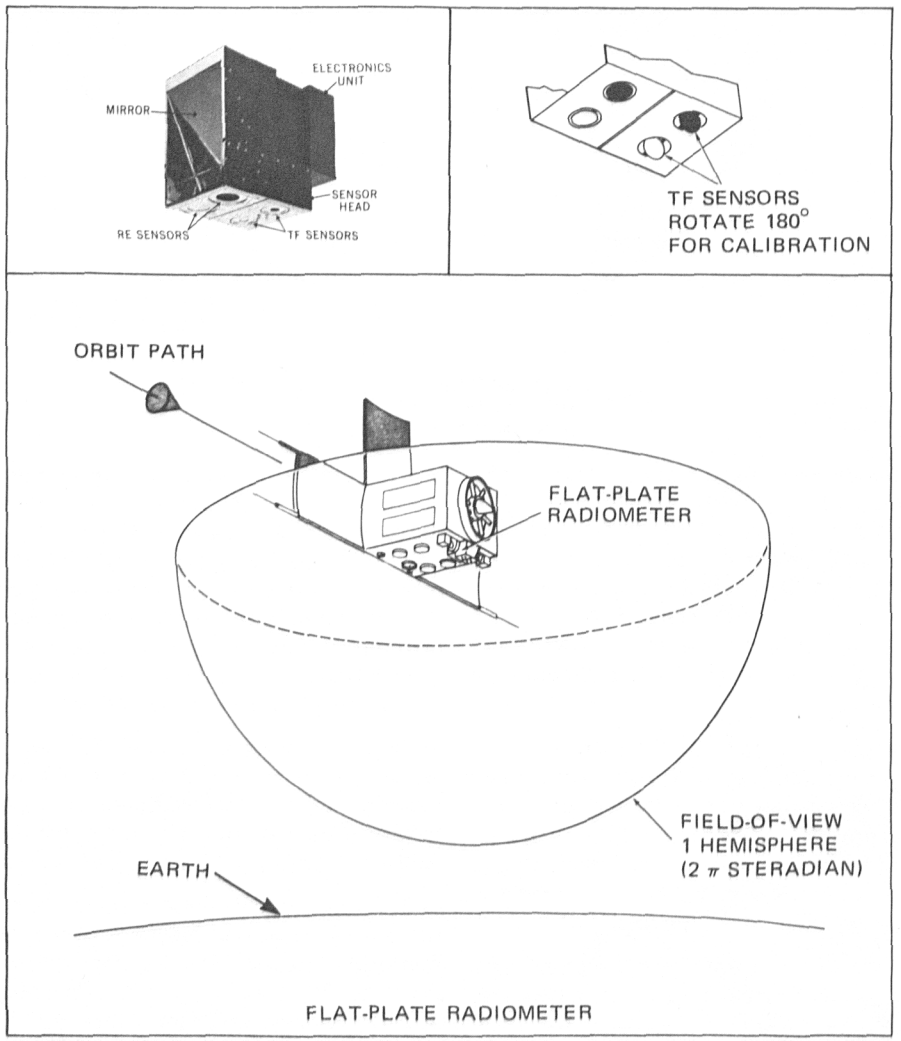
The head contains four sensors—one pair of radiative equilibrium (RE) sensors, and one pair of thermal feedback (TF) sensors—which have a field-of-view of a full hemisphere (or 2π steradians) and face the earth. Each pair consists of a black-sensor which measures the sum of the heat emitted by the earth and heat reflected by the earth over the range of 0.3 and 30 microns, and a white-sensor which measures heat emitted by the earth in the infrared range of 7 to 30 microns.

The RE sensors, thermally insulated from the sensor head, are cooled by a mirror which reflects the heat radiated by the sensors into space. During normal operation, the sun does not fall into the field-of-view of the mirror.

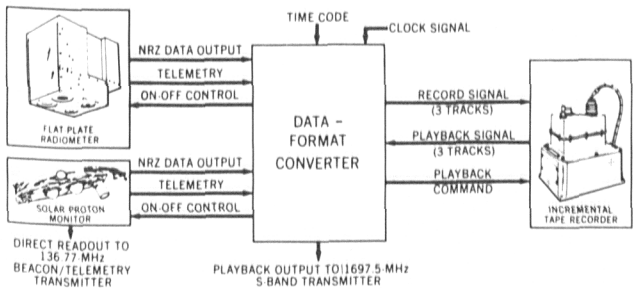
Possible surface degradation in orbit to which the TF sensors are subject may cause a shift in the infrared response range, and consequently in the radiative power input; therefore calibration is required. Heat-controlled isothermal hemispheres within the radiometer housing serve as a standard for calibration. The TF sensors are mounted on a motor-driven shaft which rotates them 180 degrees to view the isothermal hemispheres for calibration.

The FPR electronics unit commutates the outputs of the four sensors and housekeeping telemetry points, and converts the commutated analog data to a nonreturn-to-zero (NRZ) digital format for processing by the DFC.





