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EARTH RESOURCES TECHNOLOGY SATELLITE FINAL REPORT

1. SUMMARY

PREPARED FOR

GODDARD SPACE FLIGHT CENTER
NATIONAL AERONAUTICS
AND SPACE ADMINISTRATION

UNDER CONTRACT NAS5-11260

TRW SYSTEMS GROUP

IBM FEDERAL SYSTEMS DIVISION

Itek OPTICAL SYSTEMS DIVISION

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FINAL REPORT

Volume 1. Summary

April 17, 1970

prepared for

National Aeronautics and Space Administration
Goddard Space Flight Center

Contract NAS5-11260
item 5a

TRW Systems Group
One Space Park · Redondo Beach
Los Angeles County
California 90278

ROAD MAP

REVISIONS AND ADDITIONS TO FEBRUARY SUBMITTAL

This volume replaces Volume 1, Final Report, submitted in February. It differs from the previously issued Volume 1 in the following ways:

Section 1. The introductory comments have been revised to include not only the previously submitted material but the entire final report.

Section 2. This section previously discussed spacecraft studies still under way. These studies have now been completed and the results incorporated in revised volumes or written answers to GSFC's questions. A summary description of our spacecraft, our GDHS and our DCS has been provided instead.

Section 3. This section contains a summary of spacecraft and GDHS performance.

Section 4. This section includes the previous reconciliation of spacecraft tasks proposed and completed as well as a reconciliation of all remaining tasks.

CONTENTS

PREFACE

The final report for the ERTS Phase B/C study consists of the volumes submitted in February and those that are presently submitted. The contents of the first volumes of the report are as follows:

Volume	
1	Summarizes our proposed design both observatory and GDHS and presents a performance summary for both. It also summarizes the status of tasks performed under the phase B/C contract.
2	Contains the results of overall system studies, the orbit and overall system accuracy. The top system specifications are included in an appendix.
3	Describes the design of the ERTS spacecraft resulting from the study to a block diagram level of detail.
4	Presents the detailed results of the study supporting the design in Volume 3, including backup tradeoffs and analyses.
5	Presents both the design of the data collection system and the supporting analyses.
6-13	Present the plans prepared for the ERTS Phase D program called for under the Phase B/C study.
14	Describes the GDHS in summary form and the personnel and material requirements for its operation.
15-17	Presents the studies on the OCC and NDPF which led to the system described.
18	Presents the ADPE evaluation.

The 18 volumes of the final report are as follows:

Volume	
1	Summary
2	ERTS System Studies
3	Observatory System Design
4	Observatory Subsystems Study
5	Data Collection System
6	Reliability Program Plan
7	Quality Program Plan
8	Test Monitoring and Control Plan
9	Configuration Management Plan
10	Soldering Program Plan
11	Failure Reporting Plan
12	Observatory Integration and Test Plan and Launch Operations
13	GDHS Staffing and Material Usage Plan
14	GDHS Design
15	GDHS Study
16	OCC Study
17	NDPF Study
18	ADPE Procurement

1. Introduction

CONTENTS

1. INTRODUCTION

TRW has completed the spacecraft, the data collection system, and the ground data handling system studies for the ERTS Phase B/C contract. The results are reported in 18 volumes. Thirteen of the volumes were submitted in February, two of which including this volume are being reissued now. Six new volumes are also submitted at this time.

In these volumes TRW presents information generated as a result of contract work and other prior and independent studies which bear on the development of the best overall ERTS system. We have not attempted to duplicate material presented in our June 1969 proposal and its appendices, although much of the information presented then is still applicable. That material is referred to in numerous instances throughout this report. Where changes have been incorporated, however, the previous work is revised in its entirety and presented here.

In organizing the material, we have tried to collect in Volumes 3 and 14 a complete description of our proposed spacecraft and GDHS designs, including their method of operation, without, however, discussing the rationale behind the selection of these approaches; all tradeoffs and analyses that form the rationales are included in Volume 4 for the spacecraft and Volumes 15-17 for the GDHS. Volume 2 also supports some of the conclusions in Volumes 3 and 14 in its coverage of more general system studies including the orbit, the booster selection spacecraft - GDHS interrelationship, and total system accuracy. All results of the studies of the data collection system are presented in Volume 5. The plans called for in Section 7.11 of the GSFC design study specification constitute Volumes 6 through 12. Volume 13 contains staffing and material usage plans for the GDHS. Volume 18 summarizes the ADPE procurement.

2. Overall System Description

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2. OVERALL SYSTEM DESCRIPTION

2.1 OBSERVATORY

The ERTS observatory is a reliable and versatile system capable of gathering information about the world's natural and cultural resources. It provides room and weight-carrying capability for installing a variety of sensors including specifically a multispectral point scanner, a triplet of return beam vidicon cameras and their associated electronics, a real time data collection system, and a pair of video tape recorders. It includes an attitude control system which provides accurate three-axis stabilization with the horizon and orbit plane as references and an attitude determination capability for refining knowledge of the relative and absolute location of image points. Power for continuous subsystem operation and for 20 minutes of payload operation has been included. Spacecraft monitoring and control and payload data readout can take place using either STADAN or MSFN ground stations.

While a lifetime goal of one year has been established, there is a relatively high probability that ERTS missions could continue unimpaired for three years. The ERTS design is a logical outgrowth of the OGO program and makes use not only of the technology and design developed but actually incorporates OGO spare parts in many instances. Much of the reliability and flexibility are directly traceable to the OGO program.

OGO assemblies have been retained intact where possible. All of the manual override features of OGO attitude control have been retained, as have the alternate modes of control. In adapting OGO to ERTS, four principles have been consistently applied:

- The highest possible reliability for a first launch must be achieved.
- A useful life of three years is desired.
- Growth capability should be provided.
- Implementation of the design must be possible within a relatively short schedule and low cost.

The simplest acceptable approach to a design problem has been sought. For attitude determination it has been found possible to employ the same

PERFORMANCE AND PHYSICAL PARAMETERS

KEY PERFORMANCE FEATURES

PAYLOAD CAPACITY

475 pounds
18 ft^3
More than 20 min/orbit of power
Thermal control to 20 ± 10°C

ATTITUDE CONTROL

Earth pointing within 0.5 degree in pitch and roll and within 0.7 degree in yaw
Body rates kept below 0.011 deg/sec in roll and yaw, 0.008 deg/sec in pitch

PICTURE ELEMENT ACCURACY

Independent location within 2 nautical miles

COMMANDS

1 Kbit/sec rate
Storage capacity. 64, 254 executions
Power margin, USB. 30.8 db*
VHF 17 6 db*

TELEMETRY

Above 6 db system margin

12 hours of storage
1 or 32 Kbits/sec data transmission
15 Mbits/sec and 4 MHz bandwidth
*transmission payload data

LIFETIME

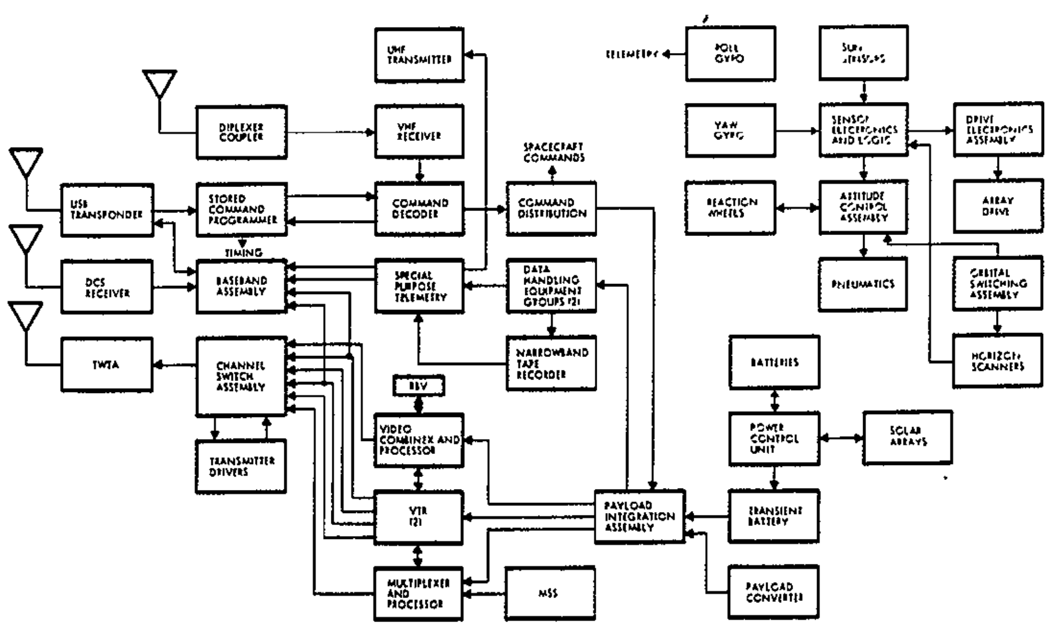
0 85 probability of 1 year
0 65 probability of 3 years

DOWNLINK POWER

MARGINS, ABOVE 6 DB SYSTEM MARGIN

VHF 1 Kbit/sec downlink	17.3
VHF 32 Kbits/sec downlink	2.2
VHF carrier beacon	24.3
Unified S-band ranging	14 7
Unified S-band normal mode downlink	4.2
Unified S-band unstabilized mode downlink	9 7
Wideband RBV downlink, 30 ft station, normal mode	37.1
Wideband RBV downlink, 85 ft station, normal mode	42.1
Wideband MSS downlink, 30 ft station, normal mode	2 5
Wideband MSS downlink, 85 ft station, normal mode	7.5

- Quad-redundant command system provides 358 discrete commands, 64 of which are storable, 127 executions (254 in 2 stores), real-time override of stored command. Timing is by two 6 4 MHz clocks with 1 ppm stability
- Control of observatory body and array is by on-off servo systems, using 3-axis reaction wheels with krypton gas jets to unload wheel momentum and wobble-gear drive of array shaft Nozzles mounted on booms providing 4-foot lever arm for yaw and roll and 1.6-foot lever arm for pitch.
- Three heated gas thrusters in the yaw plane, using attitude control pneumatics and krypton, provide orbit adjustment capacity of 70 ft/sec, at thrust level of 0.05 lb.
- The solar-cell arrays provide 22 amperes output at 33 5 volts. Average output per orbit is 500 to 650 watt-hours The spacecraft bus is 23.5 to 31 5 VDC. Payload bus is -24 to -25 VDC. Two Ni-Cd batteries provide 12 ampere-hour capacity A third redundant battery is provided.



data that guides the spacecraft plus a roll rate gyro. For orbit adjustment a highly reliable though somewhat inefficient (in weight) system has been adapted.

Some measures which might have improved performance have been rejected because of cost implications. A more efficient array configuration is possible, for example, but costs for qualification tests are an overriding deterrent. A smooth array drive during picture taking is technically possible but it is simpler and much less expensive to simply turn off the array drive with the sensor ON signal.

Like OGO, ERTS is a rectangular parallelepiped (Figure 2-1) with one side always facing earth in flight. Like OGO it employs two large solar arrays which are oriented toward the sun on a rotating support shaft. Unlike OGO the ERTS solar array shaft is always aligned with the velocity vector, accomplished by using an OGO gyro package to function as a gyrocompass controlling ERTS in yaw.

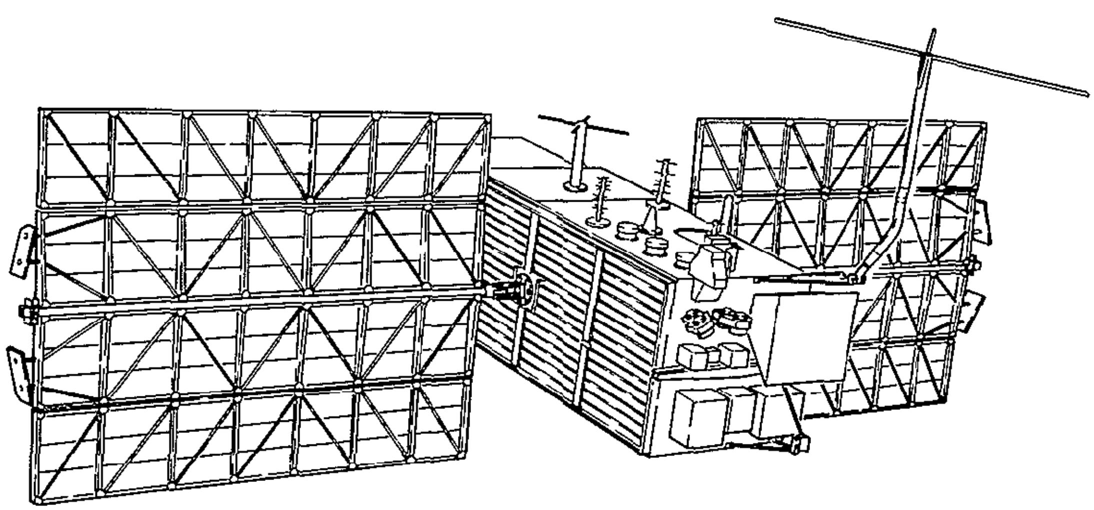


Figure 2-1
ERTS OBSERVATORY AS DEPLOYED IN ORBIT

The spacecraft folded for launch is dimensionally the same as OGO (Figure 2-2). Array tips are at the OGO positions with respect to the shroud. The tips of the attitude control booms are fixed in position as close to the shroud as possible.

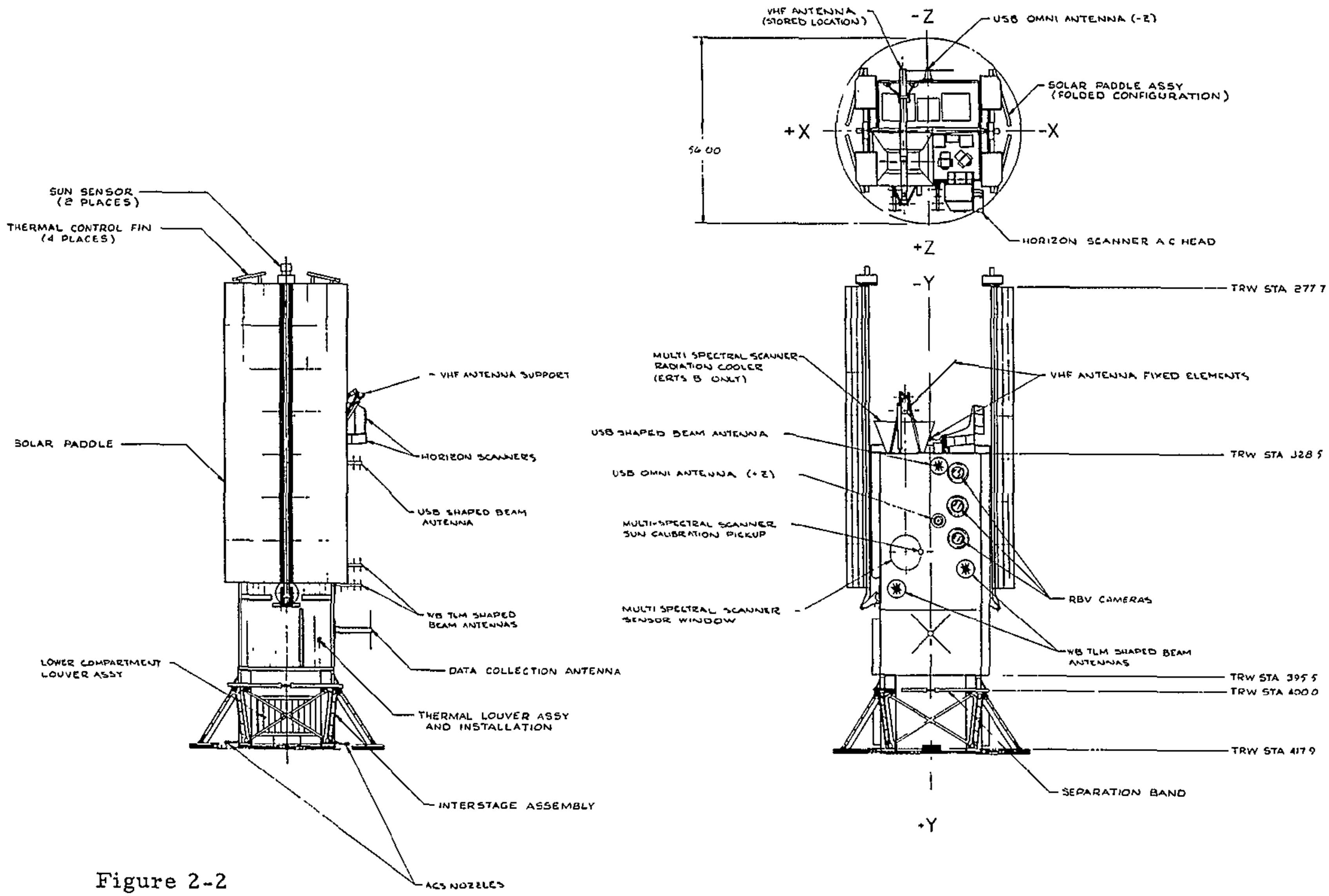


Figure 2-2

ERTS SPACECRAFT ON ITS INTERSTAGE, FOLDED AS FOR LAUNCH

The precision orbit for ERTS is achieved with a velocity trim of the spacecraft after release from the Thor-Delta. For this purpose simple thermal thrusters are added to the existing OGO pneumatic system, providing more correction capability than is anticipated to eliminate injection errors.

Thermal control of ERTS is unchanged from OGO except for added aluminized teflon surfaces under the standard thermal louvers. In the ERTS orbit, sun shines on each louvered panel briefly during each revolution and a reduced panel absorptivity is needed. Multiple layers of aluminized Mylar generally insulate all body surfaces except the two louvered panels of the array facing sides.

The ERTS solar array is 16 percent larger in area than on OGO (Figure 2-3) achieved by filling in the unused sections of the OGO array; the external dimensions of the array are unchanged. Charge control makes use of the OGO power control unit, shunting part of the array strings with OGO power transistor thermal fins when power is excessive. Spacecraft voltages are all developed with OGO distributed converters. Regulated -24 volts for the ERTS payload is supplied from a new high-power converter. Power available for payload operation varies with time of year and launch and is shown on Figure 2-4.

Communication functions of ERTS are more diverse than on OGO in that sensor data transmitted is extremely high rate and telemetry and command communication is quad-redundant. Six transmitters and four receivers are employed. Four links are S band and two are VHF. Two 10/20 watt S band video transmitters relay sensor video data while a redundant pair of 0.8-watt unified S-band transponders accomplish tracking, command, and telemetry functions. STADAN-compatible equipment performs these same three functions at VHF.

The volume and variety of command and telemetry required for the ERTS mission is not far short of the final OGO requirements. Almost the entire command decoding and distribution system of OGO is retained in ERTS. OGO telemetry formatting and handling equipment is retained intact in ERTS as are the command receiver and decoders. A new ERTS need for stored, delayed-execution commands is provided by a stored

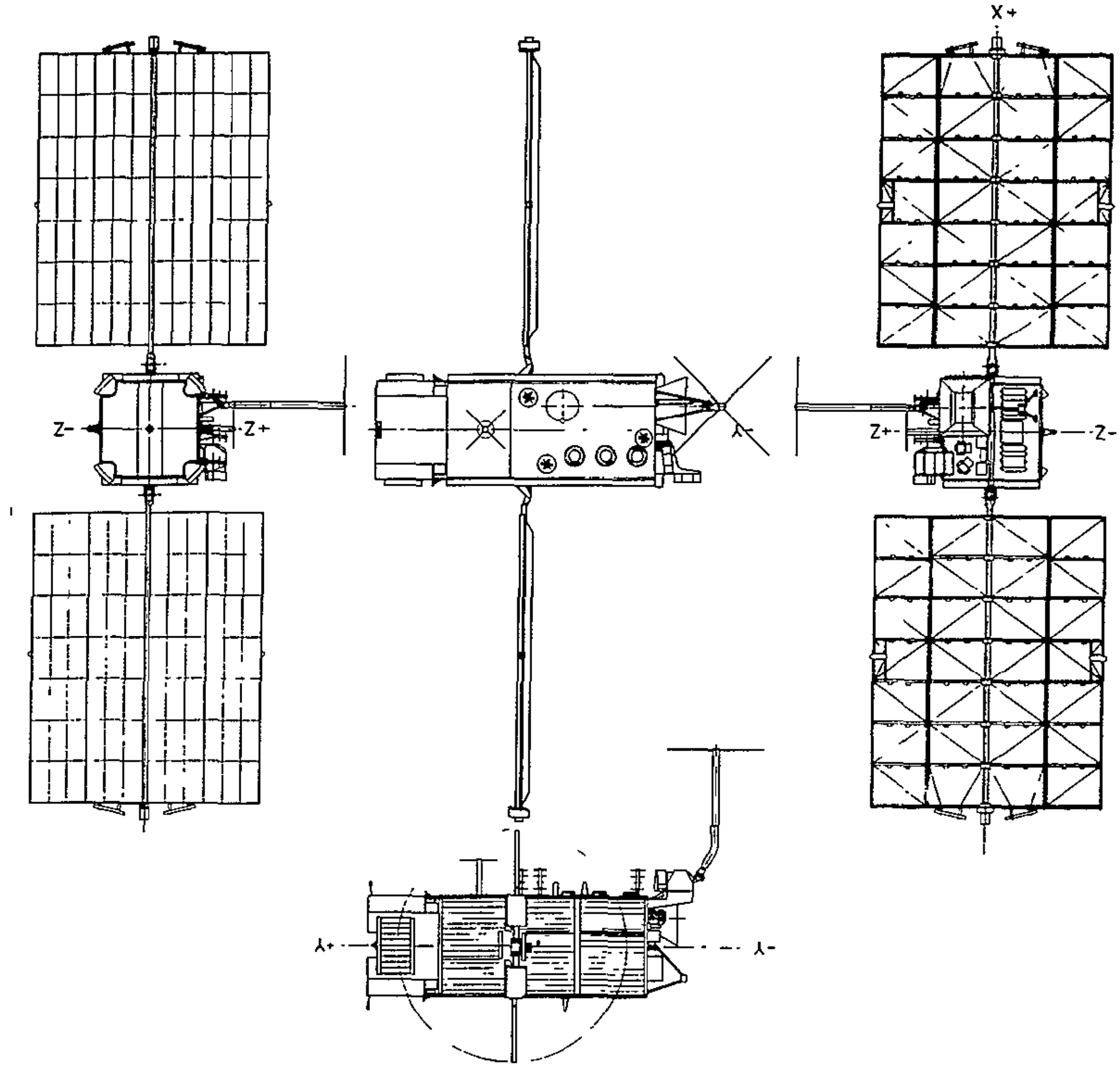


Figure 2-3
ERTS SPACECRAFT DEPLOYED AS IN ORBIT

command programmer. HDRSS derivatives of the OGO digital tape recorders are used at half speed to store narrowband telemetry data for delayed transmission.

Figure 2-5 shows some of the existing OGO assemblies used on ERTS.

