SYSTEM DESIGN REPORT FOR INTERNATIONAL ULTRAVIOLET EXPLORER (IUE)

VOLUME III
GROUND SYSTEM PLAN

DECEMBER 1974

GODDARD SPACE FLIGHT CENTER
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FOREWORD

The System Design Report for International Ultraviolet Explorer (IUE) is a three-volume document. This volume (Volume III) covers the ground system in detail, with the emphasis on the U.S. Ground Observatory. Volumes I and II contain a detailed description of the scientific instrument (telescope) and the spacecraft, respectively. A number of changes have been made to the scientific instrument, the spacecraft, and the ground system since the Phase A Report was published in March 1971. Significant changes that affect the ground system are discussed in this volume. Mission analysis, which affects the ground system as well as the spacecraft, is covered in detail in Volume II, Section 7.

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SECTION 1
GENERAL DESCRIPTION

1.1 GENERAL

The IUE Observatory consists of the flight system plus the ground system (see Figure 1.1-1). The flight system is the spacecraft including the scientific instrument (telescope). The spacecraft is one of NASA's Explorer series spacecraft. The ground system includes the U.S. Ground Observatory and the European Ground Observatory.

The U. S. Ground Observatory will be located at the Goddard Space Flight Center (GSFC), Greenbelt, Md. An overview of the U.S. Ground Observatory is given in Section 2 of this volume. Other sections contain detailed information on the U.S. Ground Observatory.

The European Ground Observatory will be built and operated by the European Space Research Organization (ESRO). Information on the European Ground Observatory is provided in Section 8.

1.2 SPACECRAFT

Details of the IUE scientific instrument and the spacecraft are provided in Volumes I and II, respectively, of the System Design Report. A brief description of the spacecraft (including the telescope) is included here for background information.

The spacecraft will be located in an eccentric geosynchronous orbit with an inclination of about 28 degrees. The spacecraft will be placed on station so that it is visible to the U.S. Ground Observatory 24 hours per day and the European Ground Observatory about 10 hours per day. This locates the point that the spacecraft crosses the equator moving south to north at approximately 50^{o} to 60^{o} west longitude.

The scientific instrument is a 45-cm-diameter telescope of f/15 Cassegrainian design using an echelle spectrograph for ultraviolet astronomy in the spectral region between 1150 and 3200Å.

The three-axis-controlled spacecraft will be able to point anywhere on the celestial sphere with an accuracy of ±1 arc-second, excluding a cone that has a 43-degree half angle centered on the spacecraft sunline. The control system will be able to repoint the telescope to a new target star over a fairly wide angle (up to 60 degrees) with a rate of 4 to 5 degrees per minute per axis and guarantee that the desired new

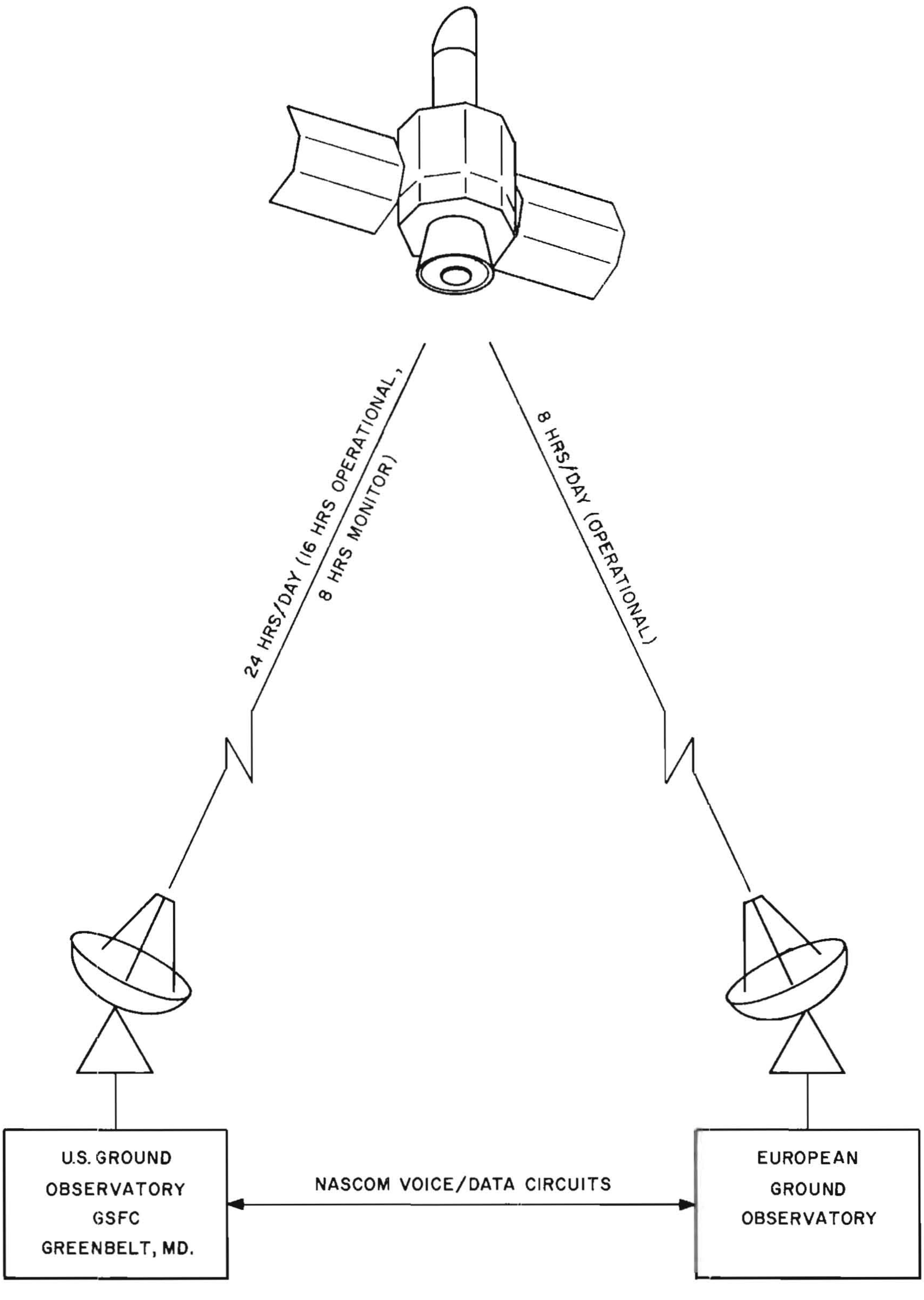

Figure 1.1-1. IUE Observatory Overall Block Diagram

target star falls within 2 arc-minutes of the center of the field of view of the acquisition camera. To perform spectroscopy on the faint stars with the desired resolution, the control system will hold a 1-arc-second-diameter star image within a 3-arc-second-diameter spectrograph entrance aperture as long as the star remains unocculted by the earth or the $\pm 43^{\circ}$ circum-solar zone.

The primary attitude sensor is the inertial reference assembly (IRA). Coordinate transformation and attitude control is done by an onboard computer. Control torques are provided by a momentum exchange system using three conventional reaction wheels arranged in an orthogonal triad. Telescope pointing is controlled operationally by the astronomers from the ground with the aid of a ground computer.

To move the telescope to a new target, the celestial coordinates of the new target are inserted into the ground computer. The ground computer calculates magnitude and direction of the pitch, yaw, and roll slews required to move the telescope to the new target. Through a series of ground commands, the spacecraft is instructed to perform the slews, one axis at a time, using the IRA as a reference. The IRA cannot preserve the inertial reference to 1 arc-second over slews of many degrees, and thus a procedure must be used to guide the telescope to point to the desired star. However, fairly large slews will be sufficiently accurate to insure location of the new target within 2 arc-minutes of the center of the field of view of the main telescope. After completion of the slew, the acquisition camera is exposed and the field image is relayed to the ground by the spacecraft telemetry system. The image is recorded in the ground computer and displayed on the experiment display. From the pattern, coordinate changes can be derived to correct the pointing to the desired star. The principle of operation resembles that of the finder telescope used with ground-based telescopes.