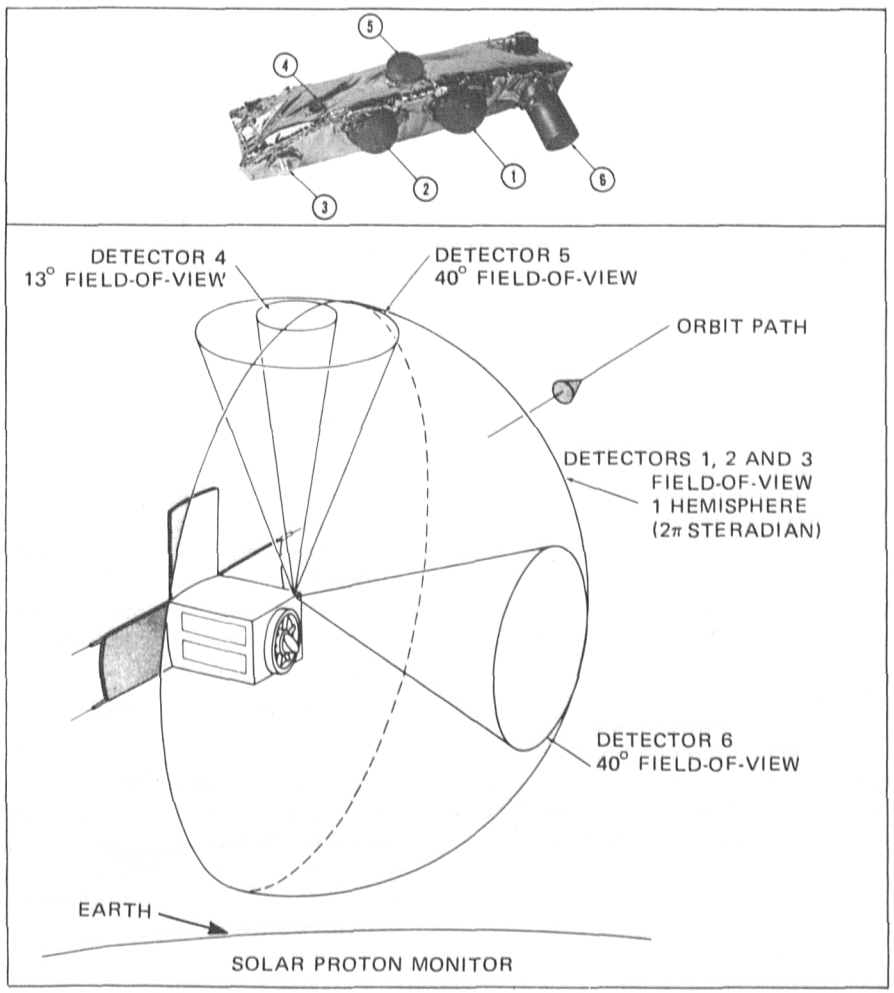
FLAT-PLATE RADIOMETER



SOLAR PROTON MONITOR (SPM)

The SPM subsystem, designed and built by the Applied Physics Laboratory of the Johns Hopkins University, continuously measures proton and electron flux activity near the earth. SPM data recorded throughout the orbit are played back upon command when the satellite is over the CDA stations, or upon command may be transmitted direct to the CDA stations by a 136.77-MHz beacon/telemetry transmitter. ESSA handles SPM data on a high-priority basis to provide warnings of solar proton storms and to measure and predict solar-flare activities, which may be hazardous to manned space exploration and interfere with high-frequency radio communications.

The SPM consists of two sections: a detector assembly containing six solid-state detectors, and associated electronics.



Detectors 1, 2, 3 and 6 face away from the sun perpendicular to the satellite's direction in orbit so that their view axes throughout the orbit are perpendicular to the earth's magnetic field. Detectors 4 and 5 face away from the earth, so their view axes are parallel to the earth's magnetic field in the vicinity of the poles.

The SPM measures flux in several ranges: detectors 1 through 3 have fields-of-view of a full hemisphere, or 2π steradians, and detect protons in the 60-, 30-, and 10-Mev range, respectively. Detector 4, with a field-of-view of 13 degrees, detects electrons in the 100- to 750-Kev range. Detectors 5 and 6 have a field-of-view of 40 degrees and detect alpha particles in the 12.5- to 32-Mev range and protons in the 0.27- to 60-Mev range.

The SPM electronics commutates the outputs of the detectors and converts the commutated analog data to a nonreturn-to-zero (NRZ) digital format for processing by the DFC.

DATA-FORMAT CONVERTER (DFC)

The DFC subsystem controls the operations of the FPR, the SPM, and the ITR. It also processes and formats FPR, SPM, housekeeping-telemetry, clock, and time-code data for storage in the ITR.

During playback of the ITR, the DFC accepts the outputs of the three tracks and combines them for transmission to the CDA stations upon command, using a 1697.5-MHz S-band transmitter.

INCREMENTAL TAPE RECORDER (ITR)