ELECTRICAL POWER DURING FIRST YEAR OF OPERATION

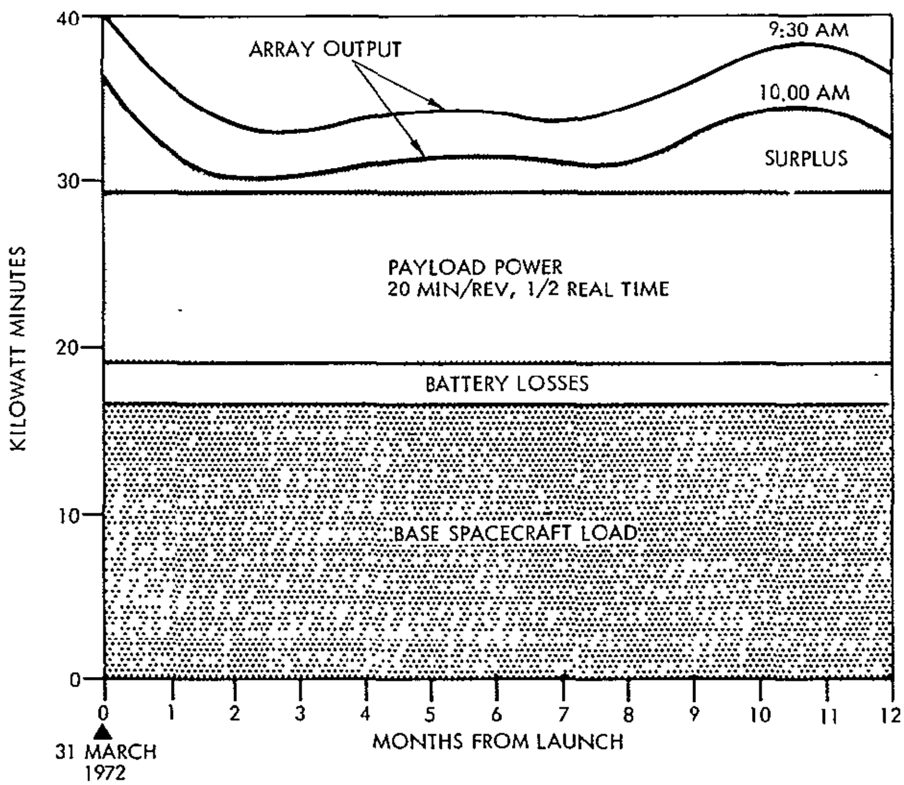


Figure 2-4
ELECTRICAL POWER DURING FIRST YEAR
of operations

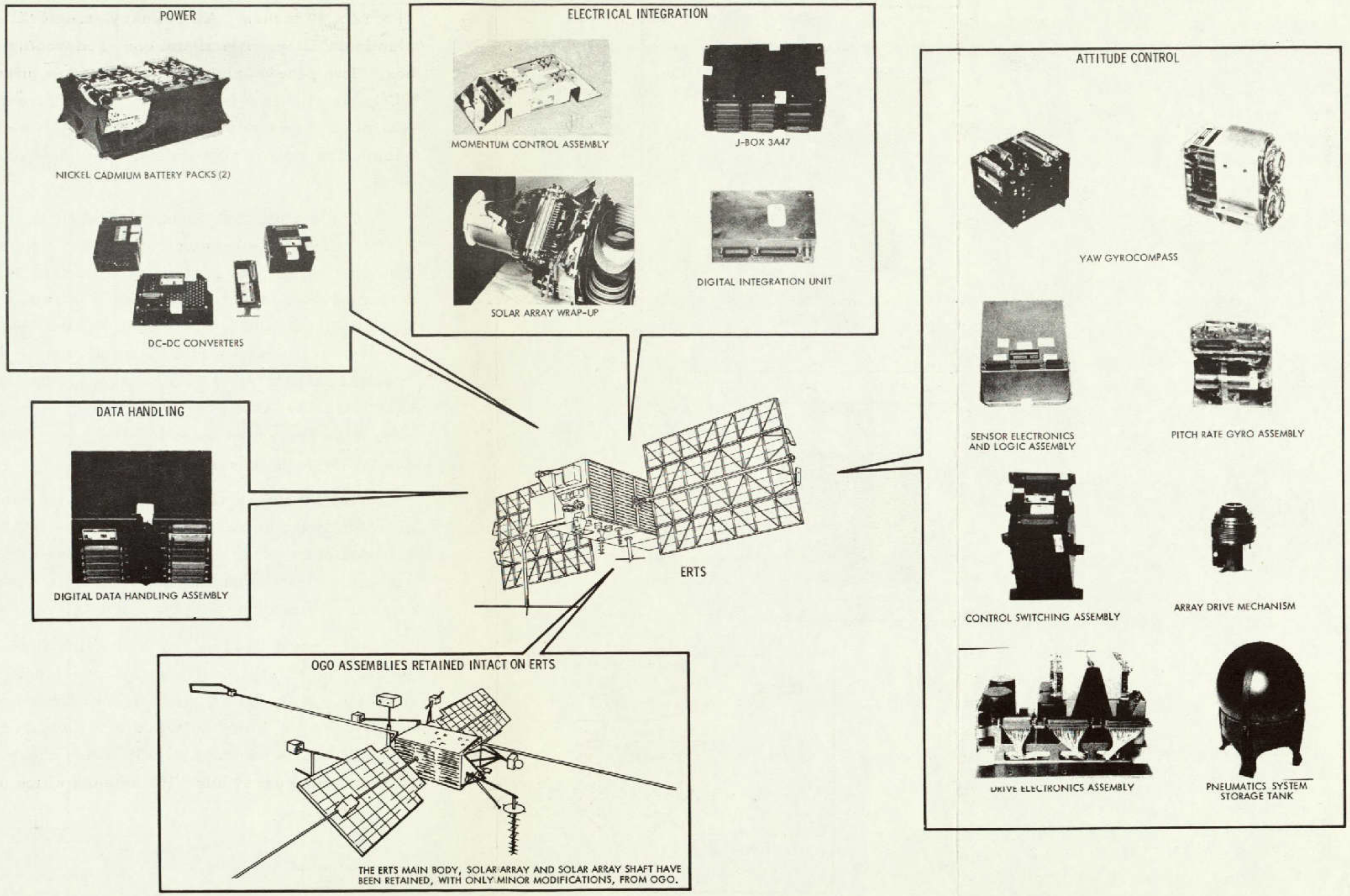


Figure 2-5
OGO ASSEMBLIES USED ON ERTS

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2.1.1 Structure

Basic frame taken from OGO is a parallelepiped of approximately 31 x 32 x 90 inches. All primary structural elements are constructed of aluminum alloy. Aluminum core honeycomb panels form the sides of the box. Two panels are hinged to provide equipment access. In contrast to OGO, the side panels extend 23 inches beyond the longerons at one end. Additional doors are also provided at this end to form a compartment for holding the video tape recorders and their associated electronics assemblies.

The sensors are mounted directly to the basic structure of the spacecraft. These members are extremely rigid and experience less thermal deformation than the panels. The horizon scanner heads are mounted on a special bracket which is designed to reduce thermal gradients and maintain alignment between the heads and the spacecraft structure. The RBV cameras are mounted on a thermally stable platform which is, in turn, mounted to the basic ERTS structure. The MSS is attached directly to the basic structure close to the attitude sensors. The yaw gyro is mounted behind the horizon scanner bracket close to the basic structural elements and the payload sensors.

The machined aluminum alloy interstage truss structure provides an efficient load path between OGO and the Delta. It consists of four bipod legs designed to carry the major loading axially in each leg element (Figure 2-6). To provide margin over OGO, the interstage is crossed braced to reduce interstage warping under lateral loads.

The solar paddles, each of which supports solar cell modules, a sun sensor, and charge controls, are constructed of aluminum alloy. The main spar of the solar paddle is an extruded square tube of 2024-T42 aluminum alloy which is bolted to a typical hinge assembly at its in-board end. ERTS, in contrast to OGO which has 13 deployable appendages, has only the solar array and VHF antenna which are deployed.

SPECIFICATION SUMMARY

STRUCTURES SUBSYSTEM

BASIC FRAME

Lightweight aluminum frame supports 1500 lb load without fatigue or deformation The structure will accommodate 495 lbs of payload (450 lbs specified in study spec 5-701-P3), and makes available 18 cubic feet of volume for payload and payload expansion (12 cu ft min specified). Sufficient rigidity to hold alignments to less than 0 1 degree. Structural safety factor of 1.50 during boost Pressure vessel safety factor of 2 00 in orbit.

Main body identical to OGO except that 5/8 in honeycomb panels (as used on OGO 5 and 6) are substituted for corrugated core sandwich panels for increased rigidity and payload mounting flexibility Main body weight is 105 lbs,

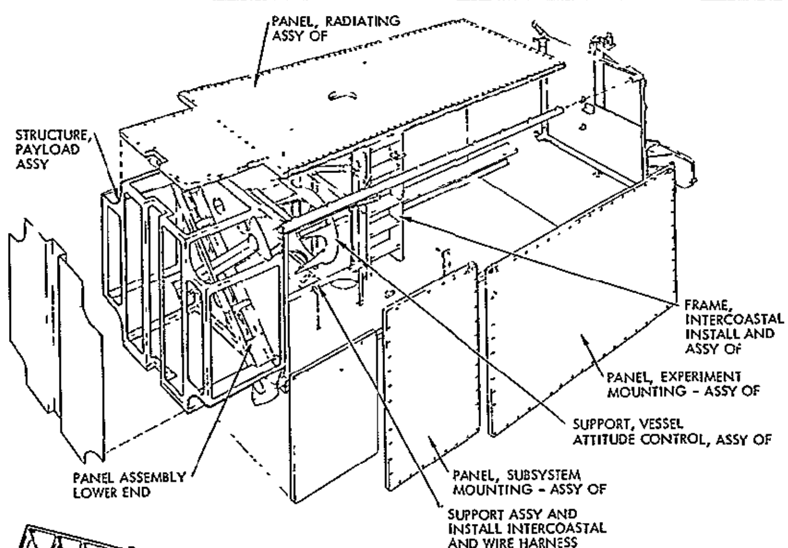
EQUIPMENT PLACEMENT

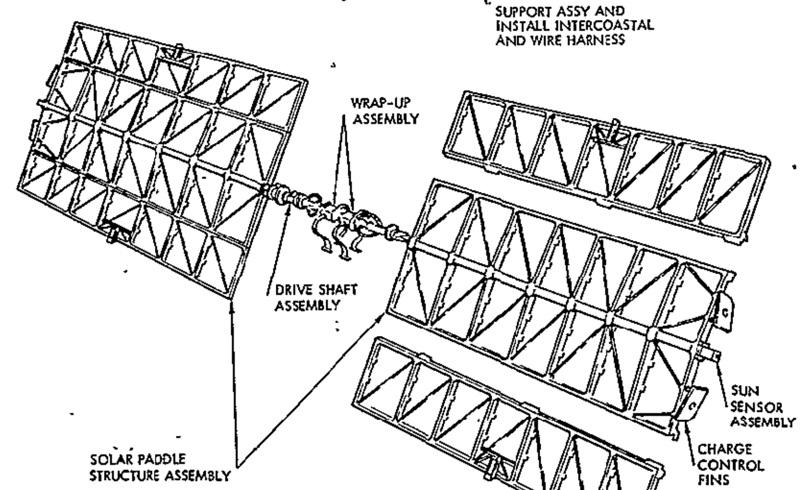
Interior easily accessible through full length doors at opposite sides of body Earth-facing panel of approximately 9 square feet available for ERTS sensor parts and equipment mounting.

SOLAR ARRAY

Primary source of all in-orbit electrical power, the two-paddle ERTS array consists of two outer sections hinged to a central section along an axis parallel to array shaft Each deployed paddle measures 7 x 6-1/4 feet and weighs approximately 58 lbs

The ERTS array employs 18,816 gridded N-or-P 2 x 2 cm solar cells with 10 5% efficiency in space Average array output in sunlight is approximately 450 watts of regulated power.





Total observatory weight is 1491.8 pounds for ERTS-A and 1506.8 pounds for ERTS-B.

Table 2-1. Weight Breakdown for ERTS

	Current Status Weight (lb)
Structure and temperature control	173.5
Attitude control system	209.0
Power supply	265.5
Electrical integration	146.5
Communications and data handling	218.3
Interstage and separation system	23.0
Payload	456.0
Total ERTS-A satellite weight	1491.8*

*ERTS-B weight summary	Weight (lb)
ERTS-B Spacecraft	1035.8
ERTS-B payload	471.0
Total ERTS-B satellite weight	1506.8

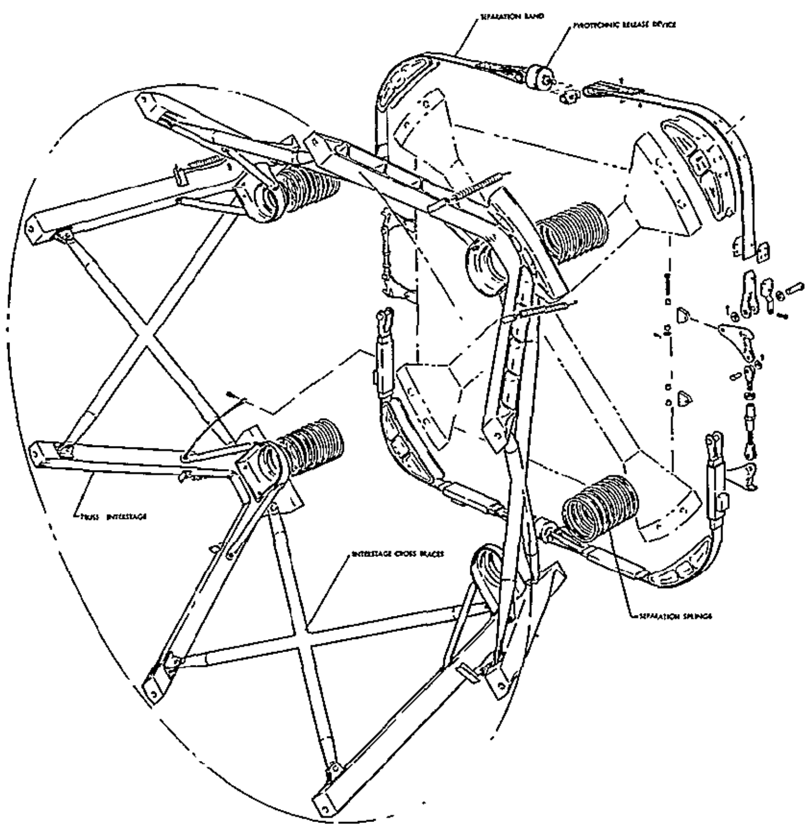


Figure 2-6

INTERSTAGE AND SEPARATION System is Modified slightly from OGO to Support Increased Forward and Side Loads

2.1.2 Attitude Control System

The attitude control system establishes and maintains the body orientation aligned to the local vertical and the orbit plane; it orients the solar array so as to achieve maximum solar power; it develops signals which after ground processing provide a precision measure of the spacecraft's attitude and, through a sequence of modes, permits control reacquisition should any circumstances cause loss of stabilization.

The earth horizon as located by any three of four CO_2-band horizon scanners and their associated electronic circuits provides a reference for determining the local vertical (Figure 2-7). Roll and pitch error signals

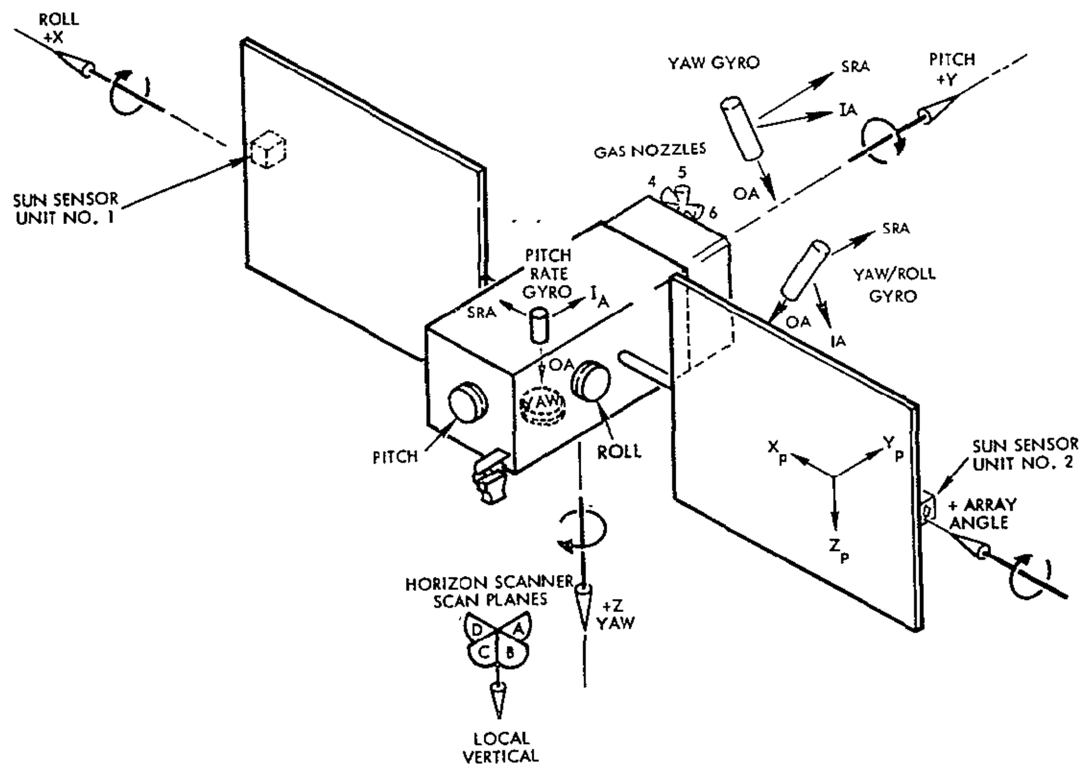


Figure 2-7
ATTITUDE CONTROL SYSTEM COORDINATE SYSTEM

SPECIFICATION SUMMARY

ATTITUDE CONTROL SUBSYSTEM

BODY ORIENTATION

Body stabilized to within 0 7 degree of geocentric-spacecraft line Body aligned to within 0 7 degree of orbit plane

REACTION WHEELS

Three reaction wheels to control pitch, roll, yaw momentums automatically unloaded at one-half full speed capacity

PNEUMATICS

Six jets for pitch, roll, and yaw control with cold krypton system Automatic operation with command inhibition

- **STORAGE VESSEL**

Volume	1299 cu in
Pressure	4000 psia

- **GAS SUPPLY**

Net weight	58 lb
Compressibility	0 77

- **GAS ALLOCATION**

Attitude Control	12 2 lb
Orbit adjust	43 5 lb
Leakage	1 5 lb
Residual	0 8 lb

HORIZON SCANNERS

Four body mounted scanners track infrared radiation gradient.

YAW GYRO

One caged integrating gyro maintains body roll axis in the orbit plane Second gyro on standby

PITCH GYRO

One spring-restrained rate gyro for sun acquisition

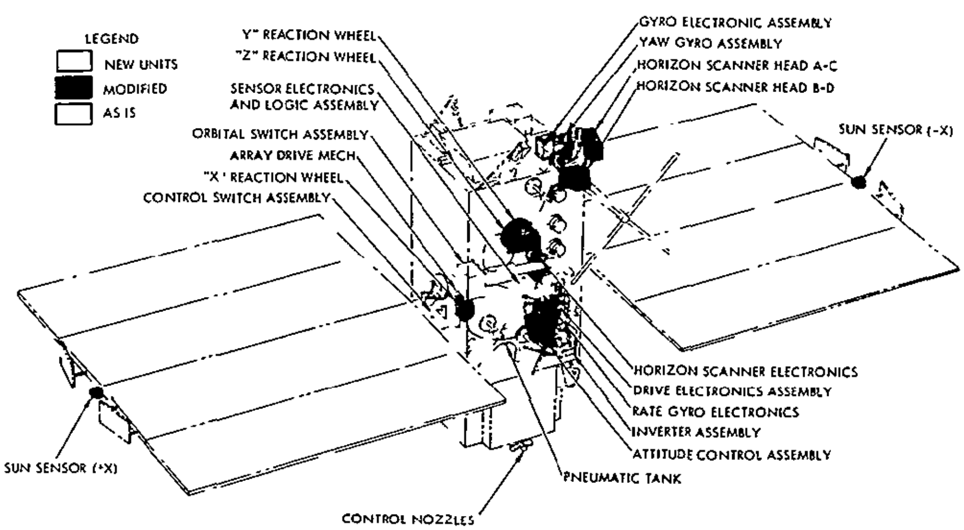
ARRAY ORIENTATION

Face of solar array roll axis oriented to within 8 degrees of spacecraft-sun line Automatic operation with payload inhibition

SUN SENSOR

Two array-mounted sun sensors provide a 4π steradian field of view, and indicate deviations about two axes between the array perpendicular and the sun line

One fully automatic attitude control subsystem to acquire and maintain three-axis stabilization and solar orientation with minimum interference to payload operation



are developed whenever the body Z axis drifts from the local vertical about either of these axes. Similarly, a gyrocompass assembly provides a yaw reference by detecting whenever the X axis does not lie in the orbit plane. Sun sensors mounted on the solar array provide a 4π steradian field of view and indicate deviations about two axes between the array perpendicular and the sun line. The error signal about the array axis controls the angle about the roll axis of the array with respect to the body. The other error signal is used only during acquisition.

Body control is effected by a pneumatic system (for angular momentum removal) and a reaction wheel system (for momentum storage). In normal control the yaw pneumatic system is disabled, and the pitch and roll pneumatic systems remove components of secular momentum stored in the reaction wheels. Torque to rotate the solar array is provided by a small servo motor through a 24, 000:1 gear train.

The spacecraft portion of attitude determination for ERTS is accomplished with the attitude control equipment and an additional gyro. One alteration is made to the OGO reaction control wheels in the use of position rather than velocity indicators. Cumulative wheel position for each axis, horizon sensor errors, solar array angle and the outputs of the two rate gyros constitutes the attitude determination data telemetered to the ground. On the ground, a computer-implemented Kalman filter is used to calibrate, smooth, interpolate, and combine the spacecraft telemetered data together with additional inputs such as ephemeris data, mass property models, torque models and ground truth when available to yield an accurate record of spacecraft yaw, pitch, and roll.

The control system operates in a "bang-bang" mode, i. e., control signals apply full positive, full negative, or no torque. The pneumatic jets and the wheel for each axis are operated in parallel with the pneumatic deadband set at 2. 5 times the wheel deadband so that normally all control is effected by the wheels. Should a wheel saturate (achieve limiting speed in either direction), a short pneumatic pulse would remove enough momentum from the system to re-establish control by the wheel. In normal operation without picture taking, however, a wheel tachometer signal calls for pneumatic removal of 25 percent of the wheel momentum whenever half saturation speed is achieved. This automatic momentum removal technique is disabled during picture taking leaving enough additional momentum storage capability in the wheel to assure that no gas discharges occur before the cameras are turned off again.

The ERTS attitude control concept is taken from OGO with the addition of a fourth or "normal" mode of control using a gyrocompass to align body to orbit plane.

During boost, the outputs from the sensors and the inputs to the torque sources and drive mechanisms are inhibited. After separation the subsystem operation is in two phases: acquisition and normal control. The acquisition phase consists of three modes: 1) array slew, 2) sun acquisition, and 3) earth search. The normal control phase is entered when the gyrocompass mode is commanded from earth and the resulting transient has settled out.