1.3 GROUND SYSTEM

The spacecraft will be visible to the U.S. Ground Observatory 24 hours per day and visible to the European Ground Observatory at least 10 hours per day. The spacecraft will be controlled from the U.S. Ground Observatory 16 hours per day and from the European Ground Observatory 8 hours per day. During the period that the spacecraft is under control of the European Ground Observatory, the spacecraft telemetry will be monitored by the U.S. Ground Observatory. In case of a spacecraft malfunction or a problem in the European Ground Observatory, the U.S. Ground Observatory will assume control of the spacecraft.

1.4 GROUND OBSERVATORY CONCEPT

The U.S. and European Ground Observatories will be designed to take advantage of the geosynchronous orbit and function with the spacecraft in such a way as to resemble a modern ground observatory as much as possible. Since the guest observers are familiar with this operation, they will be able to come to the U.S. or European Ground Observatory and, with a minimal amount of training, take an active part in the real-time control of the spacecraft and the offline processing of the image data. This approach has the added advantage that the guest observer will have the flexibility to take advantage of observing opportunities as they arise rather than depending on the pre-planned automatic sequences that are required with a near-earth satellite. The guest observer will be able to leave the observatory within 24 hours with the reduced image data. Experienced observatory personnel will assist the guest observer in target acquisition and image processing.

1.5 CHANGES TO PHASE A REPORT

Although the basic concept of the IUE (formerly SAS-D) Observatory has not changed since the Phase A Report was published in March 1971, a number of changes that affect the ground system have been made:

- The Phase A Report showed the IUE ground station located at the Rosman, North Carolina, STDN Station. The station will be located at the Network Test and Training Facility (NTTF) at GSFC. The dual 14-foot antennas shown in the Phase A Report will not be used for S-band support. See Section 4 for details of the station configuration.
- Two XDS Sigma 5 computers located in the OCC were shown in the Phase A Report. One XDS Sigma 5 and one XDS Sigma 9 computer will be used.
- The network configuration used to support the spacecraft during the transfer orbit has been changed. See Section 9 for details.

In addition, a significant change has been made in the spacecraft configuration since Volume II (Spacecraft Design) of the System Design Report was published in September 1973. The telecommunication subsystem now consists of two (redundant) VHF transponders and two S-band transmitters. All command and range and range rate support of the spacecraft will be done using the VHF link. The VHF telemetry link will be used during the transfer orbit and as backup during the mission orbit. The S-band link will be the primary telemetry link during the mission orbit. The telemetry data can be transmitted either uncoded or convolutionally encoded. Present plans are to transmit uncoded data as the prime mode during the mission orbit. Convolutionally encoded data will be transmitted only if the communication link cannot support uncoded data. During the transfer orbit the VHF telemetry data will be uncoded.

SECTION 2
U.S. GROUND OBSERVATORY

2.1 GENERAL

The U.S. Ground Observatory (see Figure 2.1-1) consists of the ground station, the Scientific Operations Center (SOC) and the Operations Control Center (OCC). Details of the U.S. Ground Observatory are provided in Figures 4.2-1 and 5.2-1.

2.2 GROUND STATION

The ground station is located at the Network Test and Training Facility (NTTF) at the Goddard Space Flight Center (GSFC). The station will be in contact with the spacecraft 24 hours per day when it is in mission orbit. Telemetry and command capability will be provided at the station. Cables between the station and the OCC will be used to transmit telemetry, command, command verification, and station monitor data, in real-time. Redundant telemetry and command capabilities will be provided at the station. Details of the ground station are shown in Section 4.

2.3 SCIENTIFIC OPERATIONS CENTER

The Scientific Operations Center, located at GSFC, consists of the Telescope Observing Center (TOC), the Image Processing Center (IPC), and the Observer Support Area. Section 5 shows details of the SOC.

2.3.1 TELESCOPE OBSERVING CENTER

When the initial spacecraft checkout phase of the mission has been completed, operation of the spacecraft and the experiment will be switched from the OCC to the TOC for normal scientific operations. During this phase of the mission the spacecraft and the experiment are operated from the TOC through the OCC C&C Computer. The function of the spacecraft control consoles in the OCC becomes one of spacecraft performance monitor, command surveillance, and general support to scientific operations. The normal TOC functions are as follows:

a. The preobserving-run preparation, planning, and training.

b. The selection of target stars.

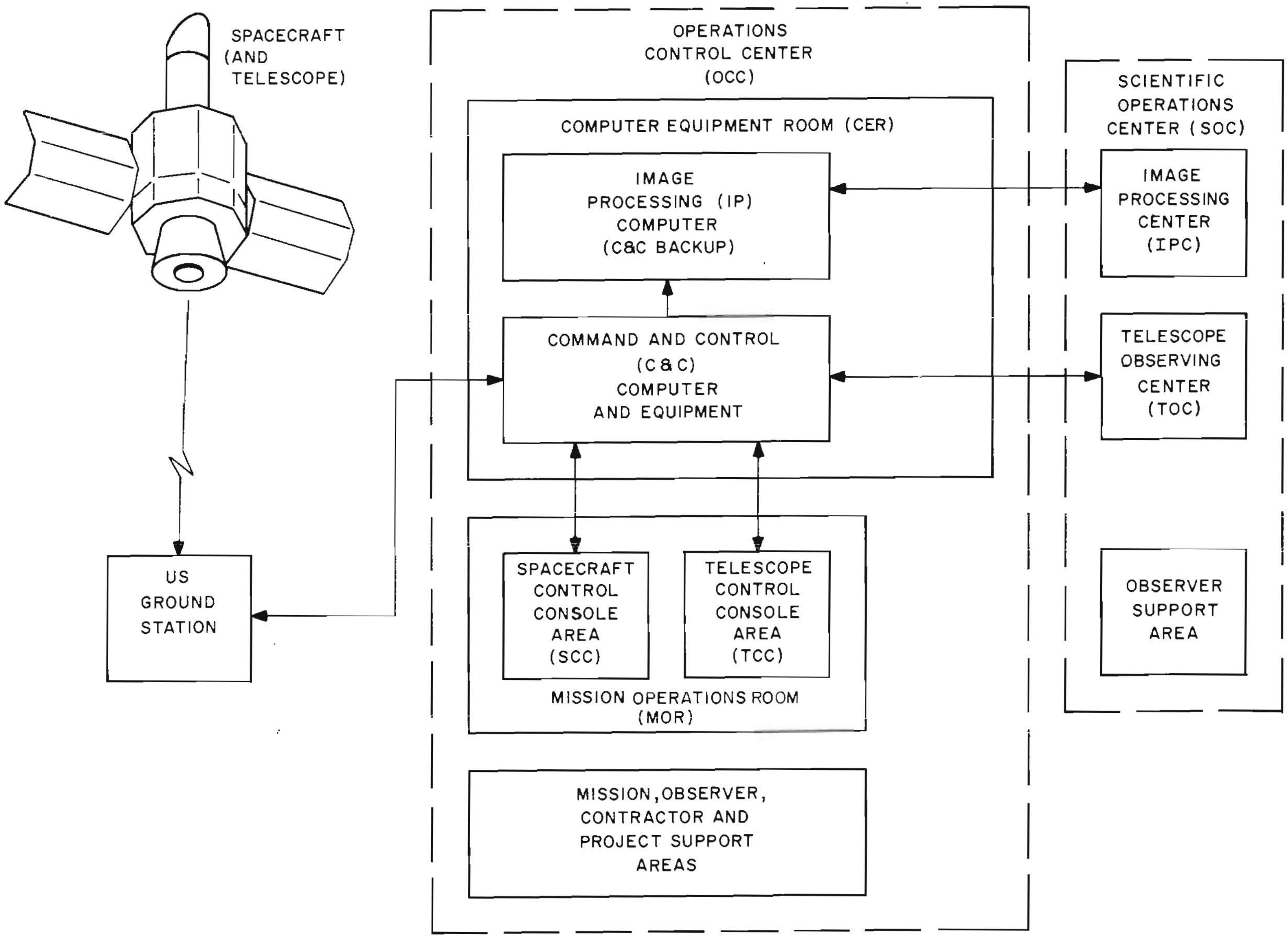

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Figure 2.1-1. U.S. Ground Observatory Block Diagram
(Backup Switching Not Shown)

c. The display and identification of targets and star fields on the acquisition camera display.

d. The initiation of spacecraft slews and experiment exposure sequences.

e. The quick-look presentation of scientific data at the end of each exposure.