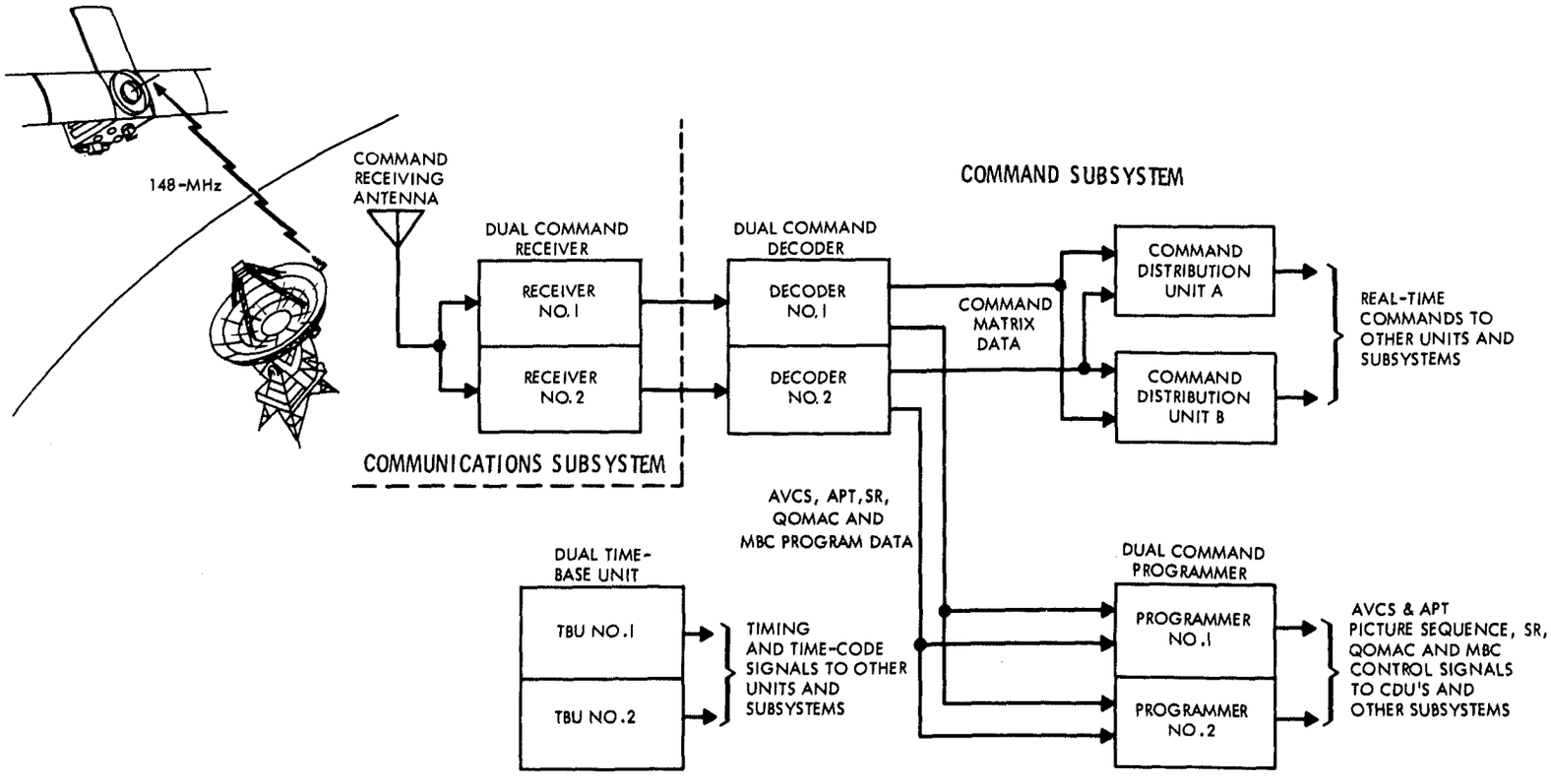
The ITR subsystem is a miniaturized digital three-track magnetic-tape recorder that serves as a storage and readout facility for FPR and SPM data recorded throughout the orbit together with clock, telemetry, and time-code data. ITR plays back the tapes to the CDA stations through the DFC, which processes all input signals to the ITR.

The ITR consists of two pressure-sealed assemblies: a tape-recorder assembly and an electronics assembly.

ITR stores on track 1 in serial-digital form the SPM digital data processed in the DFC, and on track 3 the FPR digital data combined with time-code and housekeeping telemetry data by the DFC. Track 2 stores the clock data used for reference during playback.

The ITR records data at a rate of 15 pulses per second and stores 300 bits per inch. The tape reels hold 90 feet of tape, which can store 324,000 bits per track, or a total of 972,000 bits for the three tracks, which is sufficient to record all data for three orbits. Total record time is 355 minutes. The play-back rate is about 2000 bits per second, and playback of the entire tape requires 2.7 minutes. A permanent magnet automatically erases the tape after playback.

154 835



COMMAND

The CDA stations control the operation of the satellite by programmed commands transmitted to the satellite on a 148-MHz radio signal. The command signals are received through the satellite command and beacon/telemetry antenna, routed to the dual-command receivers, and fed to the command subsystem, which stores and executes the commands for satellite operation. The command subsystem consists of four units.

COMMAND DECODER

The command decoder includes two electrically separate decoders, each operating in response to a different command-audio tone from one of two identical command receivers. Each decoder demodulates the audio tones, reconstitutes the digital data, supplies outputs to the CDU's, and sends real-time commands and data to the command programmers.

COMMAND PROGRAMMER

Redundant command programmers, each consisting of a small computer incorporating digital micrologic modules in a clock-logic arrangement, receive real-time commands and data from either decoder. The programmers obtain timing signals for synchronous operation of the programmer digital logic from the TBU. By CDA-station command, either programmer, but not both, may be selected at any time. The programmer stores time-delay data, including the information necessary for the remote operation of the AVCS, APT, and SR subsystems, and the QOMAC and MBC attitude-control coils. Real-time commands can modify the execution of the stored program. The programmer distributes outputs to appropriate satellite designations either directly or by means of the CDU's.

COMMAND-DISTRIBUTION UNIT (CDU)

Redundant CDU's, the switchboard of the satellite, use a series of latching and nonlatching relay circuits to decode and distribute all satellite real-time commands. The CDU OR's the outputs of the redundant command-decoder matrixes for redundancy selection, power control for subsystems, attitude, and many other functions. This unit also routes programmer-sequenced signals to the primary and secondary sensor subsystems.

TIME-BASE UNIT (TBU)

The redundant TBU generates precise timing signals to synchronize and coordinate all timing functions aboard the satellite, as well as a time-code signal to the primary and secondary sensor subsystems for simultaneous recording with remote data. The TBU also provides flutter and wow and clock signals to the primary and secondary sensor subsystems, respectively.

COMMUNICATIONS

The communications subsystem uses four separate transmission links to handle communications between the satellite and the ground stations.

COMMAND-RECEIVING LINK

The satellite uses a command and beacon/telemetry antenna to pick up CDA-station commands transmitted on amplitude-modulated 148-MHz carrier waves; the commands are routed to filters which reject spurious signals, and feeds the filtered transmission to dual-command receivers whose outputs are inputs to two sections of the dual-command decoder. Commands are in the form of two audio tone pairs, each consisting of an enable tone and a frequency-shift-keyed (FSK) subcarrier; each pair of command audio tones activates one of the two sections of the dual-command decoder. The tone pair is transmitted sequentially and only one tone is present at any given time. Receiver outputs are identical and consist of either the enable tone or the FSK subcarrier.