The acquisition phase of control system operation has been designed to orient the vehicle to the required references given arbitrary initial angular errors and body angular rates up to 1 deg/sec about all three axes and could occur following separation from the booster and deployment of the solar array. During the array slew mode the sensitive axis of the solar array is driven to a position parallel to the $+y_b$ axis. The sun acquisition mode is provided in order to align the pitch ($+y_b$) axis with the sun and establish a constant rate about this axis. Error signals for control in this mode are provided by the sun sensors and the pitch rate gyro. By pointing the body at the sun initially in this fashion, the solar array is rapidly oriented for maximum charging of the batteries. The fields of view of the four horizon scanners intersect on the $+Z_b$ axis. During the earth search mode the control system configuration is the same as that for sun acquisition and hence as the spacecraft rotates this axis sweeps out a plane. As the vehicle progresses in orbit this plane must intersect the earth, at which time such rotation ceases the earth acquisition is complete with the Z_b axis properly oriented to the local vertical. The yaw gyrocompass mode is then entered by connecting the yaw gyro rate output signal to the yaw axis control channel, resulting in a spacecraft slew which positions the roll axis in the orbital plane, the normal cruise orientation. Earth acquisition can be inhibited by ground command. Yaw gyrocompass control can only be effected while under ground control.

Acquisition of the observatory reference axes is initiated at a predetermined time after separation from the launch vehicle, and at any time when one or more references are lost. The sequence of acquisition ensures that the time is minimized during which the solar array is not oriented toward the sun. Acquisition of the remaining reference axis minimizes the time of acquisition consistent with other system constraints. A period not to exceed 90 minutes is required for alignment of the observatory X axis in the orbital plane.

The attitude control system for ERTS is obtained by making minor modifications to the OGO attitude control system. Most of the changes involve deletion of functions not required for ERTS. The one new package required (the orbital switching assembly) is a relatively simple electronics package providing mode switching into the gyrocompass mode and some telemetry functions. A second rate gyro package of OGO design is added for measuring and telemetering roll rate.

2.1.3 Communication System

The ERTS communication subsystem transmits digital telemetry at 1 and 32 kbits/sec and video data at rates corresponding to 4 MHz bandwidth and 15 Mbits/sec. Video data is generated by the payload sensors which operate intermittently in generating pictures of the earth. Command reception at 154.2 and 2106.4 MHz is provided.

Six carrier frequencies are used for communication and the system as a result of redundancy, includes four receivers and six transmitters plus incidental power monitoring and switching equipment.

For convenience, the communication subsystem is partitioned into three assemblies grouped by carrier frequency and function:

1) STADAN-VHF equipment

2) Unified S-band equipment

3) Wideband video equipment (S-band).

In most respects the VHF and the USB systems provide redundant functions as far as the spacecraft is concerned. Their presence, however, permits status checking and commanding from two of NASA's principal tracking and data acquisition networks. Tracking differs between these networks, STADAN providing angle tracking data only while the MSFN can provide range and range rate as well as angle information.

The VHF transmitter serves Minitrack and data transmission functions at 137.86 MHz. These transmitters can also be used to send 32 kbits/sec stored telemetry from the narrowband tape recorders. Two 154.2-MHz AM command receivers operate continuously in linear polarization diversity, providing both equipment and functional redundancy.

The unified S-band communication assembly provides uplink commands and downlink communications for real-time and stored telemetry, DCS 100-kHz bandwidth analog data, and 1 kbit/sec timing and attitude data for each of the two payload video tape recorders.

SPECIFICATION SUMMARY

COMMUNICATIONS SUBSYSTEM

COMMAND RECEIVERS

VHF	154 20 MHz	FSK
Unified S-band	2106 4 MHz	FSK

DATA TRANSMITTERS

VHF		
PCM	137 86 MHz	FM
Wideband		
VIDEO-1	2229 5 MHz	FM
VIDEO-2	2265 5 MHz	FM
Unified S-band	2287 5 MHz	
		Subcarrier
1 Kbit/sec PCM		165 kHz
1 Kbit/sec PCM		225 kHz
32 Kbit/sec PCM		300 kHz
100 kHz		1 024 MHz
1 Kbit/sec PCM		1 25 MHz

TRACKING TRANSMITTERS

VHF	137.86 MHz
Unified S-band	2287.5 MHz

VHF: 2 redundant 1/2-watt PM transmitters for tracking and 1 and 32 Kbit/sec narrowband PCM data

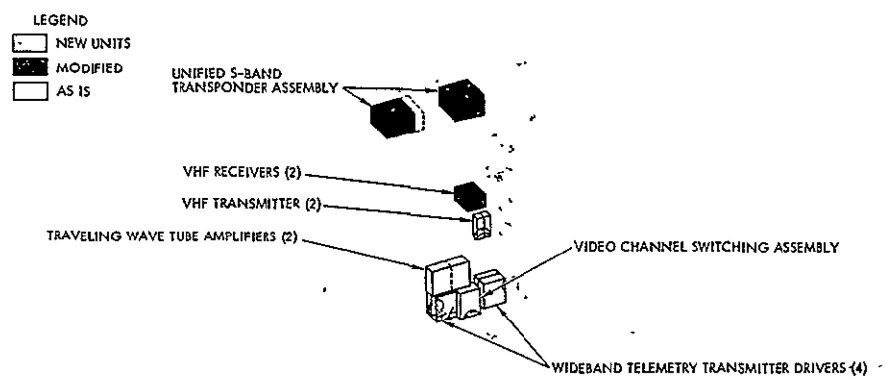
2 redundant AM command receivers.

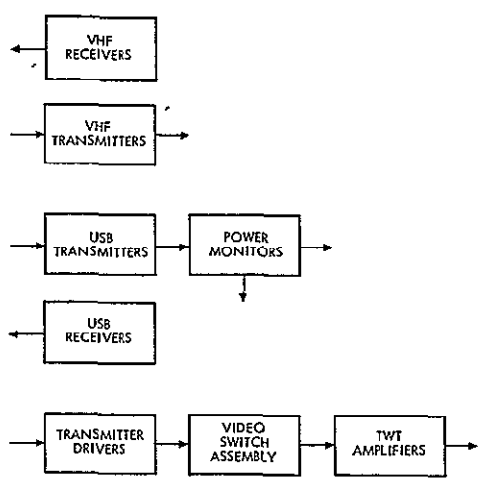
WIDEBAND 2 redundant 10/20 watt transmitters for wideband real time or playback

USB 2 redundant phase-lock receivers for command and ranging

2 redundant 800 milliwatt transmitters with 5 subcarriers to provide the following

- 1 Kbit/sec narrowband PCM from each wideband video playback
- 1 Kbit/sec narrowband PCM real time
- 32 Kbit/sec narrowband PCM real time or playback
- 100 kHz data collection system real time
- Ranging signal





During launch, or whenever the spacecraft is not earth oriented, all subcarriers other than the 1.25-MHz real-time telemetry carrier will be turned off to permit utilization of all the downlink RF power in the communication of telemetry data.

The transponders are turned on and off as units so that the proven TETR transponder design may be utilized without modification. Only one receiver at a time will be operated to eliminate any possibility of one receiver locking to spurious signals from the other. Switching can always be accomplished via the VHF command system in case the operating unified S-band receiver fails.

The wideband video data assembly, Figure 2-8, transmits the data from the multispectral scanner and the return beam vidicon at 2229.5 and 2265.5 MHz. The data can be real-time or play-back from one of the two video tape recorders. The wideband video data assembly accepts six inputs: 14.8 Mbits/sec NRZ data from the MSS, 4 MHz-bandwidth analog data from the RBV's, and data of each type from each of the two video tape recorders. All the data is conditioned for downlink transmission, and any two inputs can be transmitted on the two downlinks.

The assembly consists of a video switch unit, four transmitter drivers and two 10/20 watt traveling wave tube amplifiers. The video switch unit conditions the inputs and connects one to the 2229.5-MHz modulation input and one to the 2265.5-MHz modulation input. The four transmitter-drivers consist of two redundant units at each downlink frequency. Two transmitter-drivers are energized, one at each frequency, and these generate the two modulated S-band downlink signals. The video switch unit normally connects one downlink signal to each traveling wave tube amplifier. It can also connect a combined signal consisting of both S-band carriers to either TWT amplifier input.

The TWT amplifiers are dual-mode 10- and 20-watt output units, similar to those flown on Mariner 1969. They normally operate in the 10-watt mode with a single carrier. If a TWT amplifier failure should occur, the remaining TWTA amplifies both carriers in the 20-watt mode. This mode is less efficient since power is lost due to intermodulation and some allowance must be made for signal level imbalance in the output.

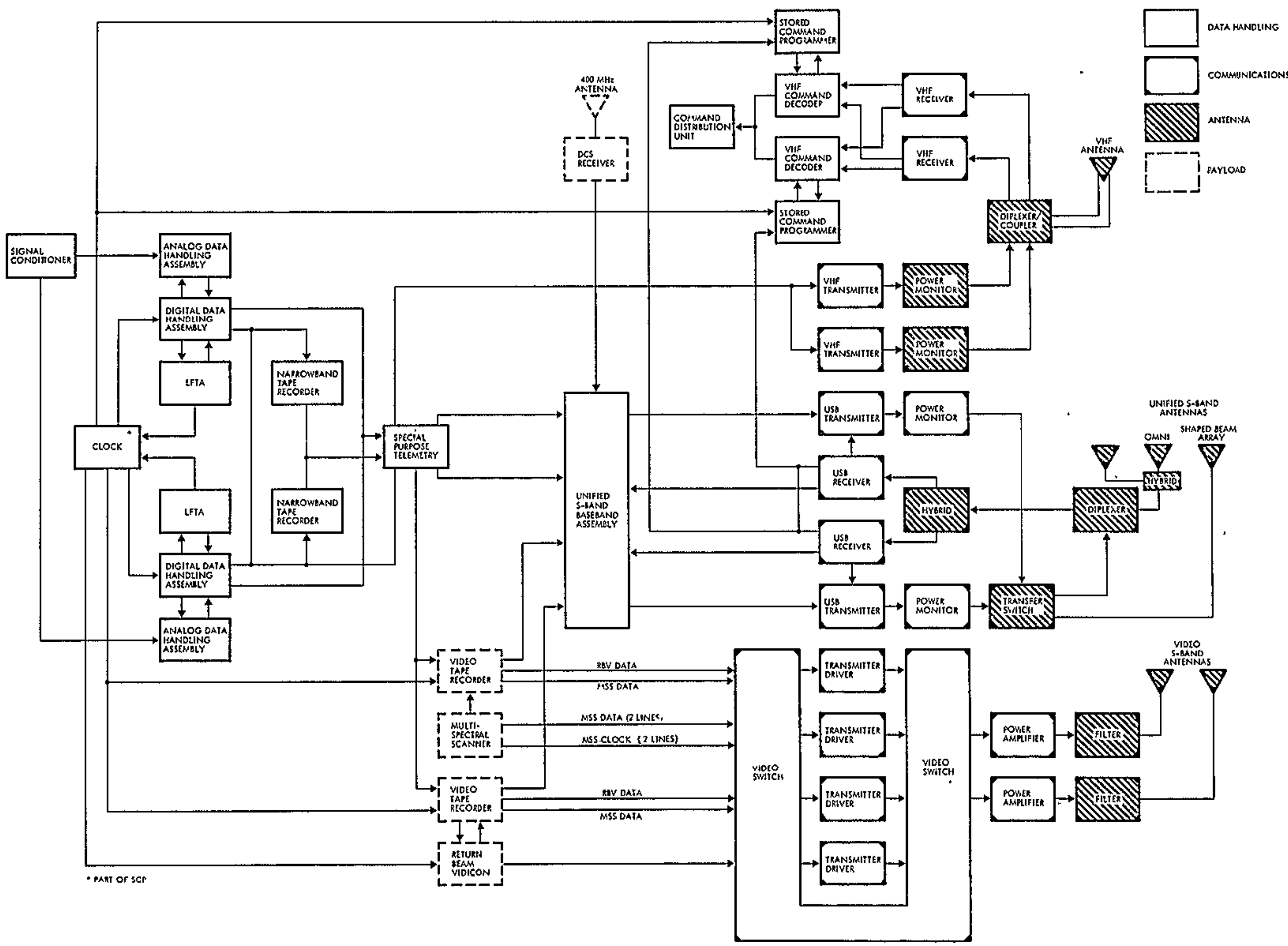


Figure 2-8
COMMUNICATION SYSTEM BLOCK DIAGRAM

The power is sufficient to provide acceptable system operation, with reduced margin. This system provides TWT amplifier redundancy without either the penalty of an extra TWT amplifier or the loss of efficiency resulting from dual-frequency operation in normal operation. Radio link power exceeds a 6-db system margin and 20-db additional command margin requirement in all cases except the VHF command link. This link is unchanged from OGO and is considered acceptable in view of the actual command powers available at STADAN stations and the acceptable OGO experience.

2.1.4 Data Handling Subsystem

The ERTS data handling subsystem formats the spacecraft housekeeping and experiment telemetry for downlink transmission and decodes the uplink command data. Storage is provided for housekeeping telemetry and commands so that the spacecraft can be exercised and monitored when it is not in view of an ERTS ground station. The data handling subsystem also contains the spacecraft clock which provides timing signals to several observatory subsystems and generates a binary time word which is inserted in the telemetry data frame and also controls the execution of stored commands.

The ERTS data handling subsystem is derived from the flight-proven OGO data handling subsystem - ten of the 14 assemblies are OGO designs. The ERTS subsystem has additional redundancy; both equipment and functional. Additional capabilities have been incorporated to provide the greater downlink data capacity required for ERTS and to provide for highly flexible operation with tracking, telemetry, and command capabilities through either MSFN or STADAN.

The most complex single items in the data handling subsystem, the digital data handling assemblies, are unmodified from the successful OGO design. The units to be used for the first spacecraft are already fabricated and tested and require only a post-storage verification test.

2.1.4.1 Functional Description

Housekeeping Telemetry

ERTS utilizes two completely redundant sets of telemetry data handling equipment. The narrowband digital data can be transmitted over a 137.86-MHz VHF link and/or a 2287.5-MHz unified S-band link. The system has two main functions, data handling and data storage. The data handling equipment groups each consist of one digital data handling assembly and one analog data handling assembly. One equipment group normally processes data for real time transmission and the other processes data into storage. These operations can be independent or simultaneous. The normal assignments of the equipment groups can be reversed by command.

SPECIFICATION SUMMARY

DATA HANDLING SUBSYSTEM

COMMAND

- 4 command access paths, 2 VHF and 2 USB.
- 2 command decoders
- 1 command distribution unit for execution routing
- 358 discrete commands, 64 of which are storable.
- Command message addressable to either real time or programmer.
- Automatic real-time command priority over stored commands
- All ERTS-unique commands are verifiable

STORED COMMAND PROGRAMMER

- 2 redundant programmers, each with
  - 127 commands and execution time tags plus sync word
  - 0 5 second between command executions
  - Total memory verification in 74 seconds at 1 Kbit/sec or 2 3 seconds at 32 Kbits/sec
  - 21-hour recycle
  - Commandable standby, clear, fill, process modes

TELEMETRY

- 2 redundant systems, each with
  - 1 and 32 Kbits/sec commandable real-time data rates
  - 9-bit digital words
  - Three 128-word submultiplexers
  - One submultiplexer commandable to main multiplexer rate
  - Manchester code

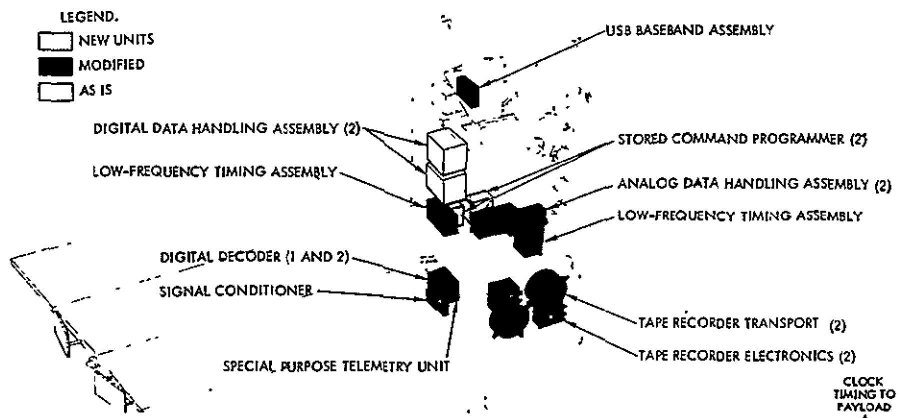
TIMING

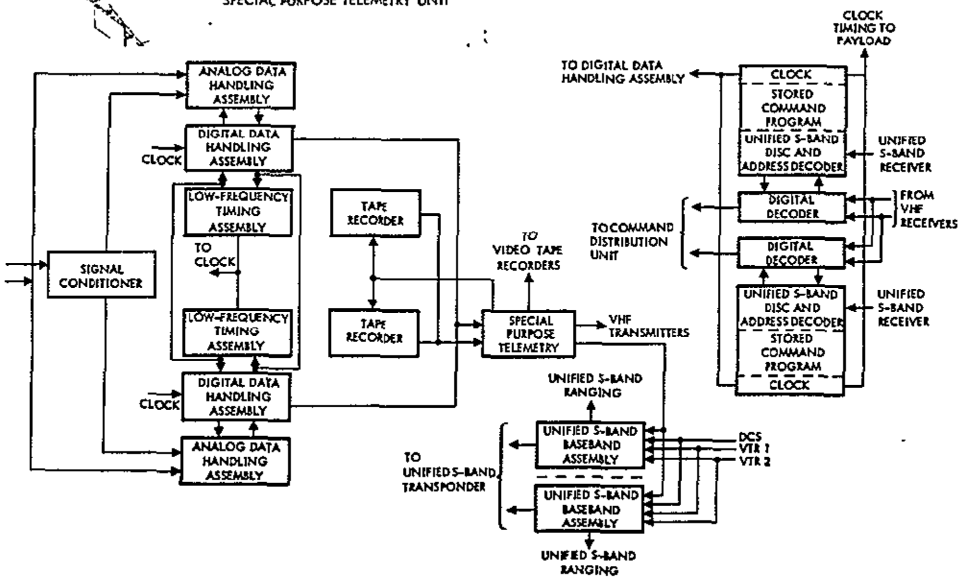
- Two 6 4 MHz clocks with 1 ppm stability.
  - Division to produce 1600, 256, 100, 50 kHz, and 1 Hz

DATA STORAGE

- Two narrowband tape recorders
- 1 Kbit/sec record Manchester code
- 32 Kbits/sec reverse playback
- Automatic record and playback switching

Two completely redundant data handling systems for stored and real-time commands, data collection and transmission.





Telemetry data are accepted in four formats: positive analog voltage, negative analog voltage, bi-level digital, and 9-bit serial digital. Bi-level digital inputs are conditioned and combined to form analog voltages. All of the analog voltage inputs, including those generated by bi-level inputs, are multiplexed and converted into digital format by the analog data handling assembly. The output of this assembly is a parallel digital data signal which is combined with the 9-bit serial digital data telemetry inputs in the digital data handling assembly, thus forming a single serial signal of digital housekeeping telemetry.

The serial data outputs from the redundant equipment groups are supplied either to the tape recorders or to the special purpose telemetry for immediate transmission by the VHF or unified S-band links. Switches within the special purpose telemetry unit allow real time data and stored data playback to be directed, by command, to the appropriate transmission path. Additionally, the special purpose telemetry unit provides 1 kilobit data for the two video tape recorders within the payload.

The equipment groups are supplemented by redundant low frequency timing assemblies and clock assemblies to generate the master oscillator frequencies, payload clock signals, coded spacecraft time and other low frequency timing required. Either assembly can be selected by command. Two real time telemetry bit rates, 1 kbit/sec and 32 kbits/sec, are provided. Data storage is at 1 kbit/sec and playback at 32 kbits/sec.

The data handling system normally provides 1 kbit/sec data for both the VHF and the unified S-band link and 32 kbits/sec playback data to the unified S-band link only. Alternate modes can be selected by command to provide 32 kbits/sec real time data to both the VHF and unified S-band links or to provide 32 kbits/sec playback data on the VHF link. Whichever mode is selected, the digital housekeeping telemetry stream is the only modulating signal on the VHF link.

The data handling subsystem generates a composite baseband signal for the unified S-band link which includes both real time and playback housekeeping telemetry data, DCS analog data, 1 kbit/sec data signals from each of the two video tape recorders, and the unified S-band ranging signal. All of these data signals are modulated on subcarrier oscillators except the ranging signal, which is left at baseband. The composite signal is phase modulated onto the unified S-band downlink.

Command

The command decoder system, four-way redundant, provides both VHF and unified S-band communication access through each of two fully redundant paths.

Each VHF command link accepts OGO-type FSK baseband from either VHF receiver. The baseband is demodulated in the input stage of the digital decoder and the resulting serial data stream is transferred to the stored command programmer unit. Here the data stream is checked for proper 7-bit address, whether or not it is a real-time or stored command and if it has priority over other activities. Real time commands have top priority over all except in-process real time commands and are executed immediately through the command distribution unit. Stored commands require a prior real-time enable command before they will be accepted by the store command programmer. Once commands are stored in the programmer, comparison of their time tag with the spacecraft clock time recurs every 64 msec. Stored commands are executed through the digital decoder and the command distribution unit when the spacecraft time matches the time tag stored with the command.

Demodulation of the unified S-band command signal takes place in the stored command programmer unit. The command format, similar to the Apollo command format, consists of 1 kbit/sec subbit data biphase modulated on a 2-kHz tone, plus a 1-KHz synchronization tone, all frequency modulated on a 70-kHz subcarrier. Portions of the stored command programmer unit extract the 1 kbit/sec subbit data, decode the five subbit code into a 200 bits/sec data stream, detect the proper address, and deliver real time commands to the digital decoder and stored commands to memory. The operation of the system is then identical to that for VHF commands for real time execution or for storage.

2.1.5 Antenna Subsystem

The ERTS antenna subsystem consists of seven antennas, two diplexers, two hybrids, filters, and two power monitors. Four different antenna designs are used as required by the VHF, UHF and S-band frequencies being employed. The installation of these antennas on the spacecraft is shown in the specification summary. The UHF and VHF antennas are non-directional; the S-band units provide 5 db gain at the horizon.

SPECIFICATION SUMMARY

ANTENNA SUBSYSTEM

OMINDIRECTIONAL ANTENNAS

VHF (1)

Uplink and downlink for commands and PCM narrowband telemetry -10 db minimum gain over 85 percent hemispherical coverage crossed dipole

Unified S-Band (1)

Uplink and downlink for commands, PCM narrowband, and data collection system data.

-15 db minimum gain over 85 percent hemispherical coverage.

Linear polarization diversity for two receiver channels

Isolated left- and right-handed circular polarization for two transmitter channels

SHAPED BEAM ANTENNAS

+5 db minimum gain at any point 55 degrees from antenna axis.