The TOC has been designed to allow a guest observer with no previous experience in making orbital observations to exercise direct control over the spacecraft and make real-time judgements pertaining to the execution of his observing program. Experienced resident staff observers, assistants, and operators will support the guest observers throughout all phases of his program.

2.3.2 IMAGE PROCESSING CENTER

An interactive console in the IPC that interfaces with the image processing computer will be provided for controlling the processing of the image data. The guest observer with the assistance of resident personnel will supervise the processing of his data offline after his observing period has ended. Normally the guest observer will have all of his data processed within 24 hours after the end of his observing period.

2.3.3 OBSERVER SUPPORT AREA

In addition to the TOC and the IPC, the SOC will also contain an Observer Support Area. This will contain office space for guest observers and resident personnel, a library, chart and catalog room, plus space for additional hardware to generate hard-copies and strip-charts.

2.4 OPERATIONS CONTROL CENTER

The OCC will be located at GSFC in a different building from the SOC. The OCC consists of the Mission Operations Room (MOR), the Computer Equipment Room (CER), and support areas for mission, observer, project and contract personnel. Section 5 contains detailed information on the OCC.

2.4.1 MISSION OPERATIONS ROOM

The MOR contains the spacecraft control console area (SCC) and the telescope control console area (TCC).

2.4.1.1 Spacecraft Control Console Area

The SCC contains display devices that interact with the primary or backup command and control computer. The normal functions of the SCC are as follows:

a. To operate the spacecraft during the launch, transfer orbit, and checkout phases of the mission.

b. To perform all command and control functions necessary to operate the spacecraft during its lifetime.

c. To continuously monitor the engineering status of the spacecraft.

d. To assume complete control of the spacecraft if an emergency occurs.

2.4.1.2 Telescope Control Console Area

The TCC will be used by resident and (when applicable) guest observers for spacecraft/telescope control during the initial checkout phase, during special observing periods, and in emergency situations. During normal observing periods resident and guest observers will be located in the TOC. The Project Manager will determine when a normal observing period exists.

2.4.2 COMPUTER EQUIPMENT ROOM

The Computer Equipment Room (CER) houses the command and control (C&C) computer, the image processing computer, and associated equipment. The CER will interface with the ground station via cable for telemetry, command, command verification, and station monitoring. A Data Operations and Control Area (DOC) located within the CER will be used to switch signals between the stations, the two computers, the SOC, and the MOR.

2.4.3 SUPPORT AREAS

Additional office space will be provided for mission, observer, project, and contractor personnel.

SECTION 3
OBSERVATORY OPERATIONS

3.1 GENERAL

This section presents in detail the various aspects of normal observatory operations. The emphasis in the chapter is directed to IUE-unique operations, although various standard operational procedures are mentioned.

After the spacecraft has been inertially stabilized and engineering checkout has been completed, the observatory will start a normal two-shift operation, with the third shift monitoring the spacecraft health and maintenance of the OCC hardware. During the third shift, control of the spacecraft will be transferred to ESRO. During this period the IUE ground station at NTTF will receive spacecraft telemetry data and transmit it in real-time to the OCC. The OCC will monitor the health of the spacecraft. In case of problems with the spacecraft or the European Ground Observatory, the U.S. Ground Observatory will assume control of the spacecraft.

NOTE

> The shifts discussed in this section are for 8-hour periods; however, they will probably not start at 0800, 1600, and 2400 hours.

The normal two-shift operational day is composed of a sequence of target episodes which vary in length according to the exposure time required at each target. Each target episode is composed of slewing, acquisition, exposure, and data readout phases.

Figure 3.1-1 details these phases of normal operations during a target episode. Since important observatory activities proceed in parallel, the operations diagram has been prepared in the form of parallel timelines for each function.

The following are major events in the timeline sequence:

a. While the spacecraft is observing some previous Target A (timelines 2 and 3) during the interval t = 0 to t = 40, the observer is selecting and setting up his activity for Target B (timeline 1).

b. At t = 40, the data from Target A is sent to the data reduction storage disk, where it is held for batch processing on the image processing computer.

c. At t = 40 to t = 45, Target A quick-look data is displayed and checked by the observer.

d. The spacecraft performs a slew from Target A to Target B from t = 45 to t = 55.

e. Target acquisition and experiment test exposure take place during the interval from t = 55 to t = 60.

f. At t = 60, exposure begins on Target B and the observer begins to select and set up for Target C.