BEACON AND TELEMETRY LINK

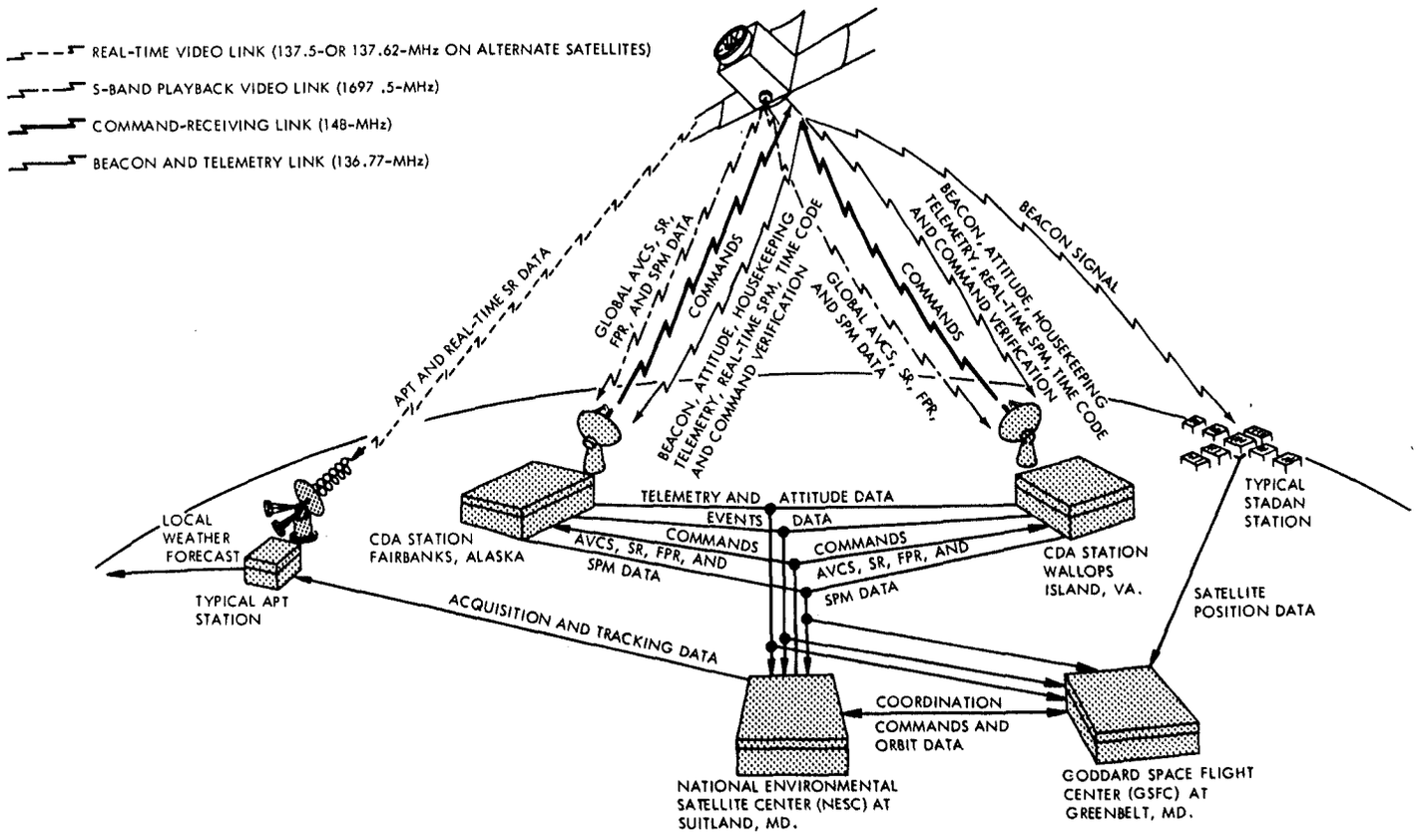
Redundant 136.77-MHz 250-mw phase-modulated (PM) transmitters transmit continuous beacon and telemetry signals on command to the CDA stations. The command-receiving and beacon/telemetry links use the same antenna. The beacon signals permit tracking of the satellite at all times during launch and operation. NASA's world-wide space-tracking and data-acquisition network (STADAN) stations intercept the beacon signals at scheduled intervals for use in orbit determination. Telemetry signals consist of housekeeping telemetry, satellite attitude, real-time SPM, time-code, and command verification data so that ground-station personnel can evaluate the performance of the satellite and its subsystems for operational control and programming of the satellite.

REAL-TIME VIDEO LINK

Redundant 137.5- or 137.62-MHz (on alternate satellites) 5-watt FM transmitters use the real-time antennas to transmit APT or SR data to APT ground stations throughout the world for local weather forecasting. Under normal operating conditions, the data come from the APT cameras during the daytime and from the SR sensors during the nighttime portion of the orbit. A backup mode permits SR transmission continually during daytime or between APT pictures.