-5 db minimum gain on antenna axis,

Wideband (2)

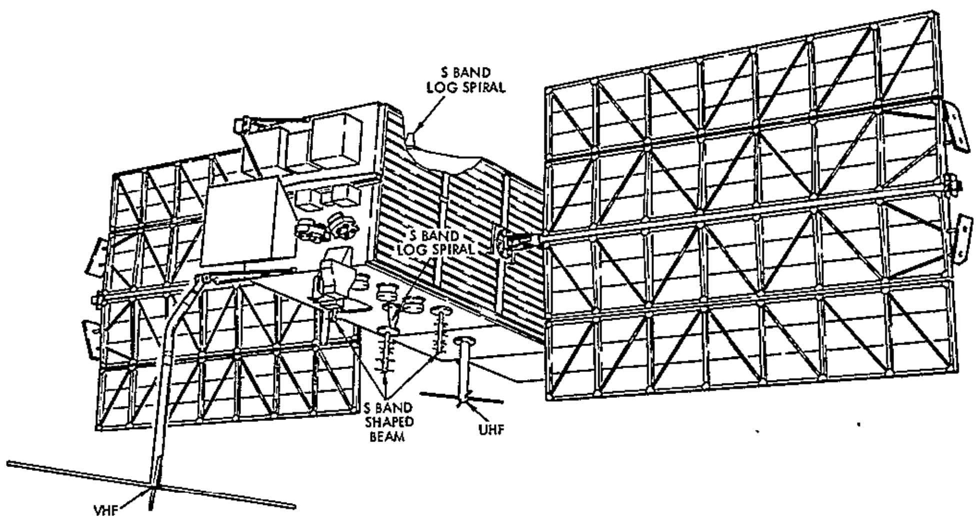
Downlink for two video transmitter channels

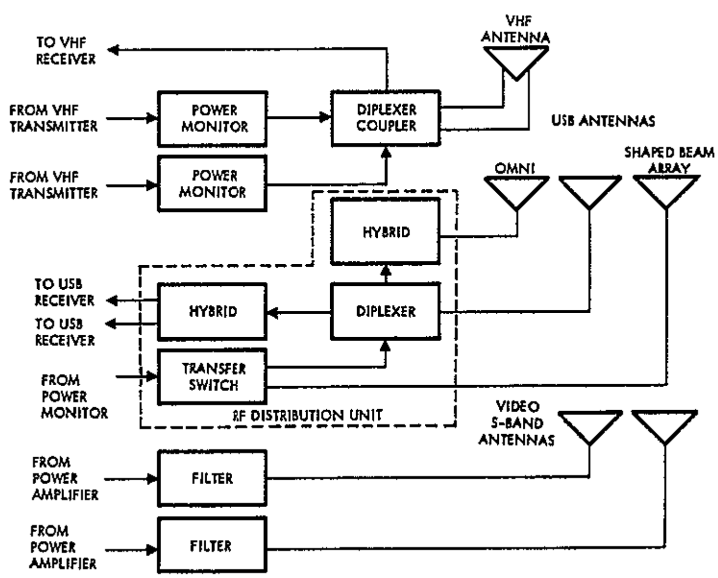
Unified S-Band (1)

Downlink for two transmitter channels

RF DISTRIBUTION UNIT

Permanently connects both Unified S-Band receivers to the Unified S-Band omni-antenna Switches Unified S-Band transmitters to either Unified S-Band omni or shaped beam antennas.





2.1.6 Power Subsystem

Primary power is supplied by oriented arrays of silicon solar cells supplemented during heavy load and during eclipses by two (nickel cadmium) batteries. In addition, the system includes charge control devices and the DC-to-DC converters for secondary power. In concept and design the ERTS power subsystem is almost identical to OGO.

Total energy capability of the ERTS power subsystem varies between 30,000 and 40,000 watt-minutes per orbit over the one-year lifetime. The electrical power subsystem, with the exception of certain converters is redundant, i.e., elements of the subsystem (power control unit, batteries, and solar arrays) are dual systems. This duality was achieved without doubling the total power capacity with the attendant weight and volume penalty. Thus, the subsystem is capable of failure mode operation as a somewhat reduced output. As a result, a charge control or battery failure can be taken out of the subsystem (by ground control) and operation continued. Two converters provide -24.5 volt regulated power to the payload bus over a range of 0 to 300 watts.

Shuttering of the RBV cameras requires 30-ampere pulse of current at -24.5 volts enduring for 90 msec. A separate small nickel-cadmium battery is provided to supply this pulse.

SPECIFICATION SUMMARY

POWER SUBSYSTEM

SOLAR ARRAY

- 2 redundant arrays
- Up to 22 amperes output at 33.5 volts.
- Total of 210 to 740 watts average output through orbit.
- Compensation for spacecraft body shadowing.

BATTERY

- Three 12 ampere-hour capacity Ni-Cad batteries.

SPACECRAFT BUS

- 23 5 to 31.5 vdc operation.

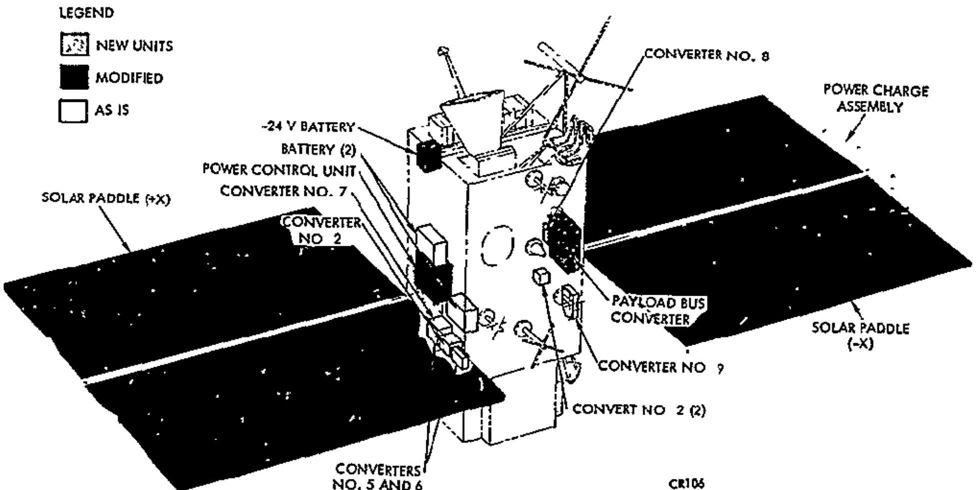
PAYLOAD BUS

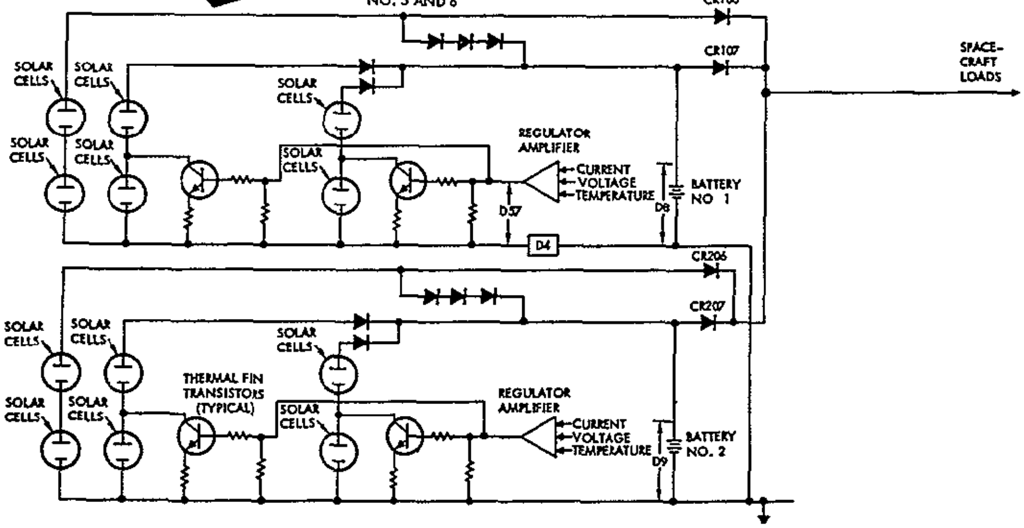
- -24 to -25 vdc operation.
- One converter to payload bus 1.
- One converter to payload bus 2
- One converter selectable to either payload bus 1 or 2.

POWER BUDGET

Continuous Loads (amperes)	
Attitude Control	2.40
Communications Bus	2.90
Data Collection System	0 03
Variable Loads (amperes)	
RBV	5.65
MSS	2.15
VTR (Record)	3.0
Wideband Transmitter	1.4 each in 10-watt mode.
Payload Converter	1.9

Two redundant power systems, each capable of supporting the full spacecraft load and limited payload throughout the ERTS eclipse orbit.





2.1.7 Thermal Control Subsystem

Thermal control is provided by a combination of active and passive techniques. Within the main body, the mean radiant environment, apart from the immediate vicinity of high power dissipation components, is 20 ±10°C. Materials used in thermal control are sufficiently stable and components so reliable that the probability of maintaining this environment for one year exceeds 0.98. Flexibility in mounting the payload is not limited in any way by thermal considerations. An equally acceptable (though different) environment exists for extra-body components including the solar array, sun and horizon sensors, charge control fins, and the antennas.

The thermal control system of the ERTS main box consists of radiating panels under active louver control and insulation. The top end panels are fully insulated, and both X side panels are under active louver control.

The only places where the surface emittance is purposely high are the four corner castings at the +Y end and under louvers on the X panels. The castings are bulky and well coupled to the panels at places where the highest heat generating components (inverter and power control unit) are located; they thereby add radiating areas in the locations where most needed. Heat loss through these castings is approximately 20 watts.

The payload environment is controlled by the active louver system of the box X panels. The RBV cameras are mounted on a honeycomb plate to avoid camera misalignment from thermal gradients on the mounting surfaces. The heat dissipated by the cameras is rejected by radiation to the interior of the observatory from the cameras themselves and to the -X panel through the honeycomb plate.

The tape recorders for the payload are mounted in a special compartment on the +Y end of the observatory. The temperature of the compartment is controlled by radiation from four concave corners and by louvers on each X panel.

THERMAL SUBSYSTEM

Maintains the mean radiant environmental temperature of the spacecraft body within 20 ± 15°C, payload at 20 ± 10°C.

ACTIVE CONTROL

Louvers

Control heat emission from internally mounted assemblies.

Maximum radiating capacity at 30°C exceeds maximum internal heat generation and absorbed external energy.

Minimum radiating capacity at 10°C is not greater than the minimum internal heat generation and absorbed external energy.

HEATERS

Thermostatically controlled and commandable electrical heating elements to maintain approximate heat balances.

PASSIVE CONTROL

Surface Coatings and Finishes

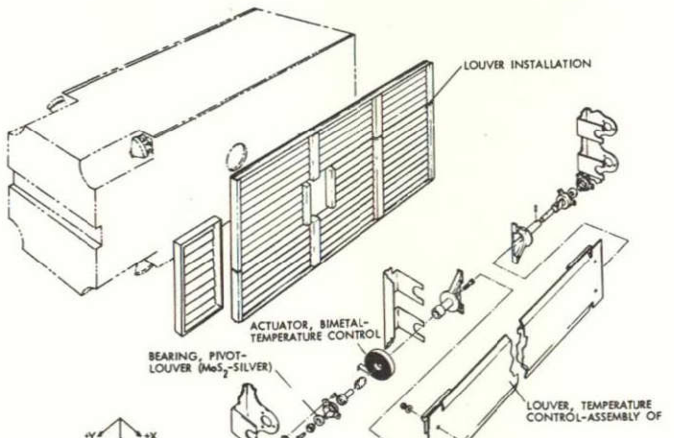
Utilize solar and earth fluxes for thermal control of appendages.

High- or low-emittance coatings provide radiative or conductive coupling between internal assemblies and active thermal control elements.

INSULATION

Thermal body shielding to minimize absorption of incident earth and solar heat fluxes and loss of internally generated heat.

TEMPERATURE DISTRIBUTION IN ERTS DURING ITS NORMAL OPERATING MODE IN ORBIT IS COMPUTED BY THE TRW THERMAL ANALYSIS COMPUTER PROGRAM, WHICH TAKES INTO ACCOUNT ALL HEAT SOURCES, RADIANT AND CONDUCTED HEAT PATHS, AND MEANS OF HEAT REJECTION. FOR OGO, SIMILAR PREDICTIONS COMPARED WITH FLIGHT MEASUREMENTS SHOWED AN ACCURACY WITHIN 1 TO 3°C. PREDICTED TEMPERATURES FOR ERTS FALL BETWEEN 14 AND 25°C, WELL WITHIN THE REQUIRED RANGE OF 20 ± 10°C.



2.1.8 Velocity Correction

An analysis of Thor-Delta N injection inaccuracies indicates that 31 ft/sec of velocity correction must be available to remove in-plane errors and 17 ft/sec must be available to remove out-of-plane errors. While operation could continue for one year without additional correction, a more precise ground-trace overlap for operation for longer than one year would require additional capability to the extent of approximately 17 ft/sec per year.

Velocity correction is accomplished using krypton gas. The tankage is the same as for the attitude control pneumatics and allocation of krypton to velocity correction provides 65 ft/sec velocity correction capability for a 1500 pound observatory. Because of the common tank, any other division of gas between velocity correction and attitude control could be effected.

Achieving the required impulse with the weight of gas allocated is accomplished by raising its I_{sp} 92 percent to 71 seconds by heating it in electro-thermal thrusters to 1600°F.

Three thrusters are employed, one for each direction of in-plane correction and one for out-of-plane corrections. Either positive or negative inclination errors can be corrected with a single thruster by thrusting only at the proper node.

The addition of electrothermal thrusters to the OGO pneumatic system offers significant reliability, operational and cost advantages over the approaches to velocity correction. The thrusters use the same gas supply, the same valves, and the same pressure switches as the cold gas attitude control nozzles, retaining the simplicity and reliability of the cold gas propulsion system. The potential for long spacecraft life is apparent since it is unlikely that orbit adjustment will consume all of the allotted propellant, unused gas will be available for continued attitude control.

At a thrust level of 0.05 pound, operation of the sensors need not be interrupted during orbit adjustment although body pointing and rates will be increased.

SPECIFICATION SUMMARY
ORBITAL ADJUSTMENT SUBSYSTEM

THRUSTERS

Three thrusters, one in each +Y, +X, and -X direction

Thrust level: 0.05 ± 0.005 pound

Average specific impulse: 65 seconds

Gas temperature: 1600°F

Thrust alignment to nozzle symmetry: ±0.15 degree

Thrust alignment to spacecraft axes: ±0.5 degree

Total thrust time: 47.8 pounds of gas expended in 21 hours of continuous operation.

SYSTEM CAPACITY

STORAGE VESSEL

Volume	1299 cu in.
Pressure	4000 psia

GAS SUPPLY

Net weight	58 pounds
Compressibility	0.77

GAS ALLOCATION

Leakage	1.5 pounds
Attitude control	12.2 pounds
Orbit adjust	43.5 pounds
Residual	0.8 pounds

SOLENOID VALVE

Provides krypton flow rate of 0.00075 pound per second.

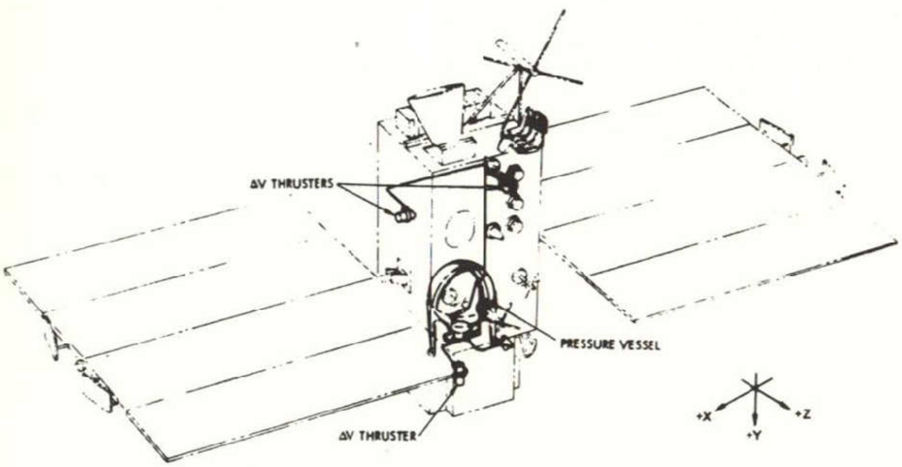
PRESSURE SWITCH

Actuates closed when pressure is greater than 30 psia.

SYSTEM OPERATION

Each thruster and associated heater operate on command and continue operation until command OFF.

Exit temperature	1600°F
Heater power	75 watts
Propulsive efficiency	92 percent
Thrust sector (orbit)	± 15 deg
Thrust time (nominal)	500 sec
Velocity gained/500 sec	0.56 ft/sec
Orbits to insert 36 ΔV	80 (48 ft/sec)
Velocity gained per pound of krypton	1.5 ft/sec
total ΔV capability	65 ft/sec
Specific impulse at 1600°F	71 sec



The thruster consists of a cylindrical cavity with a coaxial spirally-wound wire heater element as shown in Figure 2-9. The propellant gas is injected tangentially at high velocity. The gas spirals radially inward with high tangential, but low radial, velocity. In passing around and through the heater element many times, the gas is heated. It is then expelled through a conventional convergent-divergent nozzle. The thrusters weigh less than 0.1 pound each.

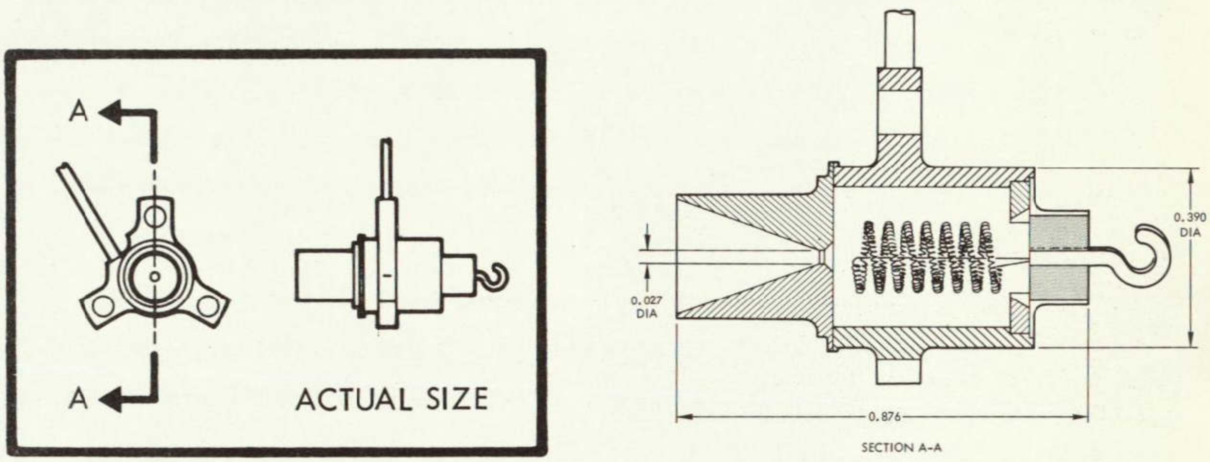


Figure 2-9

VORTEX THRUSTER has been developed for other TRW programs, and has been demonstrated at thrust levels between 0.005 and 0.050 pound.

2.1.9 Ground Support Equipment

The only new items of mechanical GSE are installation fixtures for the MSS and the RBV's: of 30 items needed, only five are new or adapted. The others are applicable unchanged from the OGO program (see Figures 2-10, 2-11, 2-12).

ERTS electrical GSE will be repackaged GFE from the OGO Program, combined with new equipment for the new S-band equipment in ERTS. The requirements for EGSE are illustrated in the system test layout in Figure 2-13 as are number and status of the major assemblies as shown in Table 2-2.

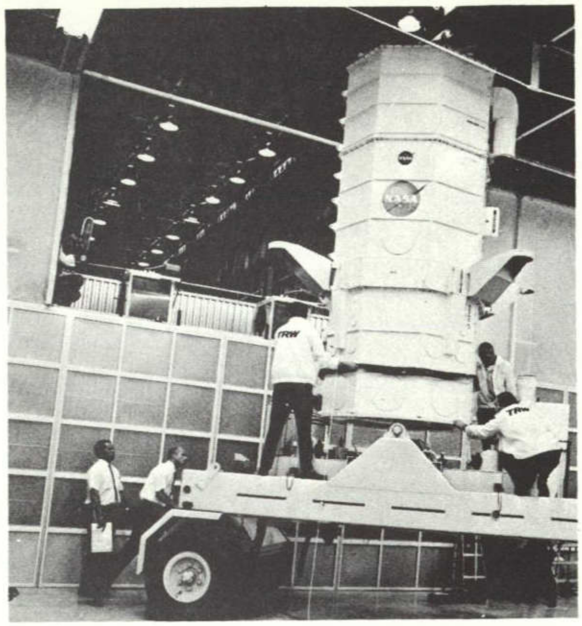


Figure 2-10

THE VERTICAL TRANSPORTER has provided protection for OGO during movement of the observatory from TRW to Vandenberg AF Base and from GSFC to Kennedy Space Flight Center.

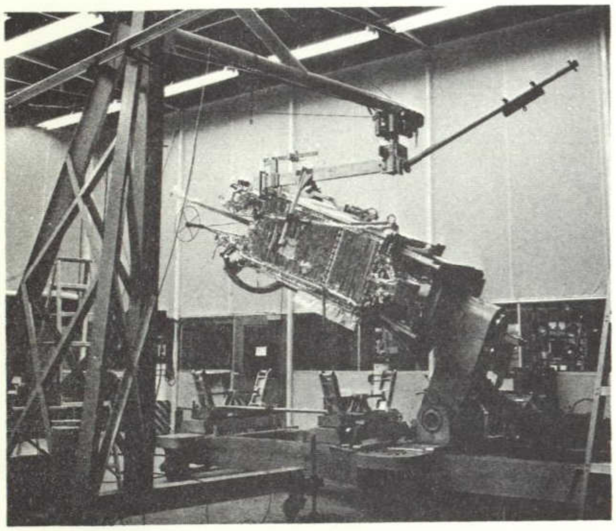


Figure 2-11

THE TORQUE-ANGLE MACHINE drives the solar array deployment mechanism through its travel while measuring the output torque by means of a load cell.

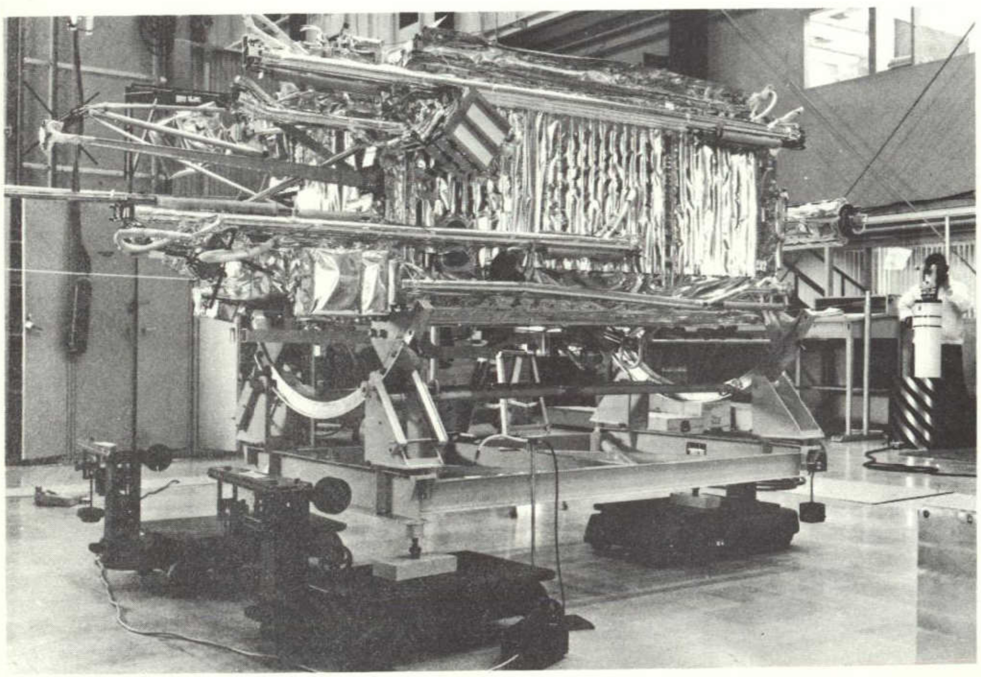


Figure 2-12

THE CENTER OF GRAVITY FIXTURE uses three beam-balance scales to weigh the observatory.