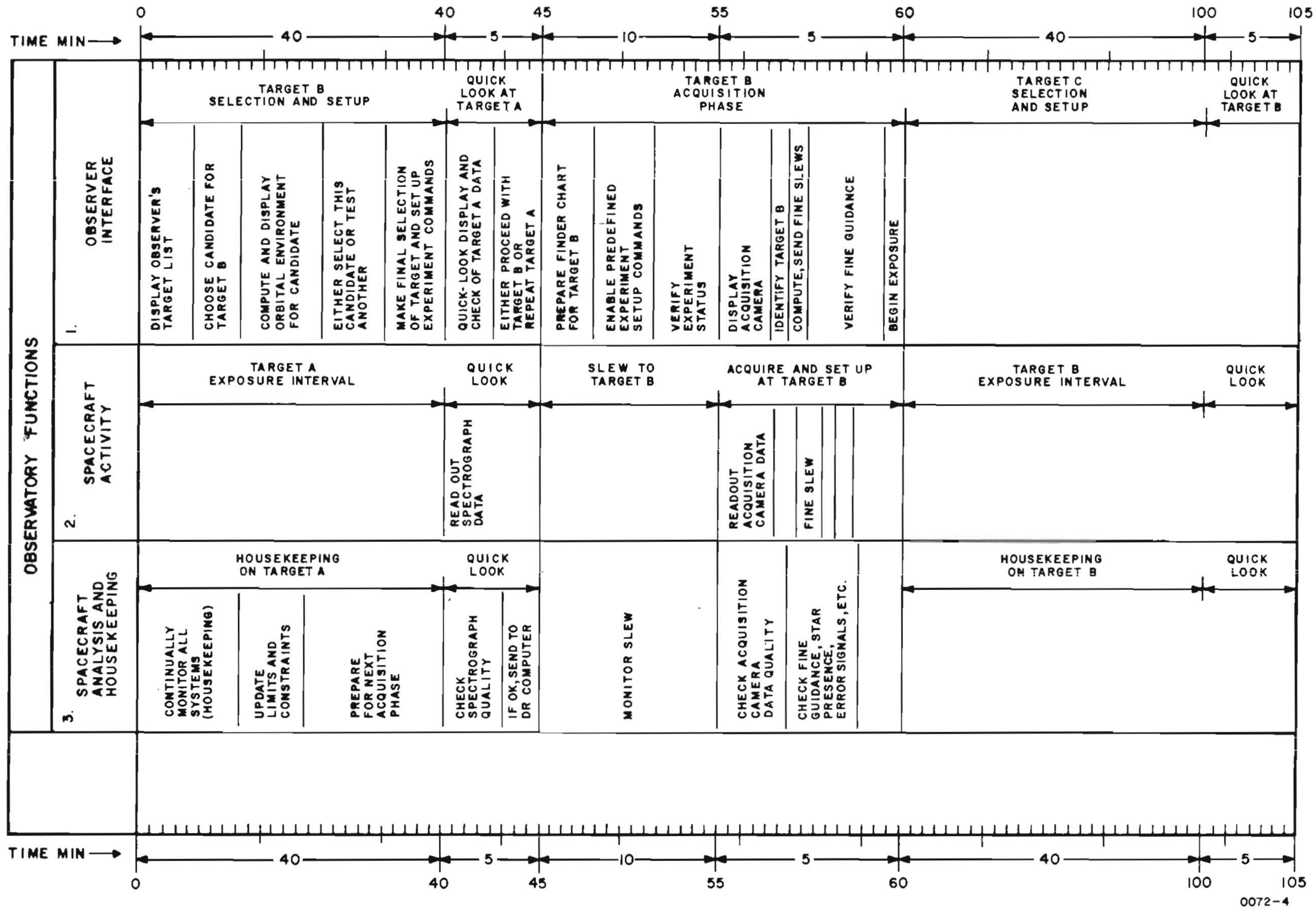

Figure 3.1-1. IUE Normal Scientific Operations Timeline

The remainder of this section is devoted to explaining features of target episode operations given in the timeline, describing other observatory functions, and describing the interface between the OCC and the U.S. ground station and the European Ground Observatory.

3.2 SCIENTIFIC OPERATIONS

The implementation of guest observer programs is accomplished in two stages. The first stage, called preobservation planning, is executed prior to a guest observer's arrival at the observatory. The objective of this planning is to maximize the number of primary targets that can be obtained in a single observing visit. The second stage covers the routine daily operational planning and execution of the observer's program.

3.2.1 PREOBSERVATION PLANNING

The viewable areas of the celestial sphere are restricted at any point in time by the positions of the sun, moon, and earth, and by the configuration of the spacecraft sun baffle. The sun baffle is designed to permit observations anywhere in the celestial sphere except for an 86-degree full angle cone centered about the spacecraft sun line and directed toward the sun. The earth moves around the sun at approximately 1 degree per day; therefore, a specific target will be occulted for a maximum of 86 days in 1 year. Sky area availability information will be compared with the guest observers' target lists, and each observer will be scheduled time when the majority of his primary targets are viewable.

Guest observers will be notified of their scheduled time and the time allotted for their observing run several months in advance. They will receive appropriate sky availability charts, and a brief description of expected instrument performance characteristics.

Target lists and star charts as well as finder field overlays will be generated for each guest observer prior to the start of his scheduled run. The target list and star charts will be available in hard-copy form for the observer. The finder field overlays may be produced in a hard-copy form or displayed directly on the experiment displays by the computer. Whole-sky charts will show the program targets as well as available viewing areas. Finder chart prints and overlays will be produced to the same size and scale as the acquisition camera field of the telescope.

TV monitors that display the output of the experiment display will be provided in the SOC to familiarize the guest observers with the display prior to the start of their observing period. In addition the experiment display console may be used during the

8-hour period each day that ESRO is controlling the spacecraft to familiarize the guest observers with the acquisition and display procedures.

3.2.2 ASTRONOMER/OBSERVATORY INTERFACE

The interface between the astronomer and the observatory is an interactive control/display terminal called the Target Acquisition and Observation Console (TAOC). This console, which is located in TOC, is manned for scientific operations by the telescope operator who is a specialist in spacecraft maneuvering and target acquisition and identification. The telescope operator is the equivalent of a night assistant in a ground-based observatory. The guest observer occupies a position adjacent to the telescope operator, where he can easily see the display, consult with the operator, and direct the progress of target acquisition and identification.

The guest observer and the telescope operator are in operational control of the spacecraft attitude during the acquisition and exposure phases of operations. The interactive display terminal provides the observer with spacecraft maneuvering and experiment control capability, supervised by the command and control computer, as well as all of the orbital environment and attitude information required to plan slews, identify his target, and obtain reliable observational data.

3.2.3 DAILY SCIENTIFIC OPERATIONS

The operational timeline (Figure 3.1-1) describes the important observatory functions associated with the acquisition and exposure phases of an observation. A nominal exposure time of 40 minutes on Target A is indicated. During this time interval, experiment control is not required and the time is used to select Target B and prepare the necessary command list. At the end of the exposure period for Target A, the spectrograph data is read out and displayed on the experimenter display console (TAOC) in quick-look form. If the observer is satisfied with the results, he initiates the acquisition phase on Target B.

The acquisition of Target B assumes a 3-axis slew of 30 degrees, which requires about 10 to 15 minutes. During this slew time, experiment setup commands are transmitted and verified. The finder charts and overlays are displayed. When the slew is completed, the acquisition camera is read out in the compressed mode and displayed in a few seconds. An interval of 5 minutes has been allowed for the identification of the target, using either hand-held finder charts, computer-generated finder field overlay displays, or computerized pattern recognition algorithms. Once the target star has been identified, the ground computer commands the fine slew maneuvers required to position the target in the entrance slit of the spectrograph. When target acquisition is verified, the exposure period on Target B is initiated and the selection and preparation of the next target begins.

The guest observer has access to computer programs which will provide him with the necessary information required to properly operate the spacecraft attitude and instrument systems. A list of support functions provided by the interactive control/display terminal, as well as a more detailed list of specific astronomer functional requirements, are provided in 6.2.2.

3.3 SPACECRAFT/EXPERIMENT CONTROL

This section provides an operational overview of spacecraft and experiment control. Additional detail is provided in the descriptions of the support software (Section 6).

A conceptual diagram of the observatory as it appears to the observer and the spacecraft controller is given in Figure 3.3-1. The figure illustrates the conceptually direct lines which exist between the observer, the spacecraft control consoles, and the command and control computer in normal operations. The observer interfaces with the observatory through software which is designed to be as transparent to him as possible.