S-BAND PLAYBACK VIDEO LINK

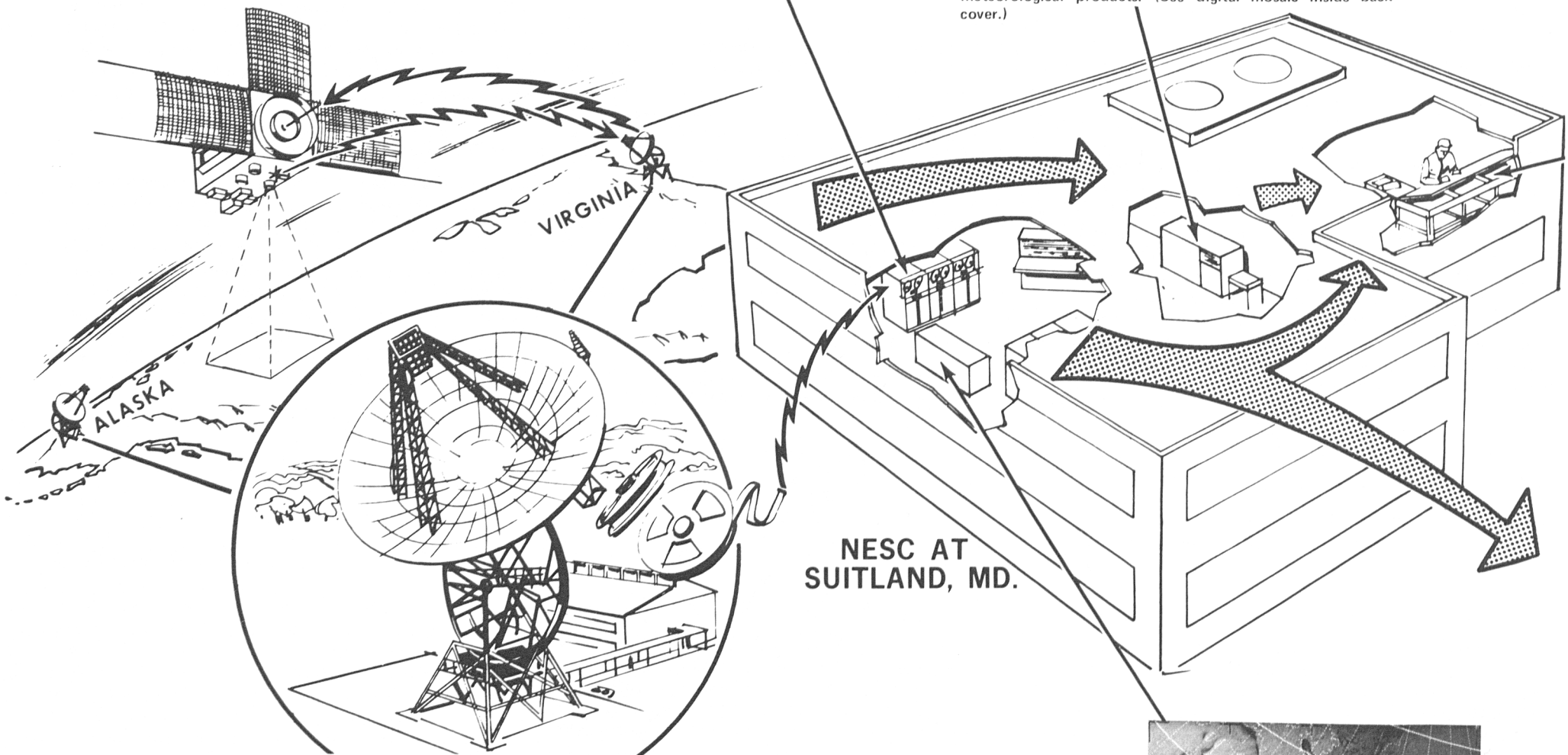
Redundant 1697.5 MHz 2-watt S-band transmitters are the major means of transmitting data from the satellite to the CDA stations. AVCS, SR, FPR, and SPM video data that have been recorded throughout the satellite's orbit are combined in a dual multiplexer, replayed on CDA station command, and transmitted as one multiplexed signal over an S-band antenna to the CDA stations. The CDA stations demultiplex and record this signal, and subsequently retransmit it down long lines to GSFC at Greenbelt, Md., and to NESC at Suitland, Md.



DATA

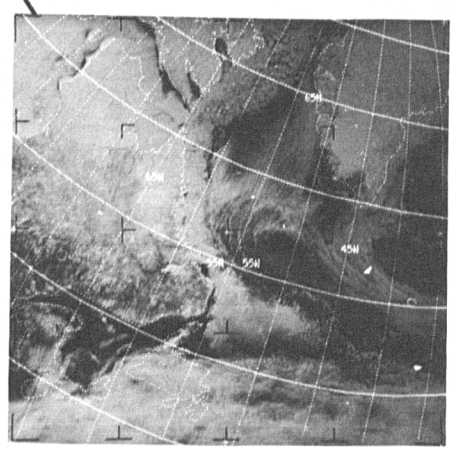
3 All AVCS and SR data, digitized for processing in large-scale computers, serve to produce mosaics of the earth's cloud cover. These data also are the source of derived products such as sea-surface temperatures, cloud-height analyses, and snow- and ice-distribution charts.

4 NESC also produces digital products photographically and distributes them over facsimile networks. NESC removes the overlap of successive views in the digital products, adjusts for differences in scene lighting, and issues the results on standard map scales and projections common to other meteorological products. (See digital mosaic inside back cover.)



1 CDA stations at Fairbanks, Alaska, and Wallops Island, Virginia, transmit programmed commands to ITOS for future operation and readout of data. ITOS transmits AVCS and SR analog data and FPR and SPM digital data to the CDA stations, which read out the data, record them on magnetic tape, and relay them by ground communications lines to the National Environmental Satellite Center (NESC) of the Environmental Science Services Administration (ESSA) at Suitland, Maryland. Telemetry data are recorded on magnetic tape and paper charts simultaneously and relayed by communications lines to NESC.

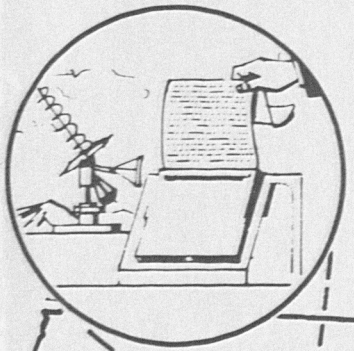
2 NESC displays AVCS and SR data on special monitors photographed by 35 mm cameras. A latitude and longitude grid prepared by computer from satellite-attitude data is superimposed on each photograph, so that personnel using the photographs will be able to define the geographical location of the picture data. (See strip photo mosaic on next page.)