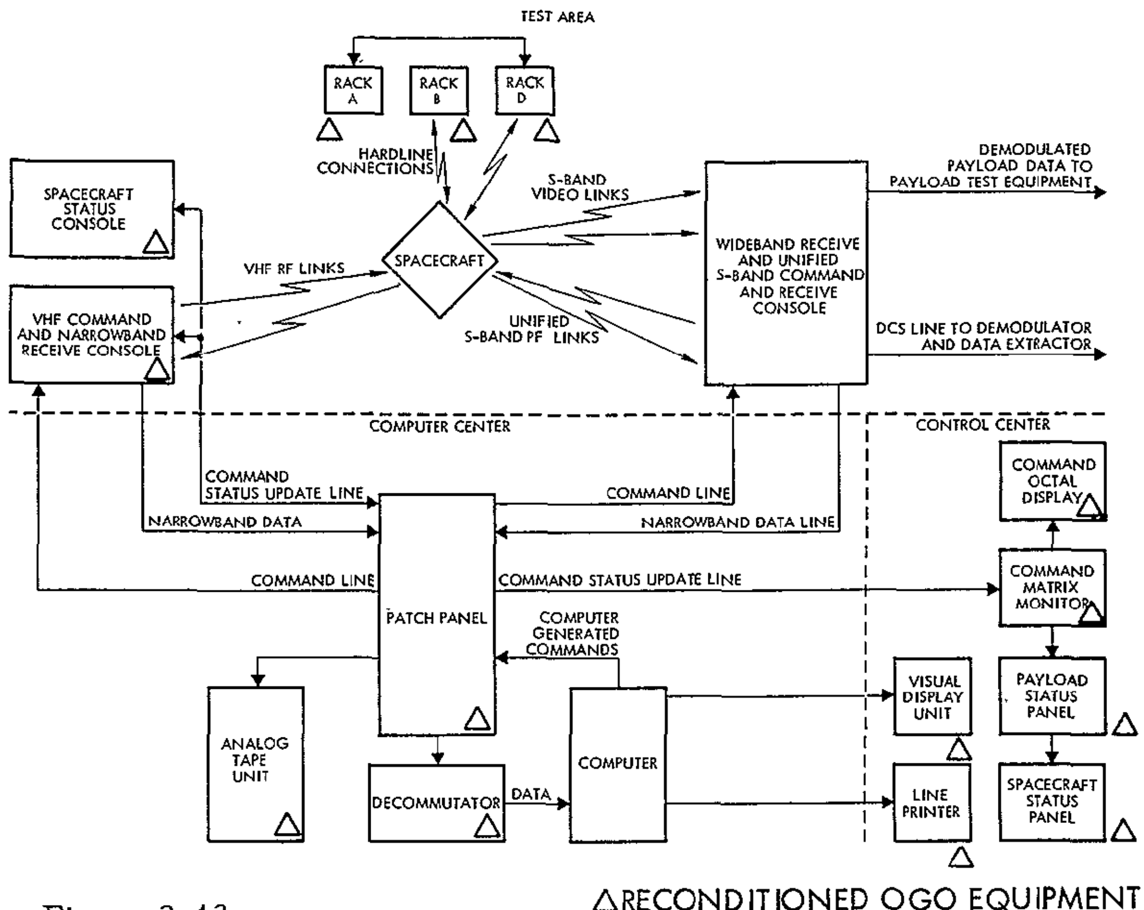


Figure 2-13

OVERALL EGSE SYSTEM TEST block diagram

The computer station compiles and processes data during system tests and presents to the test conductor a meaningful summary of real time data from a given test while retaining the capability to present for analysis all the data pertaining to any selected area.

The control center console serves as a central point for the direction of system testing and data analysis by the test conductor.

The console monitors spacecraft and payload status, displays real-time narrowband telemetry, and allows selection of any word within the telemetry format for display. The spacecraft status console contains equipment to display spacecraft and payload command status.

In the VHF command and receive console, VHF telemetry is received simultaneously by two narrowband receivers and demodulated data is made available via patch panel for distribution to a data decommutator. Two phase-lock receivers at 137.6 MHz are utilized.

Table 2-2 Major Items of EGSE

	New Design Required	No Changes from OGO	Minor Changes from OGO	Units Required for ERTS	Units Available	Remarks
Control center console		Repackage		1	2	
Peripheral equipment						
Rack A (power)		x		2	3	
Rack D (power)		x		2	3	
Rack B (attitude control)			x	2	2	Deletes extra functions
Narrowband receive console		Repackage		1	3	Buy two telemetry receivers
Command — command/receive console		Repackage		1	3	Add command encoder and decoder
Spacecraft status console		Repackage		1	2	
Wideband receive console	x			1	0	
USB command and receive console	x			1	0	
Launch command console		Repackage		1	1	Buy TWTA for USB commands

Wideband telemetry data is recovered by two receivers, one for the multispectral scanner and one for RBV data.

Unified S-band compatible commands are transmitted either hard-line or radiated by a low-level transmitter. Telemetry is received, filtered, demodulated, and made available via patch panel for distribution to a data decommutator.

The launch command console provides radiated signal levels to the spacecraft during tests at the launch site. Selectable redundant VHF power amplifiers with associated power supplies are available to boost power to levels sufficient for on-stand testing.

About half the required electrical support equipment is obtained from the OGO program.

2.2 GROUND DATA HANDLING SYSTEM

The Ground Data Handling System (GDHS) for the ERTS mission consists of two main elements which are in many respects functionally independent of each other, but which will be collocated on the third floor of Building 23 at GSFC. As a consequence of collocation, significant benefits accrue in facility design, utilization of automatic data processing equipment (ADPE), and backup operations. These two GDHS elements are:

1) Operations Control Center (OCC). This organization is the focus of all spacecraft-observatory operations which include planning, scheduling, commanding, and health monitoring.

2) NASA Data Processing Facility (NDPF). This is the facility which processes, stores, and supplies all ERTS output and provides the interface between users and NASA.

Although the OCC has been sized for comfortable operation of a single observatory during periods of peak activity, the system is capable of supporting simultaneous operation of two observatories as long as their orbits are scheduled to avoid real time conflicts in passes over ground stations.

Both the OCC and the NDPF contain the equipment and staff required to carry out their respective responsibilities. Each is designed to interrelate with the other where overall ERTS requirements so dictate. Specifically, the following three areas of commonality exist between the OCC and NDPF:

1) The GDHS ADPE consists of an integrated complex containing an IBM 360/44 and an IBM 360/85 system. The 360/44 is particularly well suited for, and is dedicated to, high speed input/output operations, servicing the real time and quasi-real-time OCC demands. The 360/85 is a powerful batch processor used to support NDPF functions, OCC offline tasks, and as an immediate backup to the 360/44 for OCC observatory control.

2) The GDHS unified display system is the basic man-machine interface in the computer aided operations of both the OCC and the NDPF. It provides the means for any display terminal to access any part of the GDHS data base, permitting, thereby the ability to backup any critical or peak

load operations which may occur. Mechanization of the system by digital television techniques results in cost-effective and highly flexible capability.

3) The physical plant constituting the OCC and the NDPF takes advantage of the economies that result from common electrical, air-conditioning, plumbing and other facilities.

Figure 2-14 illustrates the functional arrangement of the GDHS. After the ERTS system becomes operational, image and telemetry data are transmitted from the observatory to the ground stations (DCS data being relayed through the observatory) where image and DCS data are recorded and shipped to the NDPF. Data concerning spacecraft health and status, however, are placed on NASCOM circuits and sent to the OCC for performance monitoring and control. The OCC also processes these data into machine readable form so as to be available to the NDPF for image processing and annotations. Images from the NTTF are transmitted in real time to the OCC and are displayed on the unified display system (in both the OCC and the NDPF) to provide a quick look (within one pass time) at payload results.

When the image tapes arrive at the NDPF, by mail or courier delivery, they are processed in bulk and the imagery is recorded on film. Selected images are precision-processed upon request and are also recorded on film.

Both telemetry data and imagery are filed and cataloged and a montage is made of sensor coverage. This information is then distributed among the users, who analyze it for their own purposes and return abstracts to the NDPF to be filed for the use of others.

New user requests are received at the User Liaison Office, or browse room, shown toward the right-hand margin in Figure 2-14. These requests may be based on examination of recorded imagery or may be entirely new requests, developed to meet new requirements. In either case, they are ultimately scheduled by the OCC if new coverage is indicated, with due allowance for current priorities.

Figure 2-15 shows the physical layout of the facilities in Building 23, which accommodates both the OCC and NDPF with only minor changes to existing structure and housekeeping facilities. The browse room is shown

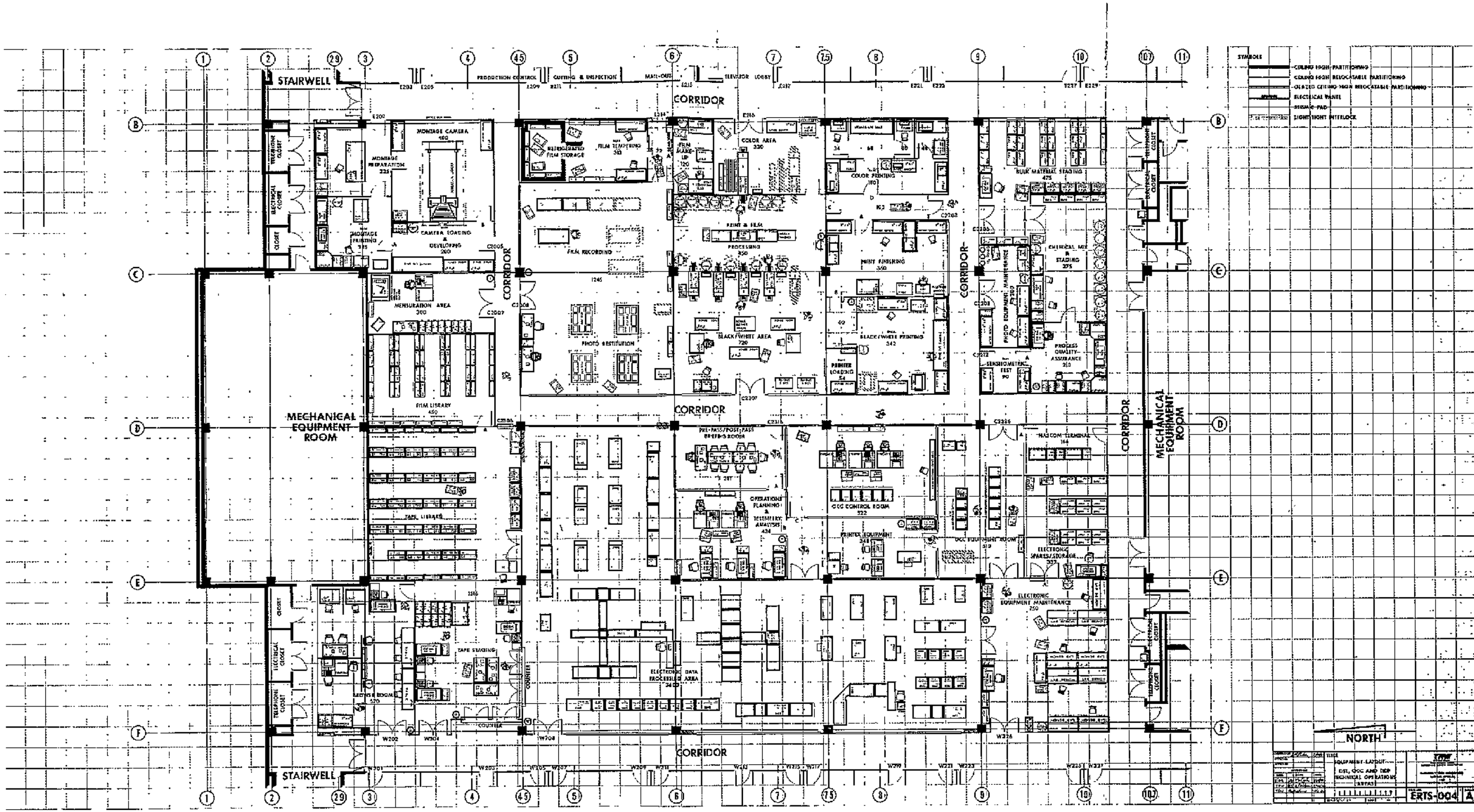


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Figure 2-15
GDHS PHYSICAL LAYOUT

FOLDOUT FRAME 1

FOLDOUT FRAME 2

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at the lower left-hand corner of this illustration and is equipped with a display console, on which data and imagery from the files can be presented. It is also equipped with light tables, on which users can examine photo-transparencies. Ordinary tables are provided for the examination of photo-prints and hard copies of listed and graphically presented data as well as for writing out requests and other paperwork.

The Control Room and the Operations Planning Room are also equipped with display consoles so that data and imagery are readily available to both the planning and scheduling staff and the people who are responsible for generating commands.

As shown in Figure 2-15, the automatic data processing equipment is centrally located between the OCC and the NDPF's tape and film libraries. This is close enough to the image-processing equipment (much of which is computer-controlled) to comply with cabling distance constraints. It also facilitates interaction between all parts of the facility.

The computers do much of the routine work involved in planning, scheduling, and commanding spacecraft operations. They manipulate digitized imagery data form image improvement, perform data-filing and information retrieval functions for the unified display system and for generation of hard copies. They also perform many clerical functions relating to inventory control of photographic chemicals and other supplies.

The facilities and equipment for turning taped information into film and other hard copy records are shown in the upper part of Figure 2-15. Suitable areas are also set aside for mechanical and electronic maintenance facilities and for storage of photo-processing supplies and mechanical and electronic spares.

2.2.1 Operations Planning and Telemetry Analysis

While the room designed for operations planning and telemetry analysis is partly visible to visitors, through glass walls, it has been deliberately made less accessible than other areas to discourage casual visits. It is equipped with two control and display consoles, two overhead displays and a clock. It is located next to the Control Room to facilitate interaction between planning and control specialists.

The activities in this area start before launch with an assessment of initial requests from users for specific coverage by the payload sensors. The OCC planner calls for a display of all requests from the NDPF files and refines the preliminary priorities (assigned by the NDPF staff on the basis of worth values) by relating them to operational constraints. These constraints imposed by such factors as cloud cover, snow cover, sun angle, and other considerations are also displayed to the OCC planner so that assignment of final priorities can be made.

Preliminary event lists are then made up, which reveal any conflicts that may exist and provide a basis for generation of preliminary command lists. The necessary ground station support is scheduled through OPSCON. OCC equipment, software, and personnel are scheduled as required for each working shift of the OCC's 24-hour operating day.

Preliminary scheduling of sensor events is predicated on the establishment of an acquisition table. This is generated by correlation of coverage requests with observatory ephemeris predictions and results in an ordered tabulation of geographic "cells" (related to a basic earth grid) versus acquisition time for each cell.

Requests for coverage, which cannot be immediately satisfied, and which are not time dependent are rescheduled for later orbits. Those that cannot be given real time coverage by the primary ground stations are allocated portions of the on-board tape recorder capacity. Since this on-board capacity is limited to thirty minutes for each of the two recorders (one for the RBV camera system and one for the MSS), the allocation problem might appear to be a difficult one. Studies, however, indicate that even on a global basis tape recorder limitations are minor.

Figure 2-16 and Table 2-3 illustrate the problem and Table 2-2 indicates that it has a simple and practical solution. The figure shows how an ERTS observatory covers the globe during a typical 24-hour period. The first table gives pass durations and corresponding acquisition times for the appropriate ground stations. Using this and similar information for a typical 18-day cycle of operation (each of which repeats its predecessor's coverage), the data in Table 2-4 were calculated to show imagery collection capability, assuming both camera systems to be in operation simultaneously but only over non-polar land masses.

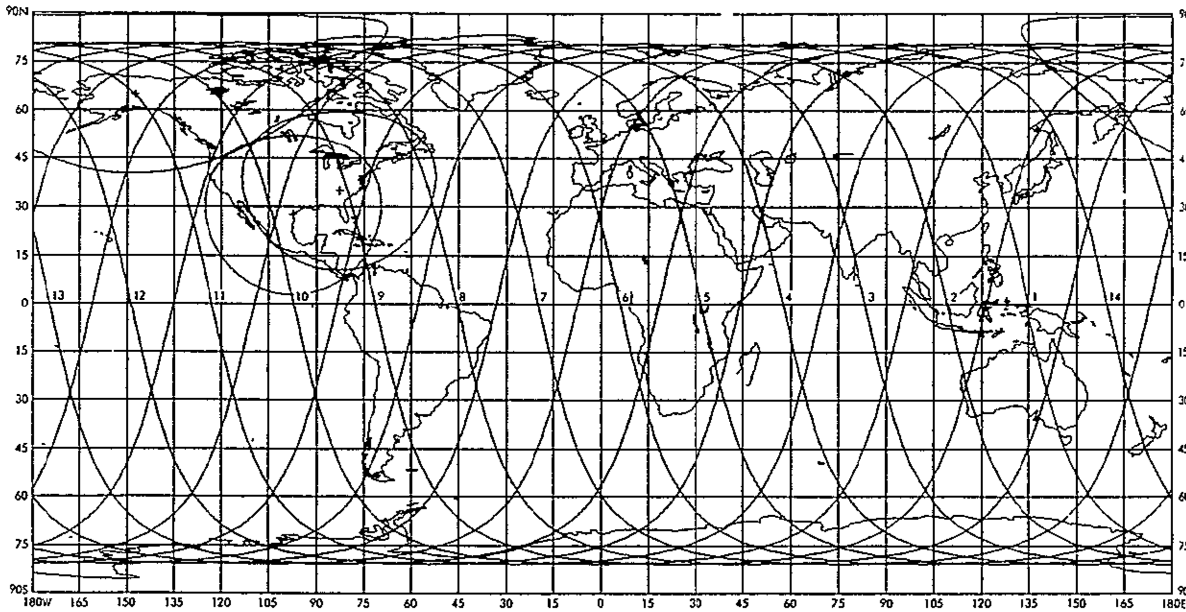

Figure 2-16

SPACECRAFT ORBITAL PATH

Table 2-3. Station Acquisition Schedule

Revolution Number	Station	Station Acquisition Time* (hr min sec)	Pass Duration (min.)
2	NTTF	02:18 00	13.9
2	Corpus Christi	02 22 25	10.7
3	NTTF	04 00 55	11 1
3	Corpus Christi	04:02 50	13.7
4	Alaska	05.37 00	11 8
5	Alaska	07 18 50	11 3
6	Alaska	09:01 05	13.8
7	Alaska	10:42 55	11.8
8	NTTF	12 11;35	7 7
8	Alaska	12 23 50	10.6
9	NTTF	13.49:25	14.2
9	Corpus Christi	13 50 00	11 1
9	Fairbanks	14:03 35	11.5
10	Corpus Christi	15 30 10	13 5
10	NTTF	15:35 10	7.5
10	Alaska	15 43:25	13.4
11	Alaska	17 24 35	14 2
12	Alaska	19:08:05	12.7
13	Alaska	20 55.50	5.8

*Station acquisition time measured from ascending node of first revolution.

Table 2-4. Typical Observatory Coverage in Relation to Recorder Capacity and Ground-Station Visibility

	Min/Day
Picture-taking opportunities	185
Station coverage	165
Recorder playback time	130
Real-time readout	35

This shows that either camera system could more than fill its recorder and that station coverage is marginally adequate. It does not, however, take into account cloud cover, snow cover, sun angle, and other factors that limit the opportunities for taking pictures that are of practical value to ERTS users. Since, in actual practice, these spoiling factors can be expected to reduce useful picture-taking opportunities considerably, the tape-recorder capacity would appear to be adequate for all practical purposes.

When all of the variables have been considered and plans have been finalized, schedules and command lista are developed and refined on the basis of any changes that may be required by ESSA weather forecasts and other last-minute considerations.

This general method of planning is followed after launch on an orbit-by-orbit basis, as observatory operation gradually settles into a practiced routine. Actual observatory ephemeris data replace predicted data, just as actual housekeeping telemetry replaces the simulated variety, and the necessary events and commands for orbit adjustment and maintenance of observatory health are fed into daily and weekly schedules as operations progress.

2.2.2 Observatory Monitoring and Control

The OCC Control Room is also designed for inaccessibility to casual visitors but can be seen through a glass wall between it and the corridor. It is equipped with three command consoles, two overhead display monitors, six strip-chart recorders and a clock. The focus of OCC real-time operations is contained within the control area. It is from here that all operational decisions are made and implemented.

The center console is manned by the operations planner controller who has responsibility for overall operation of the observatory. This requires coordination of all internal OCC activities, reviewing all detailed pass assignments and command lists, monitoring observatory command status, and transmission of commands to the spacecraft. Further, this position is responsible for coordinating and communicating with external groups such as OPSCON, MSFNOC, and the ground stations.

The data analyst is positioned at a side console and is primarily responsible for monitoring and evaluating observatory status and health. Trend analysis and subsystem engineering activities are performed utilizing cathode-ray tube displays and strip-chart recorders. Corrective action to improve spacecraft and payload performance is recommended to the operations planner controller as required.

The other side console is manned by the command generation technician. This position is responsible for monitoring the command lists and providing general command support to the operations planner controller. The computer-generated command lists are reviewed for accuracy with corrections and additions being made as required.

The overhead displays which are visible from all parts of the control room present general status information and forced alarm messages indicating any anomalous conditions.

Control Room activities begin with pre-launch exercises, involving simulated commands and the monitoring of simulated telemetry data. Actual command activities begin at injection and the return of housekeeping telemetry starts immediately thereafter. The Control Room staff then moves into full operation, generating commands and monitoring spacecraft health by analyzing telemetry data and using the quick-look imagery capability to determine how well the sensors are responding to commands.

Command list planning and preparation is accomplished by operator interaction with the computers through the display consoles. Manual initiation after review of computer prepared commands maintains the necessary human control over command functions. In the event of computer malfunction the necessary commands can be ordered by voice or teletype to be executed by the ground station command encoder.

The second major function of the OCC (monitoring observatory status and generating change commands based on this review of housekeeping data) uses either a separate carrier of the S-band link or the VHF link depending on the nature of the ground station. The data may be received in real time or from the on-board recorder. Relay to the OCC may be either in real time or through playback of the ground station recorder.

After processing, the data go to the OCC computer but selected parameters are also monitored directly by stripchart recorders as a backup in case of computer malfunction. The OCC computer automatically notifies operators if any observatory parameter exceeds prescribed values. The console operator can call up any recorded data for display to analyze the circumstances.

Existing NASCOM facilities meet almost all OCC requirements. A 20 kHz wideband link with the Texas station will be needed, however, as well as full, duplex, teletype circuits to the remote stations and SCAMA II conference voice links during the checkout, prelaunch, and launch phases. Communication with the Rosman uplink station will be through the NTTF.

2.2.3 Image Processing

Figures 2-14 and 2-15 also show functionally and physically how the image-processing equipment operates. Except for quick-look imagery, all RBV and MSS data are processed in the NDPF into finished imagery for users. Quick look images are loaded into the unified display system for review and action.