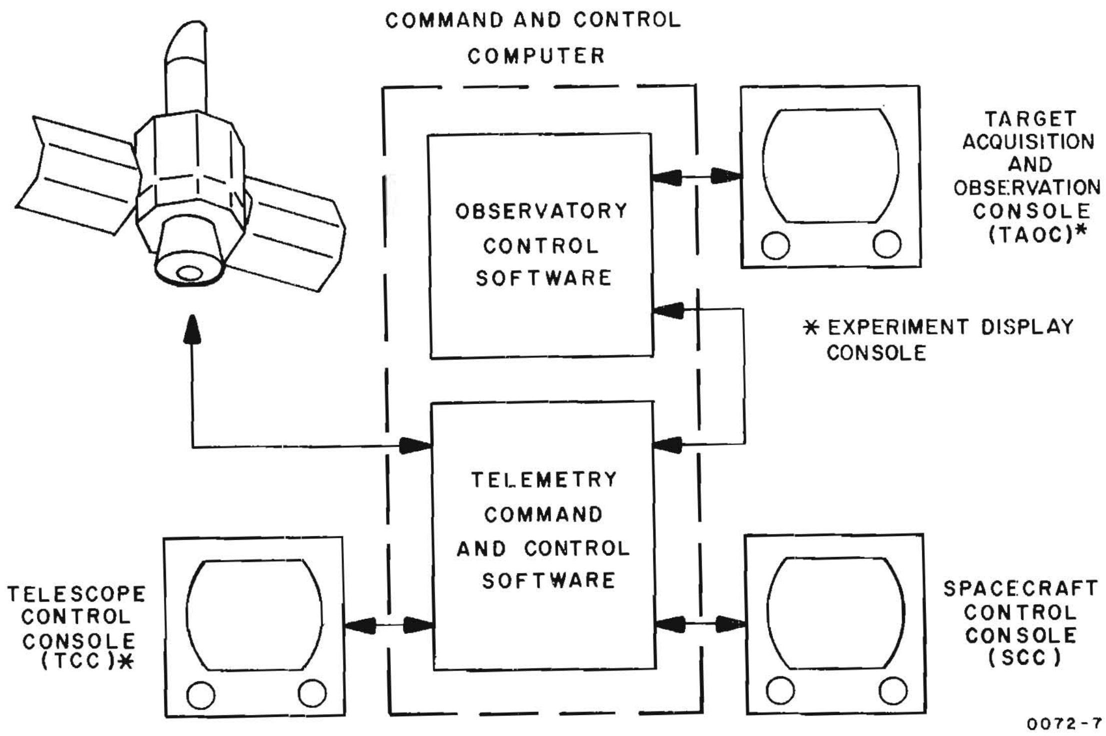

Figure 3.3-1. IUE Observatory Control

All observer requests for spacecraft maneuvers or experiment control are supervised by the computer observatory control software to ensure safety and validity, and then are passed to the telemetry, command, and control software for transmission to the spacecraft. At all times it is possible for the command controller to inhibit command transmission and assume control of the spacecraft, but normally it is expected that maneuvers and experiment activity will be allowed to pass directly through to the spacecraft after validity checks by the computer have been completed.

3.3.1 OBSERVER CONTROL INTERFACE

The interface which the observer has with the observatory is highly nonstandard when compared with past spacecraft concepts. The design intention is to give the observer as much operational control of the telescope as possible, with the only restriction being that his requests must be supervised by the computer and the command controller for safety. As long as the guest observer (assisted by the telescope operator) makes legal activity requests which fall within the scope of the term "normal," he will have control of maneuvering and telescope functions on the spacecraft. The necessary supervision will be accomplished by software computations, built-in delays, and logic switches which are normally transparent to the observer.

When the observer requests an illegal activity he will receive an error flag indication of the constraint violation. The telescope operator will be able to interpret the error and get the program back on the right track.

The observer interface (TAOC) is implemented on color graphics terminal hardware identical to the spectrograph image processing console. The support software, described in Section 6, produces interactive displays on the TAOC which will give the observer access to the entire complement of planning, maneuvering, acquisition, and status reporting software functions.

3.3.2 OBSERVATORY CONTROL COMPUTING SUPPORT

Observatory control computing support encompasses both offline and online operations. In offline operations, the support software is responsible for generating the required preobservation planning aids and for validating the guest observer's proposed program.

Most of the observatory control activity is online. Computing tasks to support the observer interface are initiated directly by the observer at his console and executed interactively. The computer provides target selection aids, either in the form of target listings or sky charts. When a target is requested, the computer validates it against all applicable constraints. If the observer desires to view the target, the computer generates the appropriate target acquisition commands. At the appropriate time, these commands are enabled by the observer for transmission to the spacecraft.

After the spacecraft has completed the slew, an acquisition camera image is taken and transmitted to the ground. This image is processed and displayed for the observer. Through a combination of automated and observer identification activities the target will be identified. Then the computer will be requested to generate the fine slew to bring the target into the spectrograph entrance slit. The computer may automatically (or the observer may manually) iterate through this procedure until the target is located in the slit.

It is extremely important conceptually to realize that the locating, as opposed to the identifying, of acquisition image features must be done by the computer. The tolerance involved is extremely tight (3-arc-second aperture in a 10-arc-minute field, or 0.5%). Acquisition of the desired target is technically feasible, probably on the first iteration, if the computer makes the fine slew calculations. This is because the computer is operating directly on the coded raw acquisition image, and hence can compute centers of light, linearity corrections, and aperture misalignments precisely.

When the observer and spacecraft controller are satisfied with the fine or offset guidance stability, the observer initiates the exposure. Typically, the observer then prepares for the next target.

3.3.3 CONTROL CENTER OPERATIONS

The Operation Control Center (OCC) bears responsibility for the safe operation of the spacecraft, and hence will always have a veto switch in line between the observer and the spacecraft. It is intended that the veto should be used sparingly and that control center operations revolve primarily around command surveillance, spacecraft performance monitoring, network interface, station-keeping, attitude operations, general support to the SOC, handover to and from the European observatory, and emergency operations.

The required housekeeping and spacecraft activity are correlated in timelines 2 and 3 on Figure 3.1-1. During the exposure interval, the control center will typically perform intensive housekeeping checks, update whatever status limits and constraints are necessary, and prepare for the next slew.

The next series of slew commands will then be sent to the spacecraft, and spacecraft systems will be monitored during the slew by the spacecraft subsystem engineers. An acquisition camera image will be taken and read out. The control center will monitor telemetry quality during readout. During the acquisition phase, the control center will monitor fine guidance, star presence, and error signals, intervening manually if necessary.

The telemetry, command, and control software required to support these and other control center functions is described in Section 6. OCC/station interface is covered in paragraph 3.6. Emergency and turnover procedures have not been formalized in this phase.

3.4 SPECTROGRAPH DATA REDUCTION

The spectrographic data reduction will be done by the Sigma 9 Image Processing (IP) computer. Present plans are to use the computer for image processing on one 8-hour shift per day, 7 days per week.

The data reduction system is designed to convert the raw spectrograph image into useful scientific information; i.e., convert the charge distribution on the target of the SEC Vidicon into intensity as a function of wavelength, I (λ). The data reduction system is not designed to analyze the I (λ) information. The guest observer will have an image processing specialist provided by the Scientific Operations Center to assist him in the data reduction of his images.

3.4.1 QUICK-LOOK DISPLAY

A quick-look display will be available when the data from one image has been transmitted to the ground and validated. This display is implemented on the interactive TAOC, which permits the guest observer, with the help of the telescope operator, to determine whether to proceed with his program or repeat the observation.

3.4.2 DATA PRODUCTS

The IUE scientific instrument is a spectrograph and hence its end product is a spectrum together with a listing that identifies the target and all status data pertinent to the observation. The spectrum will be presented in several media. This section describes the types of output that will be made available to the guest observer.

a. High-Quality Photograph. The final corrected image of the data will be converted to a photographic negative with at least as many resolution elements as the original raw data. Prints of this negative, of size 8 by 10, can be made available to the guest observer.

b. Magnetic Tape Output. Several forms of magnetic tape output will be available. The simplest form is a digital tape image of the data set that produced the high-quality photograph (8 bits per pixel). Several forms of I (λ) or I (x, y) are possible, using as many data points as there are resolution elements. The guest observer can request that the value of intensity be given in units of ergs, photons, or magnitude relative to a specified wavelength, and that the argument be given per unit wavelength or unit frequency.

c. Printed Output. A summary of the data reduction procedure applied to each image along with the relevant spacecraft and experiment status data will be provided. Estimates of the errors remaining in the data and the methods used to determine them will also be included.

d. Acquisition Field Display. A print or negative of the acquisition field display will be provided in order to verify correct star identification.

3.4.3 DATA REDUCTION ARCHIVES

The following paragraphs describe the type, volume, and lifetime of records that will be archived in the IUE Observatory Data Bank.

a. Spectrograph Images. A set of raw spectrum images annotated with spacecraft data and other information will be retained on magnetic tape for 6 months. Reduced data will be turned over to the National Data Center at GSFC after 6 months. Approximately 15 to 20 of these images will be stored on each 2400-foot tape. Calibration data tapes and information required to reconstruct the data reduction procedure will also be retained for 6 months.