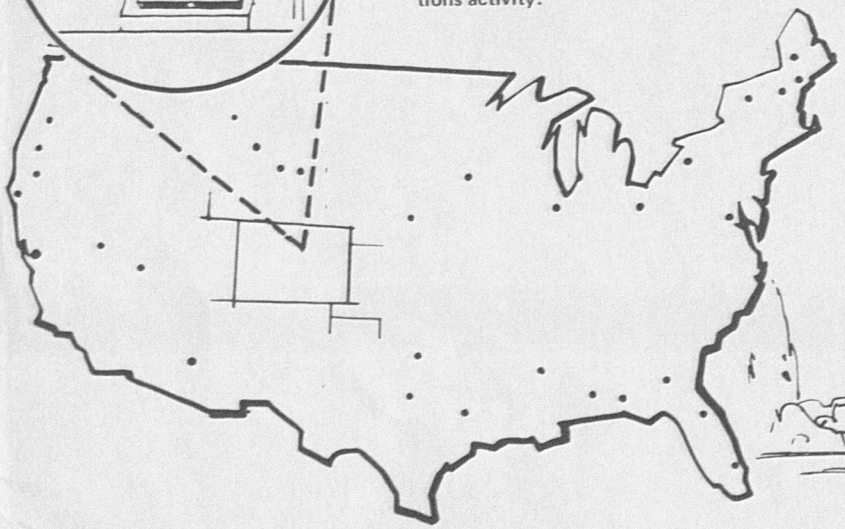
GRIDDED PHOTO

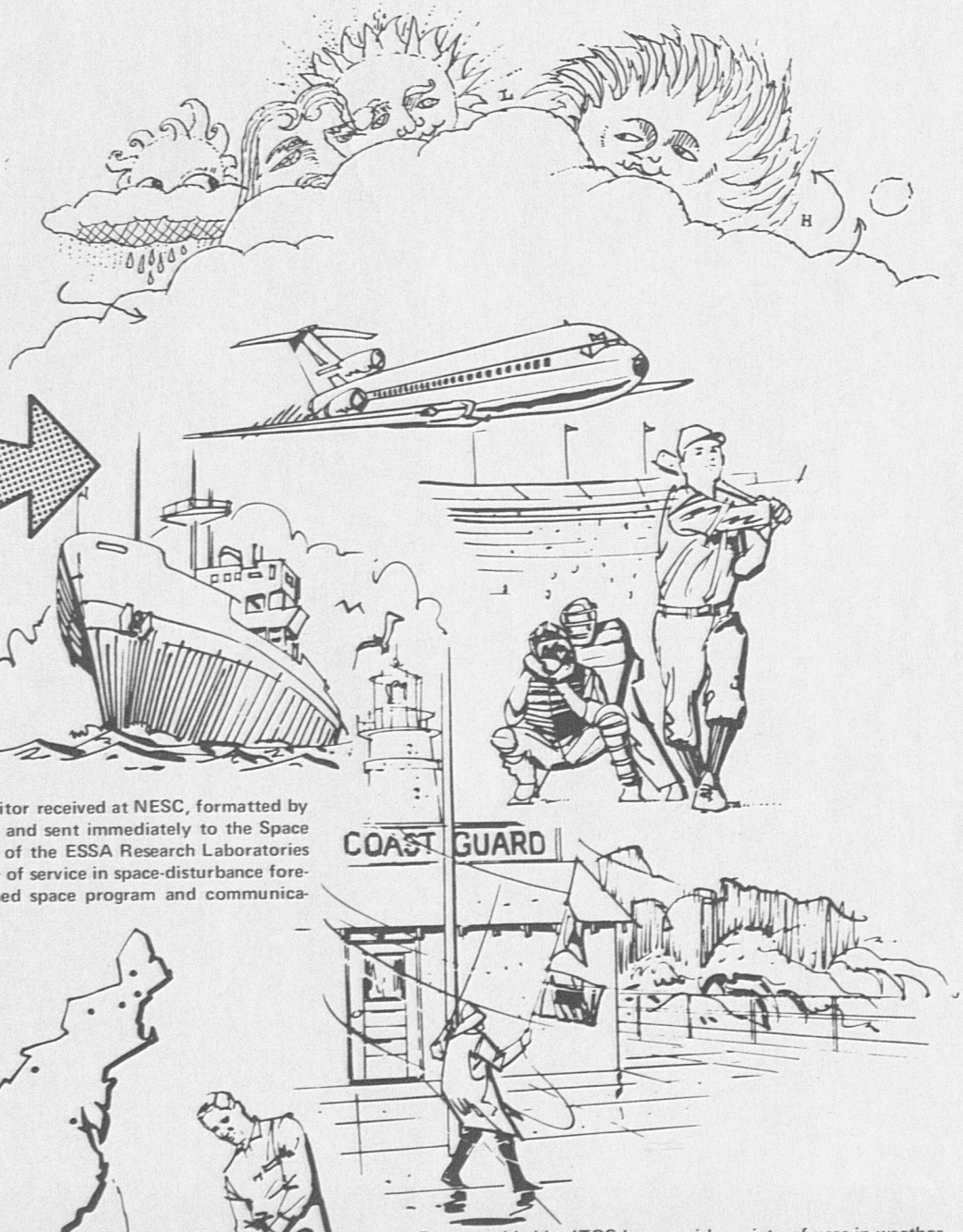
UTILIZATION

5 Principal distribution within the United States is by wire-facsimile networks to Weather Bureau, Navy, and Air Force forecasting units. Overseas areas receive weather facsimile by means of the ATS 1 satellite in the Pacific and the transoceanic cable in the Atlantic, as well as by coded teletype messages. NESC prepares and telegraphs special messages to countries which might be affected, noting the position and strength of tropical storms.