The first step in the overall process is to take tape, mailed in or hand-carried from the ground stations, and reformat the data from it onto high-density tape. This is done by putting the raw tape through a tape reproducer and a control unit which digitizes the video signals and, using inputs from the NDPF computer, annotates each frame. Separate reproducers and control units are used for RBV and MSS imagery. Their operation differs in that the RBV tape is already in separate frames, which require only annotation and digitization, while the MSS data is in digital form but comes in twenty-four continuous streams, six for each of four different spectral bands. The streams, therefore, have to be buffered and reformatted into sections that are equivalent to the RBV frames. These sections are then annotated with time, location, and other data similar to those used for the RBV material. During this process, the computer abstracts from the RBV tape, data on the reseaux (which provide a basic spatial reference for each frame) for later use in correcting images.

The high-density tape that is first produced on a recorder is Bulk I tape. It is moved to a high-density tape reproducer for playback through a tape-to-film control unit, which drives a laser beam recorder on which the digitized data modulate a laser beam that traces out the imagery on photographic film. The film is processed by standard photographic developing equipment and then printed for the archives from which it can be retrieved at any time to fulfill user requests. Bulk I film is also used to construct the basic reference for the entire ERTS system, a montage map of the terrestrial surface covered by the observatory cameras. At the end of the 18-day cycle the area covered is printed and sent out as a bound volume.

Figure 2-17 shows the basic format for annotated imagery for both the RBV and MSS cameras. The actual image is less than 8 inches square and the remainder of the 9-1/2-inch film is used to record grey scales, geographic tick marks, registration fiducials, identification number, and three lines of alphanumerically coded annotations on time, picture center and subsatellite point coordinates, spacecraft altitude and heading, sun angle, cloud cover, DCS data available, and other filing and mapping information.

If Bulk II processing is specified, the Bulk I RBV images are placed into the precision photo restitutors as inputs and computer extracted reseau corrections are made in concert with other appropriate image manipulation (see Table 2-5). MSS images are treated as indicated in the table.

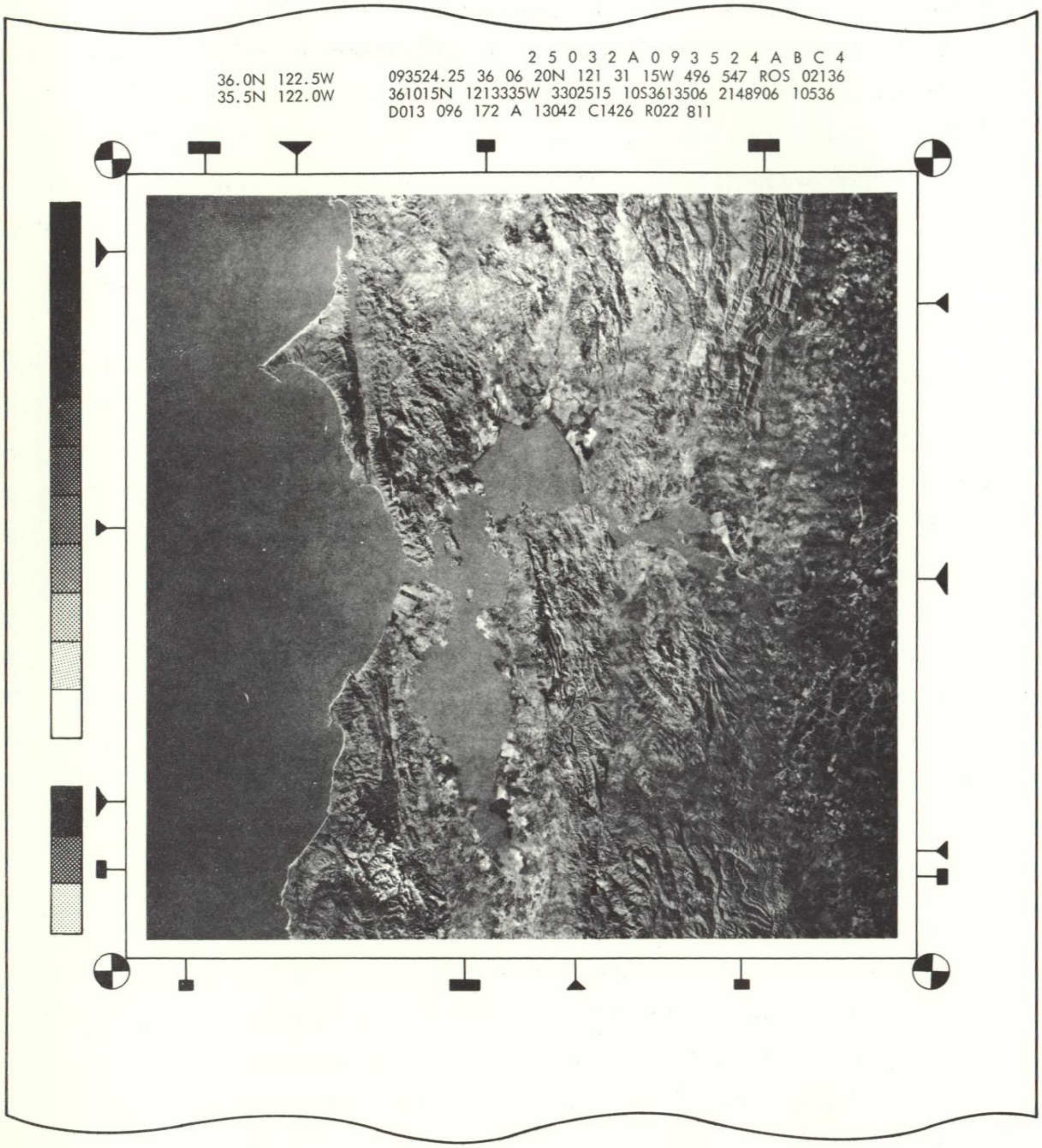

Figure 2-17
FORMAT OF ANNOTATED IMAGERY

Table 2-5. Image Processing Modes

		Geometric Corrections	Photometric Corrections	Mechanization
Bulk Modes (Operations on All Input Imagery)	Mode I	Correction for earth rotation effect on MSS images	1) Shading 2) Channel gain derived from transmitted calibration signals	Preparation of high-density tapes followed by off-line LBR reproduction
	Mode II	1) Reseau and keystone correction of RBV images 2) Correction of MSS images using attitude date 3) Projection into UTM coordinates 4) Projection to average altitude non-sea level datum (datum used identified in annotation text)	Same as Mode I	1) Computer detection of RBV reseau points 2) Computer calculation of synthetic MSS reseau based on attitude data 3) PPR processing under computer control
Precision Modes (Operations on 5 percent or less of Input Imagery)	Mode I	1) Reseau correction of RBV images 2) MSS processing by use of refined attitude data and verified ephemeris 3) Image transformation into UTM or oblique Mercator (user's choice) 4) Projection to any altitude non-sea level datum (datum used identified in annotation text)	1) Shading 2) Channel gain derived from transmitted calibration signals	1) Digital computer processing 2) Image production by LBR 3) Use of ground truth where feasible 4) MSS yaw angle refinement by correlation with one like-spectral RBV channel. Error in yaw estimate merged with other attitude data in computer processing 5) Production of corrected digital tapes
Precision Modes (NASA Option)	Mode II	Same as Mode I with choice of one or more of the following 1) RBV blemish removal 2) IMC where possible 3) Image transformations into specified grids 4) Image enhancement 5) MTF correction 6) Structured noise removal 7) Reseau removal with cosmic fill-in 8) Radiometric adjustment for atmospheric effects 9) Nonstandard composite color balance		

When precision corrections are requested the processes required are performed in the computer and a corrected tape is prepared. The latter is then used to drive the laser beam recorder, producing thereby a fully corrected image without further processing in the precision photo restitutor (except for the use of the latter device to obtain ultimate yaw attitude error estimates by correlating an RBV and MSS image from the same spectral band to obtain optimum MSS correction).

2.2.4 Photo Processing

The principal functions of photographic processing are to reproduce, in accordance with standardized procedures, the acquired imagery of the observatory sensors. The photographic process areas are maintained at positive relative pressure and are sealed in the subfloor region to prevent chemical leakage and contamination and damage to other areas.

The bulk film processing area accommodates four automatic black-and-white processors, one color processor, and twenty-six chemical holding tanks. The area is not darkened because film cassette systems are used throughout. Both laser beam recorder and precision photo restitutor cassettes are processed in this area. False color composites are made by manual techniques, backed up by capability for this process in the precision photo restitutors. Nonstandard output photo products are prepared in separate darkrooms using manual techniques. Montage assembly and reworking takes place in a special room shown at the left of Figure 2-15.

In order to reduce graininess and preserve the system MTF response, the baseline photographic system uses 9-1/2-inch film for production of initial hard-copy images. This is large enough to accommodate a 7.3 times enlargement of the 1-inch-square sensor image as well as to contain comprehensive annotation data. It is also large enough to reveal to the unaided human eye any gross deviations from geometric accuracy.

The type of film recommended for use is Kodak 2430, a fine grain duplicating film which has a resolution capability of over 300 line pairs per millimeter. At the nominal resolution of 10 cycles per millimeter for the laser beam recorder, the film's modulation transfer function is 0.95; hence, its effect on picture resolution is negligible. Type 2430 film also has a good tonal range and is unusually uniform from batch to batch. Regular sensitometric tests will, of course, be run during the program to ensure that these standards are maintained in all batches of actually purchased film.

For film and print processing, equipment has been selected on the basis of its ability to process large quantities uniformly. Simplicity of operation and ease of maintenance were also key factors. Each shift is required to produce 8000 feet of film and 4000 feet of paper, and the equipment selected exceeds this rate of production with a margin that is sufficient to allow for unusually heavy loads as well as a reasonable amount of downtime.

Although color composites made from ERTS imagery are not intended to reproduce the visual appearance of the colors in each scene, the need for consistency of color rendition is fundamental. The optical and mechanical equipment and the supplies (film, paper and chemicals) chosen for this work have therefore been selected with a view to their ability to convert all spectral signatures (as recorded in the varying tones of the black and white separations) to consistent object colors in the final composite transparency or print. The calibrated reference step wedge generated by the laser beam recorder provides the means to assure process control of image color balance. For example, the three step wedges on a set of RBV images when superimposed in the color additive process should produce a neutral black and white tone. Deviation from neutral would indicate an improper balancing of one or more of the multispectral inputs used to produce the additive color record.

Neutral tone balancing has been used as a standard in color printing for many years. In multispectral applications such as ERTS, balancing to a neutral tone for certain types of images may not produce the desired results. In the precision mode, this balance can be altered to produce records that meet the needs of the user.

The production of color negatives by manual techniques will be standard, although the precision photo restitutors are also able to perform this function if need be. Tests conducted with a Kodak registration punch and board which have been in use for several years have shown that registration is achieved to within 0.0005 inch which is on the order of 0.3 pixel.

For the photo montage that will be used as a master index to all imagery, the 1:3, 168,000 scale Lambert conformal projection of the U.S. Geological Survey has been chosen for its convenience and compatibility with the needs of the ERTS system. This requires that the 7.3-inch-square image be reduced to nominally 2.27 by 2.27 inches. After these prints have been assembled, the complete montage will be reduced by a factor of approximately 2.7 so that each frame will finally be reproduced by photolithography at slightly less than 1-inch square. Although these frames are certainly small, it is still possible to annotate each with an identification legend that will enable the user to choose any frames he wishes to retrieve for special processing.

The quality assurance plan for photographic processing operations is based on the fundamental requirement that tonal and spectral differences in final photographic material may be due only to differences in the ground scene, illumination, atmosphere, or the performance of the spacecraft system and not to variations in photo-processing materials, equipment, or procedures. To this end, sensitometric step wedges will be exposed on the head and tail of each roll of film. Following development, these will be converted automatically into a sensitometric curve by an Itek densitometer from which experienced operators can determine the nature and magnitude of changes that must be made in the exposure or the chemical processing of the film. (Similar sensitometric tests will be made on samples taken from each batch of raw film, when it is delivered.)

Processing machines will be scratch-tested and chemically certified at the beginning of each day and after any appreciable periods of shutdown. Processed film will be cleaned and waxed to ensure uniform reproduction of multiple copies. Finally, all finished materials will be microscopically inspected on light tables and defective products will be recycled to produce acceptable items for delivery.

2.2.5 Physical Storage and Retrieval

The library area, shown in Figure 2-15, is immediately adjacent to the User Liaison Office and also next to the area in which the computers and their peripheral equipment are located. This makes it very convenient for the NDPF staff to service users and to fill the requests of mission planning and spacecraft control personnel for data to be used in their work.

All magnetic tapes (video and data) are maintained by the library, as are the miscellaneous hard-copy reports which the system generates, the various reference materials used in the system, and the photographic outputs of the system.

There are two sections to the library — an active library and an archival storage area. The active library must maintain tapes and data which are current and which may be requested at any time for request processing. The archives represent the storage facility needed for all data and tapes which are outdated but still usable. They must be retained, but the number of requests are infrequent and therefore do not justify retention in the active files. The archives could conceivably be maintained in another area of the building or even in another facility. This is a judgment which can be resolved as the system evolves and as user usage can be better determined.

Proper indexing and cataloging are essential to library operations. An index file provides a record of all physical items stored in both active and archive portions of the library. This file is instantly updated and provides ready access to data needed in response to user requests. As the system accumulates coverage over several years, the file will become larger.

After a firm data base is established, there will be limited growth, with most modifications being changes to the existing files. Each frame or set of coverage will be indexed and stored in a direct access storage device so that user requests for information can be fulfilled in as short a period of time as possible. Because of the large volume of index data, and because of the response needs, it would be impractical to store the data on a serial-search medium such as magnetic tape.

However, there may be a need to retain this data on-line for some specific period of time (perhaps five years, or some other time period based on user requirements to search the older data), purging the older data and physically storing it on magnetic tape in a less accessible place. If the frequency of requests for older data were sufficiently high so as to put a burden on such a system, then it would be desirable to keep all index data available on-line via a direct access storage device.

2.3 DATA COLLECTION SYSTEM

The Data Collection System (DCS) consists of six ground based Data Collection Platforms (DCP) and the data acquisition equipment in the ERTS observatory shown in Figure 2-18.

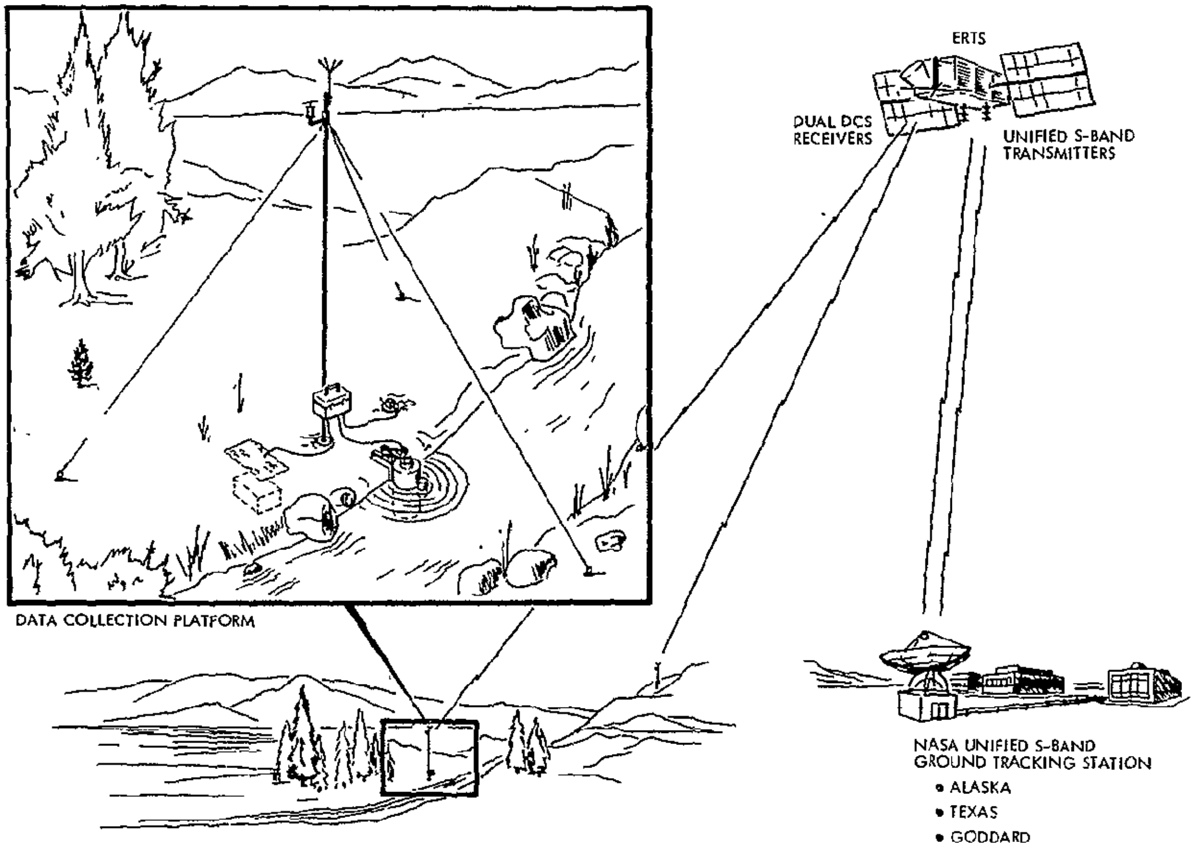

Figure 2-18

DATA FROM AS MANY AS EIGHT SENSORS ARE COLLECTED AND PROCESSED on each platform and transmitted to ERTS. The DCS receiver in ERTS collects these data from all platforms in view and feeds it to the unified S-band link for relay to the ground.

The DCP's are self-contained assemblies and consist of an eight-channel analog signal conditioner which conditions the signals from the sensors, a multiplexer which samples the data from up to eight sensors, an 8-bit analog to digital converter, a 5-watt transmitter, an omni antenna, a battery for primary power, a power converter, and the digital clocks and timers required to operate the assembly. The DCP's are connected to sensors which have been selected by NASA and user agencies such as the Department of Argiculture and the U.S. Geological Survey.

The sensor type and its purpose will vary. They will be used to measure or indicate such parameters as snow or water depth, salt contents in water, moisture content in soil, etc. The data from these sensors are collected, encoded to a pulse code modulation format message consisting of 110 bits, and the messages are transmitted approximately every two minutes.

The acquisition equipment in the ERTS observatory consists of a shaped beam antenna, a coaxial switch and redundant 400 MHz receivers. The antenna is designed to provide maximum gain at the horizons of the field of view, and minimum gain at the observatory's subtrack, and thus compensates for space loss and is able to approximately provide a constant signal strength to the receiver. The coaxial switch and the on-off operation of the redundant receiver is controlled by ground commands. In case of a malfunction of the operating receiver, the alternate receiver is turned on, and by means of the coaxial switch the signal from the antenna is routed to this alternate receiver.

The received data is converted to a 75 ± 50 KHz IF frequency by the receiver, and this converted data is in turn routed to a subcarrier oscillator (SCO) in the Unified S-band (USB) assembly. The output of this SCO is summed with the output of other SCO's in this assembly and the summed signal is used to phase modulate the USB transmitter. These signals are acquired by stations located at Fairbanks, Alaska; Corpus Christi, Texas; and Goddard when ERTS is within signal range of these stations. At these stations, the data is demodulated. Since the frequency response of the ground transmission lines between these stations and the Operations Control Center (OCC) is not sufficient to transmit the DCS data in real time, the data and coded time are first recorded, and the data is then played back at a reduced rate and transmitted through the land line. The exception to this constraint is that the data received at the Goddard NTTF, because of its proximity, can be transmitted at the real time rate to the OCC. At the OCC the data received at a reduced rate is recorded and then played back at a fast rate to get it back to its real time transmission rate. The playback data is routed through the DCS data demodulator and PCM synchronizer to the computer. The computer's output is a computer tape which is used at the NDPF to prepare computer printout data in engineering units.

3. System Performance

CONTENTS

3. SYSTEM PERFORMANCE

The ERTS Phase B/C design study specification establishes a number of performance requirements. TRW has endeavored to meet these in all instances. In certain cases relating to payload interfaces, the individual specification has been compromised to preserve the broader mission goals, usually in relation to preserving the use of existing flight-proven equipment; in particular, this is true of the spacecraft clock format. The way in which our approach meets the mission goals with respect to all payload interfaces and spacecraft and payload operation is summarized in Table 3-1. Satisfaction of mission goals with regard to the GDHS is summarized in Table 3-2.