   Microfilm or microfiche images of the printed output will be archived, and requests for copies will be honored for 6 months after completion of an observing run. The printed output will be destroyed when the microfilm copy is archived.

b. Acquisition Camera Images. An image of each acquisition star field will be retained for later verification of the star field and also as a training aid for new guest observers.

c. Observing Log. A historical listing of every spectrograph image obtained by the observatory will be produced. Included with the listing will be the information required to retrieve the data if this becomes necessary.

3.5 MAINTENANCE

Unless required for emergency spacecraft control, hardware will normally be available for preventive maintenance (PM) during the third shift, when the European Ground Observatory is operating the spacecraft.

It is likely that most software maintenance can be performed during the observing shifts, subject to higher priority computer loading. The ability of the computer system to support multiprogramming, discussed more fully in Section 6, will enable the software maintenance and development staffs to conduct their operations concurrently with observing activity.

Typically, data base maintenance activity represents a low level of load on the system. The data base maintenance staff will be able to access and modify the data base from small CRT terminals without interfering with the observing activity.

The program maintenance staff has a more difficult problem, however, as they typically must create test data sets that do not interfere with the system data base, and then execute test programs which may tie up considerable system resources, either intentionally or inadvertently. It is likely that policies governing the use of system resources during the observing shifts will have to be defined and enforced, and much of the program maintenance activity will have to be done on the third shift or on an alternate machine.

One aspect of data base maintenance which will require intermittent heavy computing support is calibration activity. It may be necessary from time to time to recalibrate inertial reference assembly gyros, image tubes, and the spectrograph entrance slit. Software for these calibrations is discussed in Section 6. These computations typically represent too heavy a load to be done during the observing day, and hence will have to be performed during the third shift.

3.6 OCC/STATION INTERFACE

The command and control computer will generate the command data that will be transmitted to the spacecraft. The 800-bps PCM command bit stream will be placed on the command subcarriers using the command encoder and transmitted via cable to the station.

This information will be applied to the command transmitter and transmitted to the spacecraft in real-time. As the commands are transmitted, they will be received by the station, demodulated, and the PCM/FSK-AM video returned to the OCC via cable for verification.

The telemetry signal received at the station from the spacecraft will be transmitted in real-time to the OCC via cable. The station will have the ability to decommutate and display uncoded telemetry data, if required for trouble shooting. Spare cables between the OCC and the station will be provided. A full-period voice and a NASCOM teletype terminal will be provided at the station. The voice circuit will be used to coordinate operations, and the teletype circuit will be used for administrative and operational traffic. Up to seven selected station parameters will be transmitted via cable to the OCC for monitoring by OCC personnel.

During the transfer orbit the OCC will interface with other STDN stations for telemetry, command, and command verification. During these periods the interface will be via NASCOM data link. The data will be transmitted at 7.2 kbps or 9.6 kbps in block form. NASCOM voice circuits between the OCC and the station will be used for coordination of operations.

3.7 OCC/EUROPEAN GROUND OBSERVATORY INTERFACE

The U.S. ground system will operate the spacecraft 16 hours per day. For the balance of the time, the European Ground Observatory will control the spacecraft. When the European Ground Observatory is to take over control of the spacecraft, the U.S. OCC will transmit information via data link to the European Ground Observatory as required. This data will be used to update the computer memory and enable the European Ground Observatory to assume spacecraft control. Before spacecraft/experiment control is to be transferred back to the U.S. OCC, this process will be reversed. In addition, scientific data can be transmitted between the European Ground Observatory and the U.S. OCC if required.

During the period that the spacecraft is under the control of the European Ground Observatory, the U.S. ground station will continue to receive the telemetry data and transmit it to the U.S. OCC in real-time where the spacecraft/experiment health will be continuously monitored. The time can also be used for maintenance on the image processing computer. Periodically the image processing computer will be used for spacecraft/experiment control to allow time for maintenance of the command and control computer.

SECTION 4
U.S. GROUND STATION

4.1 GENERAL

The U.S. ground station is located at the Network Test and Training Facility (NTTF) at Goddard Space Flight Center (GSFC), Greenbelt, Maryland. The ground station will provide mission orbit support for command, telemetry acquisition, and real-time data transmission to the Operations Control Center (OCC).

4.2 OPERATIONAL SUPPORT

Figure 4.2-1 is a block diagram of the station configuration. The 12-meter antenna system will provide the prime data acquisition capability for IUE. Backup S-band data acquisition support will be provided by the 9-meter antenna system used to support the Earth Resources Technology Satellite system (ERTS). The SATAN VHF telemetry antenna system will provide a secondary backup. VHF telemetry will be used in case of an emergency to maintain the health and safety of the spacecraft.

Appendix D contains the link calculations for the U.S. ground station. Figure 4.2-2 shows the ground track of the spacecraft in mission orbit.

The spacecraft will be operated 16 hours per day from the U.S. Ground Observatory and 8 hours per day from the European Ground Observatory. During both periods, the U.S. ground station will receive the telemetry data and transmit it via cable to the OCC, where it will be inputted to the command and control computer and processed. During the period that the European Ground Observatory is controlling the spacecraft, the OCC will monitor the health of the spacecraft. In case of emergency, the U.S. ground station will be prepared to transmit commands generated in the OCC to the spacecraft within 30 minutes.

The primary mode of data transmission for the IUE spacecraft during the mission orbit is uncoded S-band telemetry data. The spacecraft/ground station system has been designed so that the spacecraft normally operates in this mode. The discussion of bit error rate (BER) and link margins in this section and in Appendix D are based on the use of uncoded telemetry data. The spacecraft has the capability to transmit convolutionally encoded data (data rate is 1/2 transmit rate) with a constraint length of 24 bits.