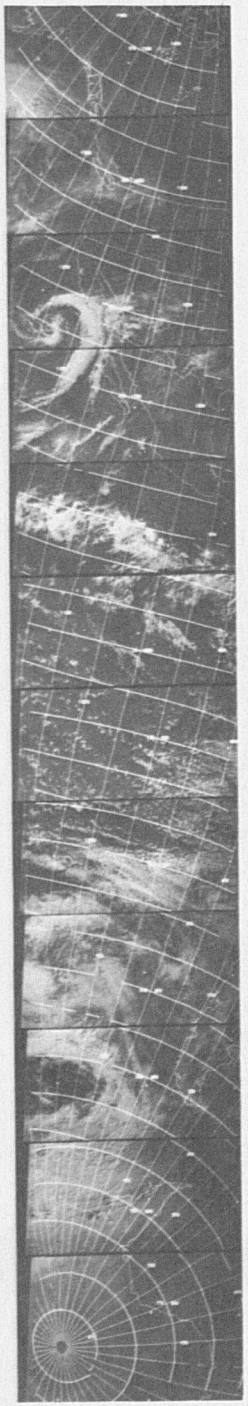


6 Data from the SPM monitor received at NESC, formatted by computer into bulletins, and sent immediately to the Space Disturbances Laboratory of the ESSA Research Laboratories at Boulder, Colorado, are of service in space-disturbance forecasting to support manned space program and communications activity.

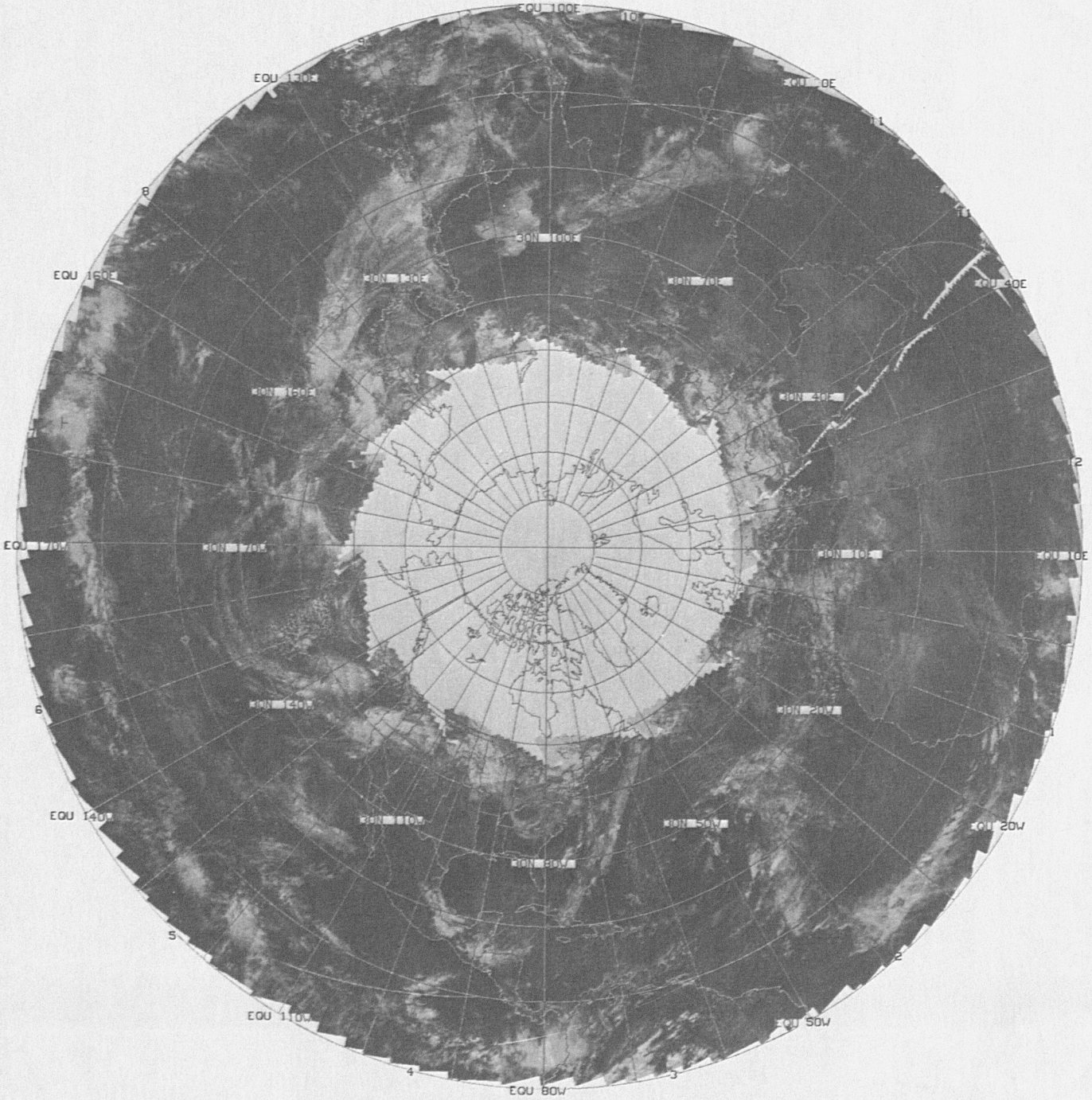




7 Data provided by ITOS have a wide variety of uses in weather forecasting: they represent an excellent source for short range forecasts of local weather. They are useful in describing the general weather patterns for input to the basic weather forecasts for tomorrow and the next day. They are particularly valuable in surveillance of the ocean areas, especially in the tropics, for warnings of severe hurricanes and typhoons. Equally important is the use of these data in meteorological research, necessary to a better understanding of weather.