Table 3-1. Summary of Specified and Actual Spacecraft Performance

S-701-P-3 Paragraph	Requirement	Performance Achieved
6.1a	Sun synchronous orbit 9:30 +30 min -0 node crossing	Power system provides 20 minute operation at year end with 30-minute launch slip
6.1b	Correct injection errors	Orbit adjust system will correct all 3 injection errors
	Adjust sensor swath sidelap	Full adjustment provided
6.1c	Control attitude to local vertical and velocity vector	This is done
6.1d	Orbit sidelap 10 percent	ΔV system can adjust as accurately as orbit can be measured
6.1e	Swath coincident to ±10 n mi at 18-day intervals	ΔV system can adjust as accurately as orbit can be measured
7.1a	Payload weight at least 450 pounds	Structure can accommodate 495 pounds above current spacecraft weight
7.1b	Volume minum 12 cubit feet for payload	Payload volume is now about 18 cubic feet
7.1c	Earth viewing area to be 125 percent of initial sensor requirements	Feasible by redistributing assemblies
7.1d	Area for MSS space-looking cooler	Is accommodated in current design
7.2	Minimum life, 1 year	Expendables sized for 3 years; wear out designs 1 year or more
7.3	Predict misalignments	Initial alignment by shim to 0.1 deg. measured to 0.01 deg
		Thermal shift less than 0.007 deg.
7.4	Recommend a launch vehicle	Thor-Delta is acceptable. Adaptation costs are truly minor. No known performance incompatibility
7.4.1	State principal moments of inertia	I_{xx} 210 slug ft^2 I_{yy} 250 slug ft^2 I_{zz} 390 slug ft^2
	State cross products of inertia	Less than 7.5 slug ft^2
	Plot allowable uncompensated momentum and moment from 0 to 100 Hz	See Section 1, Vol. 4
7.5	Pointing error less than	Spacecraft design provides
	Pitch 0.7 deg	0.5 deg
	Roll 0.7 deg	0.5 deg
	Yaw 0.7 deg	0.7 deg
	Body rates less than	Spacecraft design provides
	Pitch 0.04 deg/sec	<0.008 deg/sec
	Roll 0.04 deg/sec	<0.011 deg/sec
	Yaw 0.04 deg/sec	<0.011 deg/sec

Table 3-1. Summary of Specified and Actual Spacecraft Performance (Continued)

S-701-P-3 Paragraph	Requirement	Performance Achieved
7.5.1	Demonstrate can null initial rates	Demonstrated in orbit with OGO. Design remains the same
	Reacquire four times	Done many times with OGO spacecraft
	Show ΔV compatible with attitude control	No spacecraft maneuvers required, yaw gas must be turned on by ΔV command, fully compatible
	Locate picture elements to ±2 n mi	±2 n mi is feasible
	Goal for location accuracy one-resolution element	About 600 feet is feasible with ground truth, etc.
7.6.1	Dual uplink 154 and 2106.4 MHz 256 commands	This is provided Provides 358 commands
7.6.1.1	Execute 30 different commands from store	64 provided
	100 executions Override stored command Verify store Reliable address	127 provided (254 in the two stores) Real-time override Does that 7-bit address
7.6.1.2	Command reliability	All critical commands require arming. Shut off timers on loads over 1 ampere
	Command system redundancy	Fully redundant throughout
7.6.1.3	Command RF power margin*	
	STADAN >20 db USB >20 db	17.6 db Command 24.3 db Ranging 5.2 db
	136-138 MHz transmitter 2287.5 MHz transmitter 8-bit accuracy	Provided Provided Provided
	Transmission rate 1 kbit/sec Storage at 1 kbit/sec or less	1 kbit/sec or 32 kbit/sec 1 kbit/sec
	Playback 32 kbit/sec or less Simultaneous RT and PB over USB Link margin for bit error; $1/10^6$	32 kbit/sec Provided
	VHF Link* USB Link*	[17.7 db (kbit/sec) 2.6 db (32 kbit/sec)] [4.5 db (kbit/sec) 4.3 db (32 kbit/sec)]

Table 3-1. Summary of Specified and Actual Spacecraft Performance (Continued)

S-701-P-3 Paragraph	Requirement	Performance Achieved
7.6.3	Wideband telemetry	
	2 carriers about 2265 MHz	Carriers at 2230 and 2265 MHz
	Real time and video playback simultaneously	Provided
	Commandable 20 watt mode	Provides 10 and 20 watt modes
	Link power budget at 10 watts	
	30-ft dish S/N ratio**	Provides 37.1 db RBV, 1.7*** db MSS
	85-ft dish S/N ratio**	Provides 42.1 db RBV, 6.7*** db MSS
	Cross strapping	4 drivers. See Section 9.4
7.6.4	Tracking	
	Beacon carrier. 136-138 MHz	137.86 MHz
	USB transponder compatible MSFN	Provided
	Beacon on continuously	Provided
	Redundant transmitters	
	VHF	2 provided
	USB	2 provided
7.6.5	Data Storage	
	Video units GFE	All provisions made
	Narrowband	
	Existing space qualified unit	Modified HDRS unit is used
	Capacity >2 orbits data	7 orbits/2 recorders
	Playback/record ratio >20/1	32/1
7.6.6	Timing	
	Common clock for PCM, (command and wideband systems)	Provided
	Timing signals	
	Pulse trains as Attach. I, II, II	All provided
	Coded clock	Binary, 1.152 sec
	Update known to 1-bit time of PCM	Provided
	Clock reset	Not provided
	Clock acceleration for ground test	Provided
7.7	Power	
	20 minutes payload power/revolution	Provided
	50 percent RT, 50 percent PB	Provided
	Seasonal sun line variations	Provided
7.8	Thermal	
	Payload Environment 20 ±10°C	Provided

Table 3-1. Summary of Specified and Actual Spacecraft Performance (Continued)

S-701-P-3 Paragraph	Requirement	Performance Achieved
7.9.1	Orbit adjust	
	Eccentricity less than 0.006	<0.001 provided
	Swath overlap ~10 percent	Provided
	Westward progression	Booster provides
	18-day swath coincidence <±10 miles	<<10 miles
	Estimate injection residuals	~39 ft/sec 3σ
	Specify operation use	See Section 10
	Verify orbit	
	Altitude 496 n mi	489.7 n mi
	Inclination 99.04 deg	99.098 deg
	Predict	
	Orbit parameter variation/year	100 ft altitude/year
	Need for orbit trim after ΔV	0.007 ft/sec/year****
	Tradeoff size ΔV system versus drift	Zero drift is easy

*Above 6 db system margin

**p-p signal/rms noise; above 6 db margin

***Margin above BER 1 x 10^{-6} and above 6 db system margin

****TRW recommends this trim be accomplished but it is left to user discretion

Table 3-2. Summary of Specified and Actual GDHS Performance

Paragraph	Requirement	Performance Achieved
7.14.1.1	Building	
	The facilities should be contained within 27,000 square feet.	The design permits operations within the space allowed within Building 23.
7.14.2.1	OCC functional requirement	
	The OCC will provide facilities to generate and verify spacecraft commands; and to receive, process, display, distribute, and store spacecraft data.	Capability provided.
7.14.3.1.1	TIDP functions	
	The TIDP will receive video and PCM telemetry on tape or by broad band link. Video data will be presented in the form of bulk processed images. Some portion will receive precision processing.	Capability provided.
7.14.3.1.1.1.1	Processing of image data	
	The system will convert all video data from tape to film with such corrections as may be optimum.	The RBV data is recorded directly. MSS imagery is corrected for earth rotation (up to 8 n mi).
7 14.3.1.1.1.2	Precision image processing	
	Up to 5 percent of the imagery must be processable to the highest practical precision. Processing will be to a spatial resolution of 200'.	The system can handle in excess of 5 percent of the imagery. The overall spatial accuracy is 900' 3σ, with preservation of camera resolution.
7.14.3.1.2	DSL functional requirements	
	The DSL will control all processing. It will provide for photo copy and distribution. An abstract file and montage catalog will be developed Means to store and retrieve data will be provided.	Capabilities provided.
7.14.3.2.1	RBV imagery	
	RBV imagery must be presented on 9" x 9" or 70 mm film Annotation is required.	RBV imagery will be presented on 9-1/4" x 9-1/4" film, properly annotated.
7.14.3.2.2	MSPS imagery	
	MSPS imagery will be presented on either 9" x 9" or 70 mm film.	MSPS imagery will be presented on 9-1/4" x 9-1/4" film.
7 14 3.2.8	Montage catalog	
	A montage catalog will be provided.	Capability provided.
7 14 3.2.9	Abstract and data catalog	
	An abstract file of all data will be provided.	Capability provided.

Table 3-2. Summary of Specified and Actual GDHS Performance (Continued)

Paragraph	Requirement	Performance Achieved
7.14.3.3.2.1	RBV Bulk Data	
	The system will handle either U.S. only, or world wide, with 10 copies of each of the 3 negatives provided per picture and with 10 copies of 20 percent of the data in color.	.Capability provided.
7.14.3.3.2.2	MSPS bulk data	
	The system will handle either U.S. only, or world wide, with 10 copies of each of the 4 negatives provided per picture and with 10 copies each of 2 color composites on 20 percent of the data.	Capability provided.
7.14.3.3.2.3	RBV and MSS precision data	
	Up to 5 percent of received data will be used to produce copies as in 7.14.3.3.2.1 and 7.14.3.3.2.2, on data processed to full precision.	Capability provided.
7.14.3.3.2.4	Computer readable format images	
	Selected images will be output to high density digital tape.	All images are converted to high density digital tape.

4. Task Status

CONTENTS

4. TASK STATUS

As part of its Phase B/C proposal in June 1969, TRW generated and later modified a list of study tasks to be performed under contract. The following pages repeat those task statements and provide a brief summary of the results of each. The volume and section of this report in which a more detailed coverage can be found are also listed.

Task	Task Description	
7.1	<u>Payload Study Tasks</u>	
	1) Monitor evolving payload characteristics regarding weight, volume, view area, power requirements, commands, telemetry words, data bandwidth, unbalanced momentum, deployment, etc. Maintain current specifications for requirements spacecraft subsystems must fulfill to satisfy payload.	See Volume 4, Section 2
	This is an on-going task. Coordination has taken place in several conferences and in many informal contacts with GSFC people. Our report summarizes the status as of about 1 January 1970.	
	2) Study the interface between spacecraft and payload members particularly with regard to power, telemetry, command and clock interfaces. Develop an alternate approach to spacecraft design which adheres to Nimbus D interface specifications. Also, working with GSFC and sensor manufacturer engineers, investigate spacecraft-to-payload interface specifications which lead to fewer overall changes, greater overall reliability and/or lower overall system costs.	See Volume 4, Section 2
	Our payload interface approach has been to comply with all Nimbus interface characteristics except the 1-second coded Nimbus clock. Considerable expense would be involved in providing this capability and the mission can be accomplished with	

Task	Task Description	
	the binary 1.152-second elapsed time clock already available in the OGO design. Additional simplification to total observatory could result if the RBV shutter mechanism were redesigned to accept positive 28-volt unregulated power.	
	3) Review DCS work performed to date, redesign concept to exclude on-board recording leaving real time transponding of data to ground stations. Generate documentation presenting functional concepts and preliminary specifications.	See Volume 5
	This work is complete. Observatory equipment consists of a low-power-drain receiver. Ground equipment fully meets mission requirements.	
	4) Plan for the addition of a fifth MSS channel requiring a passive radiative cooler. Identify which spacecraft orientation is most suitable, considering power, control, thermal and velocity correction subsystems. Identify also the resulting impact on these other subsystems.	See Volume 4, Section 1.2
	The MSS cooler has been incorporated in spacecraft design and a new orientation places the array shaft in the orbit plane. Power, attitude control, thermal and orbit adjust designs are compatible.	
7.2	<u>Lifetime Study Tasks</u>	
	1) Include results of previously accomplished lifetime studies in final study report.	See Volume 4, Section 3
	Life of the spacecraft will exceed one year with a probability of 0.85 based on orbital data, test results, and reliability calculations.	

Task	Task Description	
7.3	Mechanical Study Tasks	
	1) Re-layout spacecraft subsystems and payload, including the additions of unified S-band equipment and deletion of 400-MHz transmission system. Consider an alternate layout which omits the video tape recorders. Identify the effect of planning for the VTR's and then omitting them. Back up layouts with stress and dynamics analysis and material support as appropriate. The spacecraft layout has been completed including the video tape recorders. All unified S-band equipment has been incorporated and the 400-MHz transmitter deleted. The effect of eliminating the tape recorders has been studied.	See Volume 3, Section 2, and Volume 4, Sections 1.3 and 4.1
	2) In conjunction with Tasks 7.5(7) and 7.7(4) demonstrate the mechanical flexibility of OGO for accommodating large scanning mirrors, foldable antennas, radiative coolers, and equipment for communicating with ATS-F and -G. Our spacecraft design is quite adaptable to large antennas and scanning mirrors but careful analysis of dynamics of a proposed design will be needed if the ERTS mapping precision is to be preserved.	See Volume 4, Section 1.5
	3) Consider alignment of RBV's and MSS with respect to each other and to the attitude control reference. Include thermal and mechanical deformations. RMS all components to predict totals for each sensor system. Employ these results in Task 7.15.1, Total Thermatic Accuracy, to predict overall system performance. Alignment and thermo-mechanical deformation will be small compared to 0.1 degree. The instruments are grouped together to minimize alignment problems.	See Volume 4, Section 4.7

Task	Task Description	
7.4	Launch Vehicle and Weight Study Tasks	
	1) Review the decision that the Delta N is the appropriate launch vehicle for OGO/ERTS by:	See Volume 2, Sections 2 and 3, and Volume 4, Section 4.2
	• Obtaining comparative covariance matrices and establishing the effect of vehicle choice on the orbit trim system.	
	• Updating comparison of the Delta N and Agena launch environment with respect to their effects on OGO/ERTS. Consider in particular, the effect of increased vibration inputs and increased spacecraft weight due to the additional communication and attitude determination equipment required.	
	• Studying the establishment of a launch complex for a Delta N launch OGO/ERTS; identifying new construction and equipment or modifications to existing equipment or facilities; analyzing electrical interfaces between launch complex, launch vehicles, and spacecraft.	
	• Comparing cost for vehicle, shroud, launch complex, and launch, and standby costs for the two approaches.	
	Orbit corrections have been computed using a new covariance matrix supplied by GSFC. A reduction in orbit adjustment propellant is allowed. Vibrations and other environmental characteristics of the Thor-Delta are equivalent to the Thor-Agena and the ERTS will have little risk of failure in the Delta environment. The Thor-Delta launch complex is compatible with minor harness change to ERTS. Costs have not been presented since they appear to be equal except for costs of the vehicles themselves.	

Task	Task Description	
	2) Maintain records of mass properties for evolving spacecraft design. In relation to control system generate a plot of uncompensated momentum that can be tolerated as a function of frequency up to 100 Hz.	See Volume 3, Section 2.5 and Volume 4, Section 1.4
	Our report presents the current mass properties data. Uncompensated momentum causes little effect on the attitude control system. It is, however, very important to the accuracy of MSS picture reconstitution.	
7.5	Controls Study Tasks	
	1) Prepare revisions to the attitude control system block diagrams detailing new assemblies.	See Volume 3, Figure 3-3
	Our report provides a complete attitude control system block diagram highlighting changes.	
	2) Review and verify through simulations, yaw acquisition and maintenance in non-nominal orbits. Refine the characteristics of acquisition transfer from Mode 3 to Mode 4. Document this and provide previously run control system simulations for final study report.	See Volume 4, Sections 5.1, 5.2, 5.3, 5.5, 5.6, and 5.11
	Operation in non-nominal orbits is shown to be feasible. Transfer from Mode 3 to Mode 4 and other simulations are documented.	
	3) Study techniques for reducing yaw attitude errors from 1.0 to 0.7 degree.	See Volume 4, Section 5.3.6
	Yaw error in our proposed system is within 0.7 degree.	
	4) Monitor attitude control system performance changes and parameter alteration resulting from any mass property and orbit trim revisions.	See Volume 4, Table 5-1
	This has been done and is continuing.	

Task	Task Description	
5)	In conjunction with Task 7.15.1, update and document system error budget relating knowledge of spacecraft attitude to picture element location. Investigate techniques for the reduction of alignment errors and improving attitude reference model. A system error budget has been developed. Alignment design has been studied. Attitude determination systems have been analyzed and are documented.	See Volume 4, Sections 4 and 6
6)	In coordination with Task 7.14.3(2), investigate techniques for improving attitude knowledge through the use of recognizable ground features. Work on this task is continuing. Results will be reported at the contract's end.	
7)	Demonstrate the flexibility of the control system to accommodate the addition of large scanning mirrors, foldable antennas, radiative coolers, and equipment for communicating with ATS-F and -G. The effect on attitude control is largely one of increased gas consumption.	See Volume 4, Section 1.5
8)	Study and specify an attitude determination system capable of providing the location of any point on the imagery to 2 miles as a requirement and 200 feet as a goal. The spacecraft portion of the attitude determination studies are completed. Formulation of the ground modeling is continuing and will be reported with the GDHS studies.	See Volume 4, Section 6

Task	Task Description	
7.6	<u>Communications and Data Handling Study Tasks</u>	
	1) Study the design of a communications and data handling system which includes the capacity for interfacing with both STADAN and MSFN (unified S-band) facilities. Eliminate telemetry, tracking, and command 400-MHz links and reduce narrowband tape recorder playback to 32 kbits/sec. Specify an implementation approach which meets specifications with a maximum use of flight proven hardware and minimum cost. Review redundancy requirements in light of dual systems. Examine proposed design for any potential dual-link interference, priority or failure modes.	See Volume 3, Section 4.4 and Volume 4, Section 9.6
	The unified S-band equipment has been incorporated. All interface requirements have been met. The 400-MHz link has been removed and the tape recorder playback speed reduced to 32 kbits/sec. Redundancy has been incorporated in all links and potential link interference problems analyzed.	
	2) Update command list in accordance with evolving requirements indicating command type and provisions for confirmation by telemetry. Investigate changes required to implement a 7-bit address format.	See Volume 4, Section 8.5 and Volume 3, Sections 5.7, 5.8, and 5.9
	An updated command list containing 257 commands has been prepared. Command system mechanizations discussed. The 7-bit address has been incorporated.	
	3) Verify appropriateness of stored command programmer design. Re-evaluate the need for the number of and types of commands required. Provide block diagram. Indicate interfaces with other spacecraft equipment. Evaluate the impact of eliminating the video tape recorders on the stored command programmer design.	See Volume 4, Section 8.1 and Volume 3, Section 5.6

Task	Task Description	
	The stored command programmer concept previously proposed has proven suitable for ERTS mission requirements. Eliminating the video tape recorders would greatly reduce the need for a programmer. Only the orbit adjust commands would require storage.	
4)	Identify critical commands and show the design planned to avoid catastrophic results from any single execution or failure to execute a command.	See Volume 4, Section 8.6
	There are few truly critical commands and these are protected by arming or other second level requirements for execution.	
5)	Identify requirements for and the design of all telemetry, tracking, and command equipment changes needed to satisfy revised RF carrier frequencies.	See Volume 3, Sections 4 and 6, and Volume 4, Section 9.7
	The greatest impact of revised frequency requirements on our spacecraft is the need for a new VHF transmitter. A TETR transponder meets unified S-band requirements. All antennas are accommodated.	
6)	Define tape recorder improvement program to achieve increased life expectancy. Change proposed readout rate from 64 to 32 kbits/sec.	See Volume 4, Section 8.2
	A significant tape recorder improvement program is planned which will increase the mean time to failure substantially. 32 kbit readout will be incorporated.	
7)	Review the narrowband telemetry system interfaces and evaluate appropriateness of design simplifications such as removal of the experiment submultiplexer. Consider requirements for interfacing with unified S-band equipment.	See Volume 3, Section 5.2 and 5.4, and Volume 4, Section 8.4

Task	Task Description	
	The narrowband telemetry interface is acceptable but the data volume is such that the third multiplexer must be retained.	
8)	Refine the design of the wideband transmitters, drivers and switching assemblies. Monitor solid-state power amplifiers for possible inclusion instead of TWT's. Recalculate power budget and identify the consequences of 30-foot diameter ground antennas instead of 40 foot.	See Volume 3, Section 4.5 and Volume 4, Sections 9.1 and 9.8
	The wideband system design is complete. Alternates including a solid-state transmitter have been studied. Power budgets are presented in detail. All link margins meet specifications except VHF command uplink which is accepted based on OGO design similarity.	
9)	Investigate in detail the data format and requirements from both imaging sensors, and optimum cross-strap technique for achieving redundancy for transmission of wideband data including the possibility of simultaneous playback and record.	See Volume 4, Section 9.1 and Volume 3, Section 4.5
	Cross-strapping has been incorporated. Simultaneous playback and record is feasible. Dual mode (10-20 watt) provides backup operational mode.	
10)	Refine spacecraft clock configuration. Confirm with GSFC that approach using OGO clock meets ERTS requirements.	See Volume 3, Section 5.8
	The use of the OGO 1.152-second clock meets mission requirements and requires fewest changes. It is incorporated as part of the programmer assembly.	

Task	Task Description	
7.7	Power Study Tasks	
	1) Determine detailed power requirements of payload equipment through coordination with GSFC and sensor designers. From this update power profile for 20-minute sensor operation. Assume 50 percent real time and 50 percent recording of sensor data.	See Volume 4, Section 11.1
	The sensor and other power needs have been updated and used to generate a revised power profile. Twenty minutes of payload operation are possible under worst case conditions.	
	2) Confirm or modify design of payload bus converter. Specify technique for supplying RBV shuttering signal.	See Volume 3, Sections 7.7 and 7.9, and Volume 4, Section 11.5
	The converter design is adequate although two will be required to support known payload peak currents. The RBV shutter pulse will be supplied by a small nickel-cadmium battery.	
	3) Review and demonstrate adequacy of total power system design. Specifically consider the impact of adding unified S-band equipment and a separate attitude determination system.	See Volume 4, Section 11
	A review of our total power subsystem including the addition of the unified S-band equipment has necessitated utilization of a full OGO array.	
	4) Demonstrate that the addition of large scanning mirrors, foldable antennas, radiative coolers, and equipment for communicating with ATS-F and -G do not degrade power subsystem performance through, for example, array shadowing.	See Volume 4, Section 1.5

Task	Task Description	
	For a particular configuration of large antenna that was studied, the worst example of a shadowing problem and its effect on array output is a reduction of power capabilities of about 2.5 percent.	
	5) Provide documentation in final study report of previous studies leading to the present choice of power subsystem design including curves of array power as a function of sun angle.	See Volume 4, Sections 1.2 and 11
	Our report contains the results of previous studies and curves of the array power as a function of sun angle.	
7.8	<u>Thermal Study Tasks</u>	
	1) Confirm proposed thermal design approach for ERTS is adequate for specific equipment layout and detailed payload thermal data. Use updated OGO computer program to provide greater payload detail.	See Volume 3, Section 9 and Volume 4, Section 13
	Computer runs using proposed equipment layout indicate that all internal components (except local hot spots accounted for in design) are maintained between 10 and 30°C.	
	2) Investigate implications of including passive radiative cooler on ERTS-B.	See Volume 4, Sections 1.2 and 2
	The MSS passive radiator cooler has been fully incorporated in the ERTS design. The establishment of certain MSS interface specifications and their consequent effect on placement of antenna and attitude control booms is still evolving.	

Task	Task Description	
7.9	Orbit Study Tasks	
	1) Refine analysis of detailed effects of orbital parameter variations on mission performance, paying particular attention to the resulting along-track, cross-track and altitude displacement. Re-inforce analysis with computer runs and an input to Task 7.15.1, and determine the effect on the quality of picture reconstruction.	See Volume 2, Sections 3.2 and 3.3
	Detailed analysis of orbital perturbations from higher tesseral harmonics of the geopotential, from lunar and solar gravitation, and from atmospheric drag have been completed and reinforced with computer runs. The effects of these perturbations on image location and quality will be incorporated in the total system accuracy study delivered in April.	
	2) Refine calculations of the ground lighting intensity and shadow angles for the ideal orbit and for orbits with inclination insertion errors.	See Volume 2, Section 3.5
	Solar shadow angles and their azimuths have been calculated for subsatellite points at latitudes from 60°S to 60°N for 20-day intervals throughout the year. Calculations for a nominal launch and one which slips 30 minutes are presented as representative.	
	3) Refine drag analysis and extend to atmospheric conditions prevailing at the time of ERTS-B launch.	See Volume 2, Section 3.2
	The atmospheric drag analysis is included as a part of Task 7.9(1). Computer runs were made using predicted solar activity for a March 1972 and a March 1973 launch.	