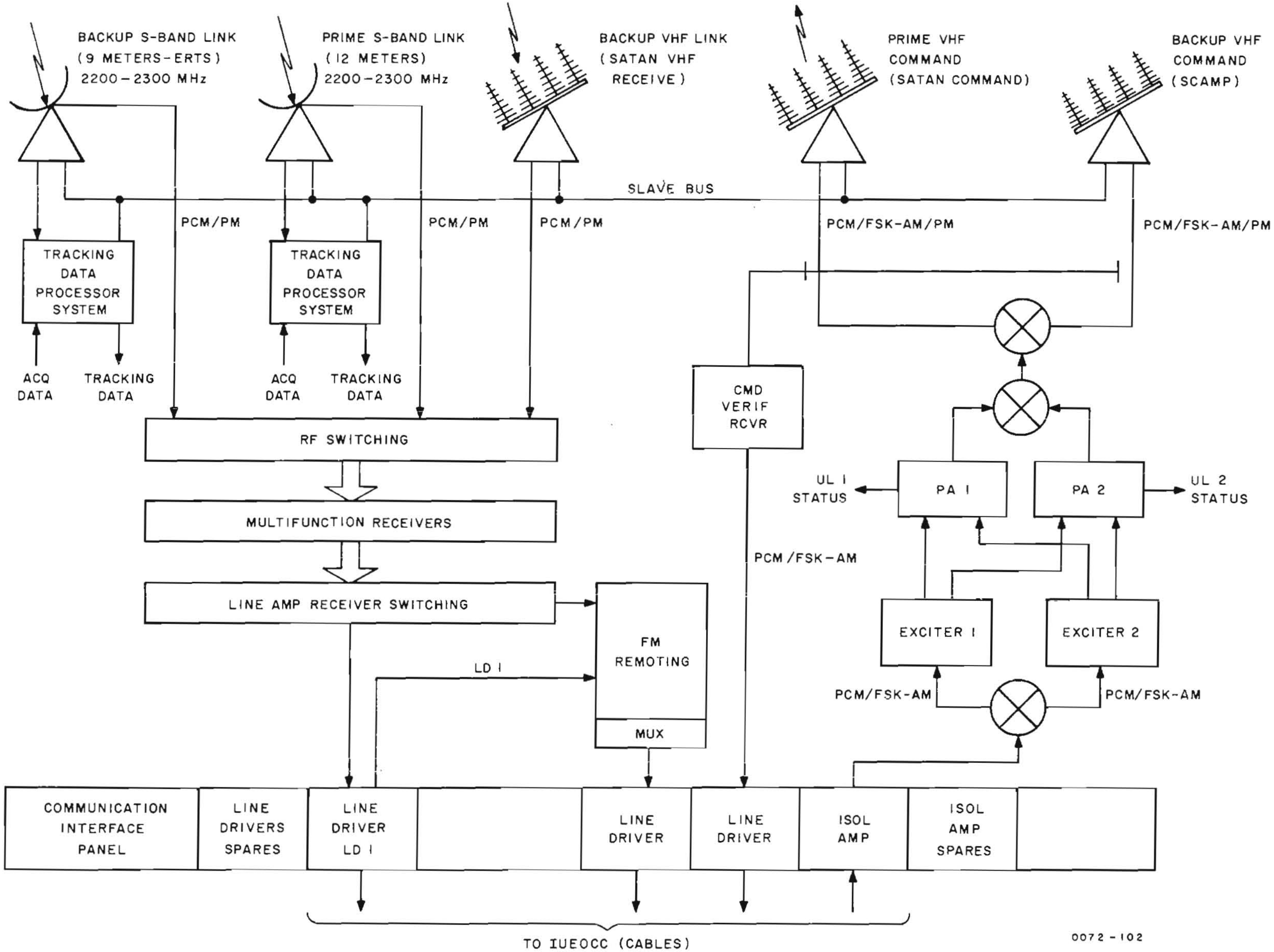

Figure 4.2-1. U.S. Ground Station Equipment Configuration Block Diagram

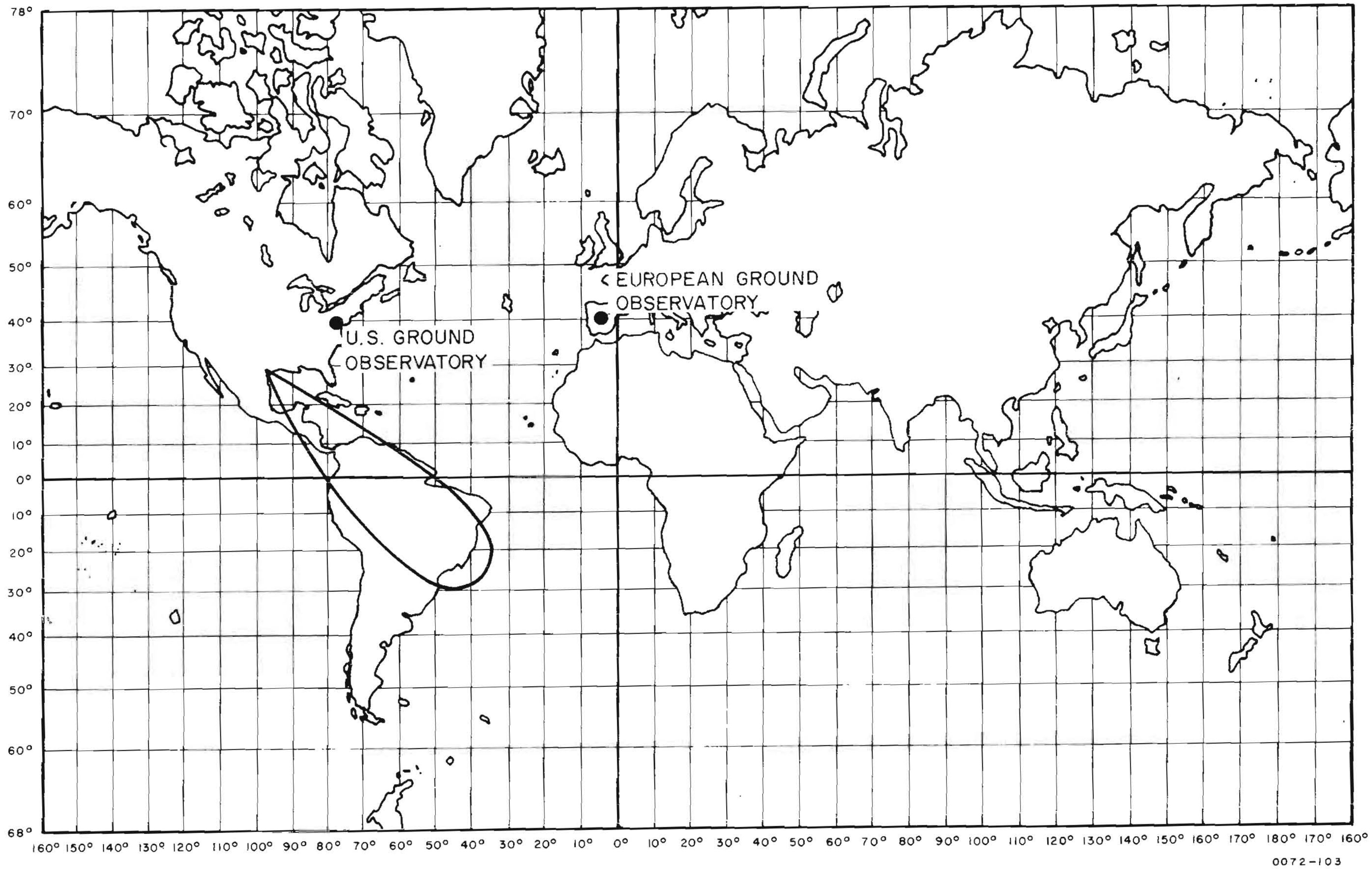

Figure 4.2-2. Ground Track of IUE Spacecraft in Mission Orbit

It is not planned to use the coded mode unless the link will not support the transmission of uncoded data. If the coded mode is used, the data acquisition link margins will be increased by approximately 6 db. The sequential decoding (if required) will be done in the Operations Control Center.

The 12-meter antenna system will have 24 hours per day visibility of the spacecraft and a positive signal margin at all ranges with a 10^{-6} BER. In order to provide a high degree of reliability, the 12-meter antenna system will be periodically scheduled to go down for preventive maintenance. During these periods, the ERTS 9-meter antenna system will be scheduled to support IUE. The ERTS antenna will have 24 hours per day visibility of the IUE spacecraft, but the link will not support a 10^{-6} BER during most of this period. The ERTS antenna system is also committed to support ERTS. Therefore, the preventive maintenance on the 12-meter antenna system will normally be scheduled as follows:

a. When the 9-meter system is not scheduled to support ERTS and can support a 10^{-6} BER or

b. When the European Ground Observatory is controlling the spacecraft. In this case, the degraded BER should be sufficient for monitoring the health of the spacecraft.

If the BER drops below 10^{-6} while the U.S. Ground Observatory is operating the spacecraft, the Project Operations Director can elect to command the spacecraft to transmit coded data. This action will increase the signal-to-noise ratio by approximately 6 db.

The VHF telemetry link provides a secondary data acquisition backup. In case of emergency, the spacecraft can be commanded to transmit the telemetry data at a reduced rate via VHF. It is planned that this mode be used, if required, to maintain the spacecraft health in an emergency situation.

Primary command support for the spacecraft will be provided by the VHF SATAN command antenna system. The VHF SCAMP antenna system will provide backup command support. The 800 bps PCM commands will be generated by the computer in the OCC and transmitted in real-time on the FSK-AM subcarriers via cable to the ground station. The commands will be PM modulated by the command transmitter and transmitted to the spacecraft. As the commands are transmitted, they will be received by a stub antenna, demodulated, and returned via cable to the OCC for verification. Table 4.2-1 summarizes the telecommunications frequencies for IUE and the supporting ground system.