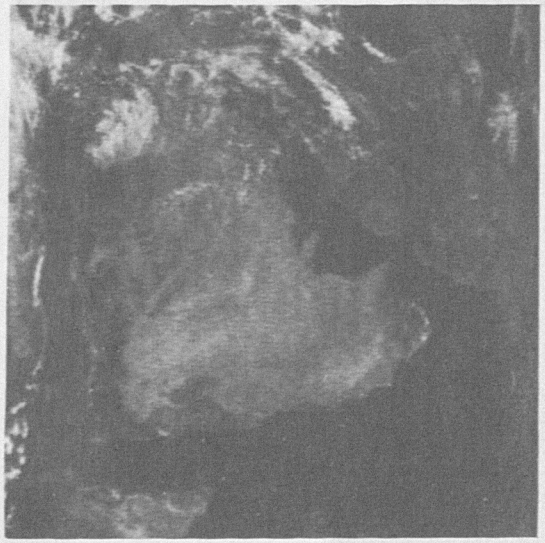
STRIP MOSAIC OF GRIDDED PHOTOS



Digital mosaic of the northern hemisphere generated by computer at NESC, Suitland, Md., from pictures received from ESSA 9 (TOS-G).

Scanning radiometer visible and IR daytime images of Saudi Arabia and Red Sea recorded 2:24 p.m., Feb. 11, 1970, by ITOS 1 (TIROS-M)

VISIBLE



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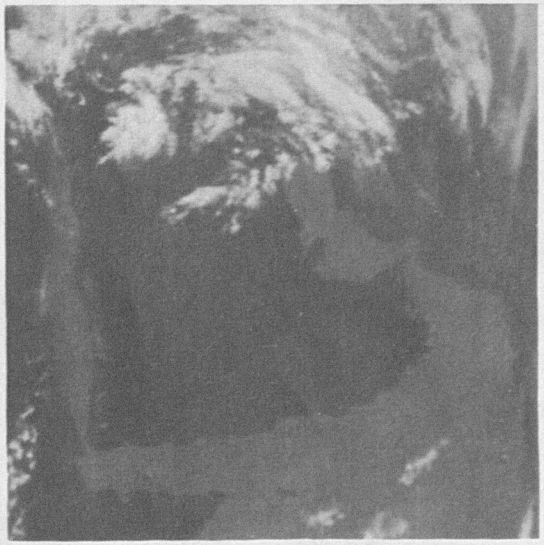

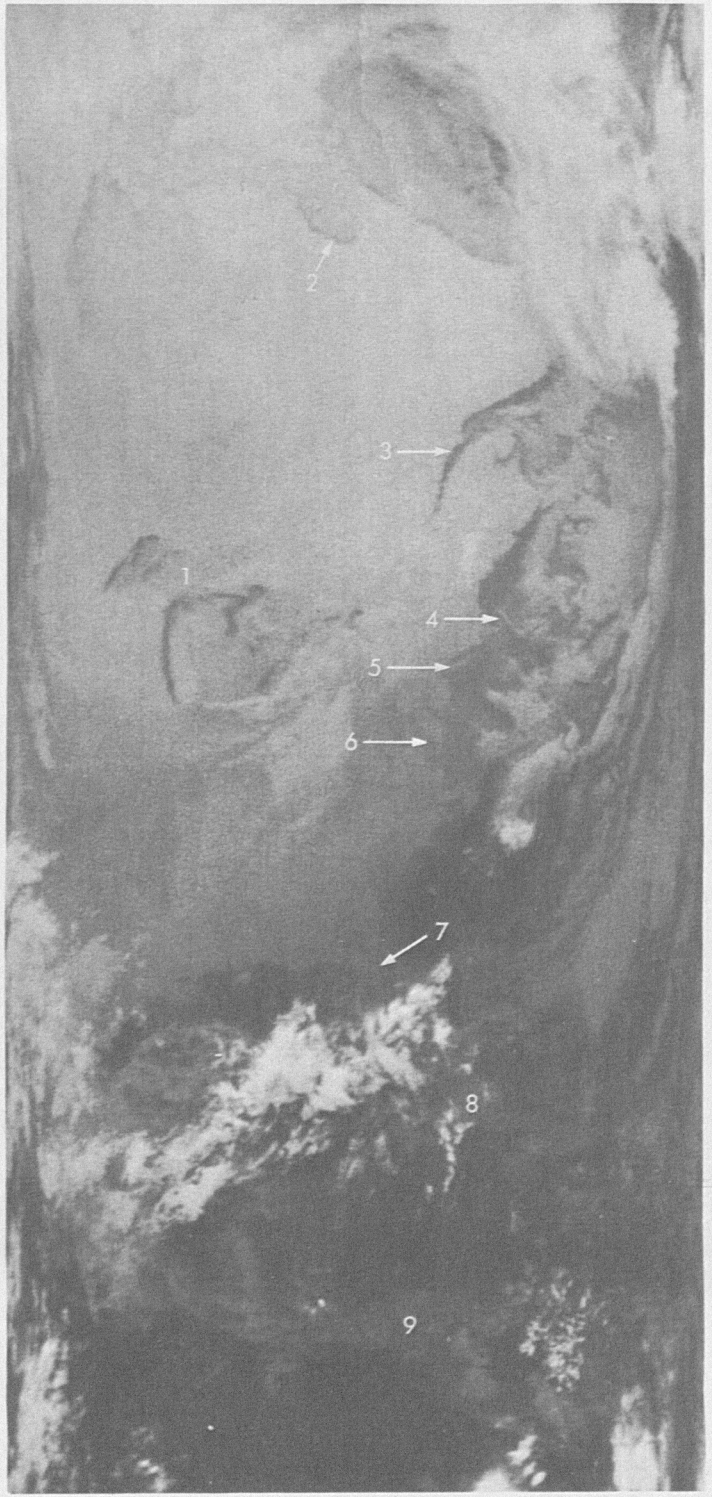

ITOS 1 (TIROS-M) scanning radiometer direct IR nighttime image of eastern coast of United States, 4 a.m., Feb. 20, 1970

1. Great Lakes
2. James Bay (Lower part of Hudson Bay)
3. St. Lawrence River
4. Cape Cod
5. Long Island
6. Chesapeake Bay
7. Florida
8. Cuba
9. Central America

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