Task	Task Description	
	4) Document results of above and provide previous orbital studies for final study report. The above tasks (7.9(1), (2), and (3)) and the work presented in Appendixes B, D, E, and F of our June 1969 proposal complete this task.	See Volume 2, Section 3
	5) Document results of previous velocity correction system studies for final report. Detailed results of our previous studies are contained in Appendixes C, H, and I of our June 1969 proposal and summarized here.	See Volume 3, Section 10 and Volume 4, Section 7
7.10	<u>Spacecraft Hardware Study Tasks</u>	
	1) Update and complete the matrix of major spacecraft assemblies in the form given in Attachment VI, Section 1.9.16 to the Design Study Specifications for the Earth Resources Technology Satellite, ERTS-A and -B. Include impact of revised specification on command and data handling system. A complete equipment list with the desired entries has been prepared.	See Volume 4, Section 14
7.11	<u>Performance Assurance Study Tasks</u>	
	1) Prepare an overall system design specication for ERTS. Deliver model documents of typical mechanical and electrical design specifications and test procedures. These specifications are completed.	See unnumbered pale green volume, delivered as item 2 of the contract.
	2) Update the reliability model for OGO to the depth considered adequate to assess ability to meet the ERTS lifetime goal. Discuss any weak system links and preferred approach to enhance the reliability.	See Volume 4, Section 15.1

Task	Task Description	
	The ERTS reliability model has been updated. A 0.85 probability of one-year operational life is calculated.	
3)	Prepare a consolidated list of parts, materials and processes used in existing assemblies and planned for use in the ERTS.	See Volume 4, Appendix B
	A complete list of ERTS parts has been prepared.	
4)	Make available to the government one copy of existing performance assurance documentation such as assembly failure-effects analyses and qualification test reports for existing hardware proposed for use on ERTS.	
	The data is available on request.	
5)	Develop a reliability program plan reflecting compliance with NPC 250-1 at both prime and subcontract level. Develop a maintainability program plan compatible with MIL-STD-470 for the ground data handling system.	See Volume 6
	The reliability plan is submitted as Volume 6 of this report.	
6)	Develop a quality program plan reflecting compliance with NHB 5300.4(1B) at prime and major subcontract level, and NPC 200-3 as a minimum at the part and material supplier level.	See Volume 7
	The quality control program plan is submitted as Volume 7 of this report.	
7)	Prepare a chart indicating the extent of compliance of existing OGO assemblies with MPC 250-1 NHB 5300.4(1B) and GSFC specification S-320-G1. A report of the results including the preferred approach to bring assemblies into compliance will be furnished as a study result.	See Volume 4, Section 15.2

Task	Task Description	
	All OGO components have been developed and tested to meet equivalent specifications. New items will be designed to conform.	
	8) Develop a test monitor and control program plan that conforms to and assures compliance with the integration and test requirements.	See Volume 8
	The test monitoring and control plan is submitted as Volume 8 of this report.	
	9) Develop a configuration management plan that complies with the intent of GMI 8040-1.	See Volume 9
	The configuration management plan is submitted as Volume 9 of this report.	
	10) Develop a soldering program plan that complies with the requirements of NHB 5300.4(3A).	See Volume 10
	The soldering program plan is submitted as Volume 10 of this report.	
	11) Develop a failure reporting plan which is compatible with GSFC's malfunction report system.	See Volume 11
	The failure reporting plan is submitted as Volume 11 of this report.	
7.12	<u>Integration, Test, and Launch Support Plan Study Tasks</u>	
	1) Define the design approach to electrical integration of payload with the spacecraft. Verify feasibility of command status reporting, payload shutoff timers, slip rings.	See Volume 4, Section 12
	Electrical integration design including cabling and junction boxes is straightforward. Command status reporting will be provided on all new commands. Payload shutoff	

Task	Task Description	
	timers protect the system if an off command is not received. Payload status will be provided by payload design. Existing commands held over from OGO are largely reported on telemetry as described in our June 1969 proposal, Appendix K, page K-55. Slip rings will not be used.	
2)	Perform brief review of potential electrical and radio frequency interference problems between payload and spacecraft.	See Volume 4, Section 12.5
	Potential electrical interference has been studied and with normal care can be controlled.	
3)	Develop plan for integration of the spacecraft and payload, the proposed testing, facility requirement, and launch support. The plan will include sequence, required test items, schedule, and facility requirements.	See Volume 12
	A summary of the integration and test plan and the launch operations plan are submitted as Volume 12 of this report. The complete plan is Part II, Volume 18 of our proposal.	
4)	Identify all spacecraft functions not demonstrated in all-up spacecraft testing.	See Volume 4, Section 16.6
	The only identified all-up testing omissions tend to be straightforward, and those functions will be verified in other tests.	
5)	Study revised environmental specification and its impact on subsystem and spacecraft testing. Verify and confirm with GSFC that spacecraft qualification is not required.	See Volume 4, Sections 4.2 and 16.1

Task	Task Description	
	The results of the revised environmental specification study show that the spacecraft testing sequence encompases these values. The results are discussed in conjunction with studies of the structure. Some alternate test approaches are also discussed.	
7.13	<u>Ground Support Equipment Study Tasks</u>	
	1) Describe ground support equipment required for spacecraft and payload testing including new requirement. Explain application and define new requirements to the block diagram and interface level of detail. Portray total result on a matrix table as in Section 7.10. Include impact on the GSE of the revised specification on the communications and data handling equipment.	See Volume 4, Section 17, and Volume 3, Section 11
	The required ground support equipment, its adaptation from OGO, and its implementations have been thoroughly studied, and the results are reported.	
7.14.1	<u>System Engineering and Integration Study Tasks</u>	
	1) Review the expected requirements of each potential user in terms of areas of interest, frequency of coverage, resolution, multicolor registration, type, and volume of outputs, etc. Consider Cases A and B. Identify requirements which have a very strong impact on system design and perform tradeoff study of user needs and system specifications.	
	NASA instructed TRW not to contact users: thus this task was not done.	

Task	Task Description	
2)	In cooperation with SSD engineers, study sensor or spacecraft modifications that could facilitate GDHS design or improve its performance. Consider sensor reticles, photometric calibration techniques, refined attitude-determination devices, etc. Improved attitude determination is provided by adding a gyro. A projection reseau system was analyzed, as well as 9 x 9 pattern etched on the face. The use of RBV photometric calibration was considered.	See Volume 2, Section 4, and Volume 17, Section 2.3.4
3)	Coordinate studies which will specify a collocated OCC and NDPF. Coordinate and summarize system studies including detailed descriptions of the major functions of all major equipment down to the subsystem level, performance characteristics of all systems, and all major interfaces within the facility. The study shows the desirability of having the OCC and NDPF collocated so that the NDPF computer can back up that of the OCC and facilitate operational communication.	See Volume 15, Section 2
4)	Coordinate definition of required hardware, software, and manpower of the collocated OCC and NDPF. Identify common equipment which could provide backup. Develop the basis for OCC-NDPF integration, while maintaining their functional independence. Volume 14 describes the hardware, software, and manpower for the collocated NDPF. The basis for integration is discussed in Volume 15, Section 2.	See Volumes 14 and 15

Task	Task Description	
	5) Determine implications in terms of hardware duplications, communications problems, and performance degradation (if any) for the situation where the OCC and NDPF are not collocated. The principal impacts of non-collocation are to complicate communication and to eliminate the possibility of using the NDPF computer as a backup to that of the OCC.	See Volume 15, Section 2
	6) Perform tradeoff studies in the conceptual and detailed system design of the facility. These are to include: equipment and software commonality between OCC and NDPF; the effects of changes in the workload on performance and throughput; the use of newly developed versus state-of-the-art equipment, including NASA-GSFC equipment. System simulation, equipment calibration, and system testing will be considered in the study. A unified display is discussed in Volume 17, Section 4. Throughout the processing study, two load cases have been considered to determine throughput performance.	See Volume 17
	7) Compile preliminary specifications for all hardware to be used in the GDHS. Incorporate the results of surveys of equipment available, or in advanced state of development. Included are film recorders, annotation devices and media, displays, and computers. Include data on performance, cost, and delivery. The specification volume gives these data.	See Appendix to Volume 14

Task	Task Description	
	8) Compile preliminary specifications for all software systems required and their functional use in the GDHS. For each software system investigate requirements, develop preliminary design concepts, investigate hardware and software interfaces, and prepare flow diagrams. Systems to be included are telemetry and image data processor, data services laboratory, test and diagnostic, and operations.	See Appendix to Volume 14
7.14.2	<u>Operations Control Center Study Tasks</u>	
	1) Analyze and completely define OCC functional requirements; identify new requirements paying particular attention to the addition of unified S-band equipment in the SSD. Also investigate the impact if the video tape recorder is deleted. The unified S-band places no new requirements on the OCC except for the word format. This is described in Volume 16, Section 6. See Volume 16, Section 13 for an analysis of the effects of removing the recorder.	See Volume 16, Sections 1, 6, 7, and 13
	2) Define and verify identified types of data needed in OCC. Refine data handling procedures and processing techniques. Volume 16, Section 4 defines the types of data needed to operate the spacecraft. Weather and user request data is described in Sections 7 and 12.	See Volume 16, Section 4
	3) Perform detailed analysis of computer system type and size requirements for the OCC. Generate OCC computer system specification with consideration for compatibility with the NDPF computer. Included as part of ADPE feasibility study and specification already delivered to NASA.	See ADPE feasibility study and specification

Task	Task Description	
	4) Define OCC display requirements. Review and integrate command, control, and edit capability with display system. Generate display system specifications with consideration to universal-type displays. Display requirements in the OCC have been defined and compared with those of the NDPF. Based upon these, a common digital TV system has been studied.	See Volume 16, Section 8, and Volume 15, Section 4
	5) Complete identification of ancillary hardware items (data handling equipment, special storage devices, etc.) required for the OCC. Generate ancillary hardware specifications.	See Volume 14, Section 2.6
	6) In conjunction with SSD engineers, define ERTS peculiar equipment required at STADAN or MSFN stations and generate hardware specifications.	See Appendix to Volume 14, and Volume 16, Section 13
	7) Define the types of software required and their functional use in the OCC. For each software system investigate requirements, develop preliminary design concepts, investigate hardware and software interfaces, and prepare flow diagrams. Programs to be included are: • Spacecraft utilization scheduling software • Command generation and validation software • Telemetry processing software • Spacecraft performance monitoring software • Sensor-coverage evaluation software • System simulation software • Test and diagnostic software	See Volume 16, Section 9

Task	Task Description	
	Volume 16, Section 9, defines the types of software required. Characteristics of software flow diagrams, etc., are presented in Volume 14.	
8)	Investigate ground facilities scheduling software needs; consider the dual interfaces between STADAN and MSFN. Survey existing NASA-owned scheduling software for applicability. Recommend an approach to the scheduling task (include flow diagrams demonstrating support objectives).	
	No firm requirement was established for such software. It has thus been eliminated from the system.	
9)	Define the sizing, speed, etc., of the computational capability required for forecast/predict orbital position from NASA-furnished orbital elements.	
	NASA will supply the predictions; the required capability is thus zero.	
10)	Identify and analyze hardware/software and other tradeoffs required in the OCC design. Consider space utilization, redundancy/reliability, efficiency utility, etc.	See Volume 16
	Software tradeoffs and selected hardware areas were analyzed.	
11)	In cooperation with SSD engineers, specify a spacecraft simulator system designed to allow checkout of compatibility and operations between the spacecraft and STADAN, MSN or NTTF ground stations, and between ground stations OCC and NDPF. Investigate feasibility of using actual spacecraft components in the simulator system. Provide design concept formulation for the simulator, specifying hardware and software components.	See Volume 16, Section 11

Task	Task Description	
	The requirements for spacecraft simulator are developed in Section 11 of Volume 16. Spacecraft components to be employed are listed therein. Spacecraft PCM telemetry tapes will be used for training and checkout of ground station and OCC.	
12)	Identify each OCC function to be performed and provide a description of each position. Generate an OCC staffing plan in accordance with these results.	See Volume 16, Volume 11, and Volume 13, Section 1.3
	The OCC requires 40 people; functions have been identified. Positions were selected on the basis of a 24-hour, 7 days per week operation.	
13)	Generate detailed time-based outline of preliminary operational procedures. Generate an ERTS launch operations plan demonstrating procedures for acquisition, stabilization, and orbit trim. Generate an ERTS utilization plan demonstrating a typical 18-day operations cycle assuming maximum coverage and taking into consideration spacecraft power, recorder management, and other constraints.	See Volume16, Appendix A, and Volume 16, Section 3
	The plan for operating the spacecraft is given in Volume 16, Section 3 and Appendix A. Typical operations are evaluated from a standpoint of spacecraft power tape recorder life, etc., in Volume 16, Section 3.	
14)	In conjunction with Task 7.14.3.1(12), consider the advantages and disadvantages of carrying out all spacecraft and sensor telemetry processing in the OCC rather the TIDP.	See Volume 14
	Study was done. PCM telemetry will be processed in the OCC.	

Task	Task Description	
7.14.3.1	Telemetry and Image Data Processing Study Tasks	
	1) Refine distortion model of image handling system from ground scene to TIDP receipt including geometric and radiometric consideration. Distinguish between RBV and MSS imagery.	See Volume 17, Section 2.2
	A comprehensive study has been made of the errors of both sensors.	
	2) Analyze techniques for the use and value of identified terrain features in locating imagery, correcting attitude data, and removing distortion.	See Volume 12, Section 5.3.3
	An algorith has been developed and evaluated to incorporate ground truth data to correct RBV and MSS.	
	3) Consider the degree to which distortions can be removed while recording on film from video tape by modulating recording beam intensity and/or position using a priori or real time distortion data and a process computer. The input data would include sensor calibrations, previously established disturbance torques predictions, spacecraft telemetry, and other pre-evaluated parameters.	See Volume 17, Sections 2.1, and 2.8
	This type of correction requires an electron beam or CRT recorder. Since the form of reproducer selected is a laser beam recorder, this method of distortion correction is not applicable.	
	4) Review candidate techniques and equipments creating film copies from RBV and MSPS video signals. Consider electron-beam and laser-beam recorders. Consider photometric and geometric fidelity, ease of beam and/or intensity modulation, and throughput.	See Volume 17, Section 2.8
	The study examined laser-beam electron-beam, incoherent light-beam, and CRT recorders. The optimum choice is a laser-beam recorder.	

Task	Task Description	
5)	Study and analyze the use of available digital image processing equipment including conversion, storage, display, special processors, and reproduction devices. Identify effects on quality and throughput expected as well as new state-of-the-art devices needed. The study examined a wide array of devices and techniques. These are described in Section 2.3 through 2.9.	See Volume 17, Section 2
6)	Study the removal of errors based on information within the image using available correlation techniques. Study the suitability of existing equipment such as ARES and EROS. Prepare preliminary specifications in terms of components, input, output, film sizes, and definition of imaging chain. The study shows that the best approach to correction using internal data is based on a 9 x 9 reseau. Available optical devices were surveyed (Section 2.4) and film size was selected as 9" x 9"; the rationale for this and the image chain are given in Section 5.	See Volume 17, Sections 2, and 5
7)	Survey and analyze the use of available digital image processing techniques such as image calibration, appropriate map projection conversion, gridding, distortion removal, scaling, enhancement, and registration. Identify output quality achievable, throughput, and algorithm applicability.	See Volume 17, Section 2
8)	Consider application of methods of photo-restitution using a digitally provided control image including methods of preparation of the control image.	See Volume 17, Section 2

Task	Task Description	
	This method is, in essence, the one used in Bulk Mode II. The digitally provided control image has been replaced by digital signals driving the PPR as a printer. In precision mode, a processed RBV image is used to generate error signals to improve MSS yaw corrections.	
9)	Using the results of the previous eight tasks, establish level of distortion removal (i.e., registration, geometric, photometric, and orthophotometric) appropriate for bulk and precision image processing, based on degree and ease of processing techniques available and throughput. Consider use of computer, analog correlation of scene detail, use of ground truth, and photographic manipulation of image. Evaluate two approaches for bulk processing, one with minimum requirement for either geometric or radiometric distortion correction; the second with such corrections as are appropriate for the degree of registration desired. Also evaluate the two approaches to precision image processing one using occasional ground truth and ACS telemetry data and the other using the best ground truth and a precision attitude determination system. A family of techniques was developed for both bulk and precision processing; a tradeoff was then performed to optimally select the two bulk modes. Ground truth introduction has also been studied.	See Volume 17, Sections 2, 3, and Volume 2, Section 5.3
10)	Identify annotation data requirements such as position and orientation of image, lighting conditions, time and date, location, etc. Consider types of data needed and provide required annotation information, including orbit, attitude, and calibration. Identify source of such data, including MFP-A, spacecraft telemetry, and the image itself. Define system requirements needed to assure that the	See Volume 17, Sections 2.7, and 3.5, and Volume 14, Section 4.1

Task	Task Description	
	data is provided including system hardware and software. Consider alternate annotation schemes to those suggested by NASA/GSFC and make recommendations for a preferred scheme. The annotation requirements were studied; the annotation content and sources of data were defined.	
11)	Define a procedure for preparation of 100 x 100 mile prints from MSS imagery with 10-mile overlap. Consideration will be given to the problem of having these prints cover the same areas as corresponding frame of RBV imagery. The MSS images are "sliced" into pictures which have the same coverage as the corresponding RBV pictures. Overlap is provided, just as with the RBV images.	See Volume 14, Section 3.1.5.2
12)	In conjunction with Task 7.14.2(14), study and specify the requirements for narrowband telemetry data including amount of required processing, formatting, and printing. Determine quality control techniques for telemetry data and determine conversion and limit-checking techniques. Volume 24, Section 2 of the proposal cover the processing requirement. Volume 17, Section 3 of the study covers formatting, storage, and retrieval.	See Volume 17, Section 3
7.14.3.2	<u>Data Services Laboratory Study Tasks</u>	
1)	Based on a system analysis, specify the information files required in the DSL. For example, index/abstract catalog, master digital data, ground reference data, digital image data, archive location index, and management production control. This specification will also include file maintenance, retrieval (including Boolean logic), output procedures, and formats.	See Volume 17, Sections 3 and 4

Task	Task Description	
	All file structures were defined. An examination of various retrieval systems was made.	
2)	Perform a survey and tradeoff analysis of available data management systems for use by the DSL. Specify the system that best satisfies the requirements of the NDPF. A number of data base systems were studied. The final choice will depend on the final computer selection.	See Volume 17 Section 4.3
3)	Specify image-indexing techniques, including automatic computation from ephemeris data and use of ground features (four to five points per swath) to improve location accuracy of index. An indexing scheme has been developed for retrieval based on PCM data processing. See also Volume 2, Section 5.3.3 for use of ground truth.	See Volume 17, Sections 3, and 4.3.3
4)	Study and tradeoff use of digital index of imagery (contained in the abstract file) in conjunction with the montage catalog. Include possibility of some users performing searches with their own computers. The digital records required to define the available imagery will be in a form usable by anyone with compatible equipment (Section 4.3.4); the basic method of identification will be the montage (Section 5.11).	See Volume 17, Sections 4 and 5
5)	Study and specify requirements for handling DCS data including techniques for correlation with RBV and MSS imagery. DCS data and ERTS imagery can often be used well together. The correlation between these involves both proper annotation of imagery and a suitable storage and retrieval scheme for the DCS data.	See Volume 17,

Task	Task Description	
6)	Study and propose preferred methods for digitizing imagery and for shipping image data in digital form. An examination was made of all available storage media; high density digital tape was selected as the best overall medium.	See Volume 17, Section 4. 2
7)	Study and specify system requirements to enable the exchange of data abstracts between the users and NASA. A study has been made of user abstract exchange; a recommended approach has been developed.	See Volume 17, Section 4. 3. 4. 3
8)	Study and determine requirements for abstracting screening, display, and viewing imagery in the DSL by NASA. Prepare specifications of configuration and performance of required equipment. Quality assessment will be done in the DSL but abstracting will not because of the need for specialized personnel. Display, screening, and NASA viewing is provided by the unified display system.	See Volume 17, Section 4. 3. 4. 3, and Volume 14, Section 4
9)	Perform a survey of photographic processing techniques and equipment that have application to the DSL Photo Services Laboratory. By tradeoffs considering throughput, provision for expansion of workload, quality, and cost, select candidate equipment types for inclusion in the facility. Results will contain but not be limited to specification of performance, delivery information, and configuration of the selected equipment. Selected equipment is described in Sections 5. 8 through 5. 10. The equipment specified is commercial, and thus requires no procurement specifications since equipment is defined by maker and model number.	See Volume 17, Section 5

Task	Task Description	
10)	Survey and perform tradeoff study to determine photographic material type, format, size chemistries, and characteristics of image recording media including archival requirements considerations. The available materials were traded off against performance requirements. A 9" x 9" film size was selected.	See Volume 17, Section 5.8
11)	Analyze throughput, materials, and equipment (i.e., photo laboratory system design) in terms of cost-effectiveness, volume, provision for expansion of workload, quality, and workload variations. The production output is described in Section 5.4.2.	See Volume 17, Section 5
12)	Study the application of a multiple print photographic material such as the Itek RS process for the introduction of annotations in the photo laboratory. The need for this type of material was examined; because of the annotation plan selected, no need was found for the material.	See Volume 15, Section 5.8
13)	Study and define procedures and equipment for preparing montage catalogs of all RBV and MSS imagery collected in an 18-day cycle. Recommend a scale for the montage. Provide means to identify the individual images comprising the montage. Section 5.11 describes the process and scale of the montage.	See Volume 17, Section 5.11

Task	Task Description	
	14) Provide a design of the photographic processing capability including all working photographic services. Define information and equipment interfaces including introduction of annotation in the photo laboratory. Section 5 describes the photo processing facilities; we will do annotation in the PPR or LBR rather than the photo laboratory (see Sections 2. 4 and 2. 8).	See Volume 17, Sections 5, 2. 8, and 2. 4
	15) Study and specify a production control system to perform scheduling, data accounting, and request management. A complete plan for production control has been defined.	See Volume 17, Section 4. 4
	16) Perform study and analysis of various map projections for advantages/ disadvantages to user agencies. Recommend a specific map projection system. Various projections were examined; the UTM projection was selected for routine projection. Oblique mercator available on request.	See Volume 17, Section 2. 1
	17) Investigate and define archival storage media and retrieval methods for those digital data determined to require such techniques for efficient operations. Digital data will be stored in the form of magnetic tapes and in high density disk files.	See Volume 17, Section 4. 3
7. 14. 4	<u>Facility Design Study Tasks</u>	
	1) Establish a detailed listing of all equipment, work spaces, facility accesses, etc., needed to define the ingredients of the GDHS. Equipment is listed in Section 2 of Volume 22, and in the listings of Volume 22A. Space allocation and access is discussed in Section 2, the facilities plan.	See Proposal Volume 22

Task	Task Description	
2)	Review the design and performance of NASA/GSFC-developed equipment and other equipment, existing or under development to determine if it can be used efficiently in the facility. The PCM data handling equipment is a standard unit. Section 3 discusses the MSS demultiplexing equipment which is NASA provided. No requirement for payload test equipment has been established within the GDHS.	See Proposal Volume 24, Sections 2, 3, and Volume 28
3)	Prepare a floor plan for the GDHS showing equipment layout, material, and information flow. Also show all associated functions such as quality control, production control, maintenance, and accounting. The overall floor plan is presented in Figure 1-1, which also shows the location of all functional areas and equipment. Information and work flow is shown in Section 2.	See Proposal Volume 22
4)	Specify requirements for power, lighting, sound reduction, air-conditioning, humidity control, water, drainage, and floor support. Supply estimate to GSFC as soon as possible. Electrical requirements are described in Section 6; air conditioning, humidity control, water, drainage, and floor support are shown in Section 5.	See Proposal Volume 22
5)	Study and propose an input/output patch and switching system for maximum utilization and flexibility of equipment. An analysis has been made of the patch and switching; an optimum configuration is proposed.	See Proposal Volume 24, Section 5

Task	Task Description	
	6) Prepare a staffing plan including an estimate of manpower costs for the operation and maintenance of the GDHS with a brief description of each function. The GDHS has 189 personnel, based on Case A (5 days per week in NDPF).	See Volume 13, Section
	7) Prepare an estimate of material requirements and costs, such as type, quality, annual usage of film, photographic paper, chemicals, strip charts, magnetic tape, etc. Data quantity requirements have been established.	See Volume 13, Section 2
	8) Prepare a plan for installation, system checkout, performance evaluation, and operations of the facility for ERTS-A and -B. A GDHS integration and test plan has been developed. Further description of operation is found in Volume 30 of the Proposal.	See Volume 12, Section 3
7.15.1	<u>Total Thematic Mapping Accuracy Study Tasks</u>	
	1) Study total thematic accuracies expected from each sensor by parametric simulation of sensor image generation continued refinement of overall error function including computer model, and computer analysis for various parametric conditions of interest. For each data processing mode, error analyses were performed to obtain overall system mapping and photometric accuracies for both MSS and RBV payload.	See Volume 2, Section 5

Task	Task Description	
	2) In coordination with SSD and GDHS engineers, refine analysis of total communications link as it affects picture quality. The total communications system has a secondary effect on S/N degradation.	See Volume 2, Section 5.6