In addition to the telemetry data which will be transmitted via cable to the OCC, certain station parameters will be monitored and transmitted to the OCC. Redundant cables will be provided between the ground station and the OCC.

Table 4.2-1
NTTF Frequency Bands of Operations

Ground System	Band	Operation	Range (MHz)	IUE Frequency (MHz)
SATAN/SCAMP	VHF	VHF command	148--154	148.98
SATAN	VHF	VHF telemetry	136--138	136.86
9-meter antenna system	S-band	Telemetry	2200—2300	2249.8
12-meter antenna system	S-band	Telemetry	2200—2300	2249.8

4.3 DATA ACQUISITION SYSTEM

4.3.1 ANTENNA SYSTEM

4.3.1.1 12-meter System

In order to provide a bit error rate (BER) of 10^{-6}, the 12-meter antenna system will be modified by the addition of 33° K low noise parametric amplifiers (paramps). A listen-only feed, optimized at the IUE S-band frequency, will replace the present multiband feed. These modifications will result in a system noise temperature of approximately 80° K (at an elevation angle of 56.5°). A program track mode will be required since the antenna system will not have auto-track capability. A tracking data processor system (TDPS) at the station will provide the program track mode capability. Interrange vectors (IRV) will be periodically generated and inputted to the TDPS for antenna positioning.

4.3.1.2 9-meter ERTS Antenna System

The 9-meter backup system is equipped with a cryogenically cooled paramp and has a system noise temperature of approximately 97° K (at an elevation of 56.5°). The system is designed to cover the 2200- to 2300-MHz band.

The 9-meter antenna can be operated in either the program track mode, using a TDPS or in the autotrack mode.

4.3.1.3 SATAN VHF Antenna System

The SATAN VHF antenna provides 20.5 db of gain in the 136- to 138-MHz range. This antenna provides 24 hours per day visibility of the spacecraft and a BER of 10^{-6} at 1.25 kbps.

4.3.2 TELEMETRY RECEIVERS

A total of 12 multifunction receivers (MFR) located at the station can be used in the support of IUE. Radio frequency (RF) switching will be provided so that any of the receivers can be switched to any of the antennas. The MFR has a maximum bandwidth of 20 MHz and operates between 400 and 500 MHz. Frequency converters, associated with each antenna, will convert the S-band and telemetry signal down and the VHF telemetry signal up to this frequency range. The MFR can also function as an auto-track receiver for the 9-meter and SATAN receive antennas.

4.4 VHF COMMAND SYSTEM

4.4.1 ANTENNA SYSTEM

4.4.1.1 SATAN Command Antenna

The SATAN, which will be the prime command antenna, has 24-hour-per-day visibility of the spacecraft and a positive signal margin (using the 10 kw power amplifier) at all ranges. The SATAN command antenna has a gain of 20 db.

4.4.1.2 SCAMP Antenna

The SCAMP antenna which has spacecraft visibility 24 hours per day will provide backup to the SATAN command antenna. The SCAMP antenna has a gain of 16 db. The antenna feed will be modified to handle 10 kw. Using the 10-kw power amplifier (PA), the SCAMP antenna system also has a positive signal margin at all ranges. The SCAMP antenna will also be modified for slaving capability.

4.4.2 COMMAND TRANSMITTER

Two exciters and two 10-kw PAs capable of being cross-strapped will be supplied. Another 10-kw PA will be provided for additional backup.

4.5 STATION MONITORING PARAMETERS

To increase the operational confidence factor, a maximum of seven station parameters (for example, receiver AGC, uplink status, telemetry line driver status, etc.) will be FM-remoted to the OCC.

4.6 COMMUNICATIONS INTERFACE PANEL

For operational convenience and troubleshooting, a communication interface panel (CIP) will be provided at the station. The CIP will contain a sufficient number of line drivers and isolation amplifiers (including spares) for adequate signal distribution. Cables, (including spares) will be provided between the station and the OCC.

4.7 TRACKING

VHF range and range rate (RARR) will be provided by the Space Tracking and Data Network (STDN) station at Rosman, North Carolina.

In addition, antenna angle tracking data from the U.S. ground station and other STDN stations may be obtained to augment the RARR tracking data.

SECTION 5
OPERATIONS CONTROL CENTER AND SCIENTIFIC OPERATIONS CENTER

5.1 GENERAL

The Operations Control Center (OCC) and the Scientific Operations Center (SOC) work together to control the IUE spacecraft during the various phases of the mission. The SOC provides operational control of the spacecraft during normal scientific operations, while the OCC assumes control during launch, transfer orbit, and checkout phases of the mission, as well as during any emergencies. The OCC continuously monitors and evaluates spacecraft housekeeping data and reviews all commands transmitted to the spacecraft. Ground system coordination will be accomplished from the OCC.

5.2 OPERATIONS CONTROL CENTER

The OCC systems can be divided into four basic elements: (1) the mission operations room (MOR), (2) the data operations and control area, (3) the prime command and control computer and associated electronics systems (DOC), and (4) the image processing computer system. Figure 5.2-1 is a system block diagram of the OCC and SOC.

The OCC and related spacecraft command and control functions will be located on the ground floor of Building 14. (See Figure 5.2-2.) In addition, space will be provided in the Building 14 annex for the OCC operations personnel, mission support computing personnel, and for project and observer personnel.

The offices in the annex will be constructed by November 1974. In December 1974, a refurbishment and reconfiguration of the ground floor of Building 14 will start. The OCC refurbishment will be complete and ready for the complete computer installation by May 1975.

5.2.1 MISSION OPERATIONS ROOM

The function of the control and display consoles in the mission operations room (MOR) is to provide the mission operations team with the information necessary to make command and control decisions and the means to implement these decisions in an effective and timely manner. The MOR equipment layout is shown in Figure 5.2-3. The MOR contains five spacecraft control positions and a telescope control console. The spacecraft control positions will be designated for use by the project operations director, the command controller, and the three spacecraft subsystem engineers. Each console is equipped with an alphanumeric CRT display and a standard terminal input keyboard for operator communication with the command and control computer. In addition, the consoles are equipped with a communications panel. A standard TV monitor with selection switches is provided for each operating position. Two strip-chart recorders (SCR) will be shared by the subsystem engineers.

The alphanumeric CRT is the primary MOR display mechanism. This display and its input keyboard will provide the flexibility to satisfy virtually all operational display requirements and, in addition, provide an effective mechanism for the operations personnel to fully utilize the processing capabilities of the computer to support the observatory program. Through the input keyboard, the operator will be able to access any of the pages in the display library for viewing on the CRT. He may also view on the adjacent TV monitor any page being viewed on any other interactive CRT in the MOR and computer room. Spacecraft subsystem engineers will also be able, through the keyboard, to specify the data assigned to their strip-chart recorder channels. The interactive nature of the consoles is of particular importance to the command controller. By means of the keyboard, he may introduce or call any command or command list in the system, verify its correctness by viewing it on the CRT, transmit it to the remote station, and observe the reception, transmission, and spacecraft verification.

An experiment display (telescope control console) will be provided in the MOR for performing star acquisition and spectrum data display. The command and control computer will provide real-time data to the star acquisition display for experimenter control of the spacecraft and initial viewing of spectrum data. This display will be located in the MOR for launch and early mission support, special operations, emergency operations, and backup to the experiment display in the SOC.

The actual display will be a high-resolution TV picture of the spectrum of the stellar object or the field of view of the star acquisition camera. The unit will provide flicker-free image presentations of digitally encoded data in pseudocolor. The color scale will have at least 16 levels of intensity and the screen size will be at least 12 by 12 inches.

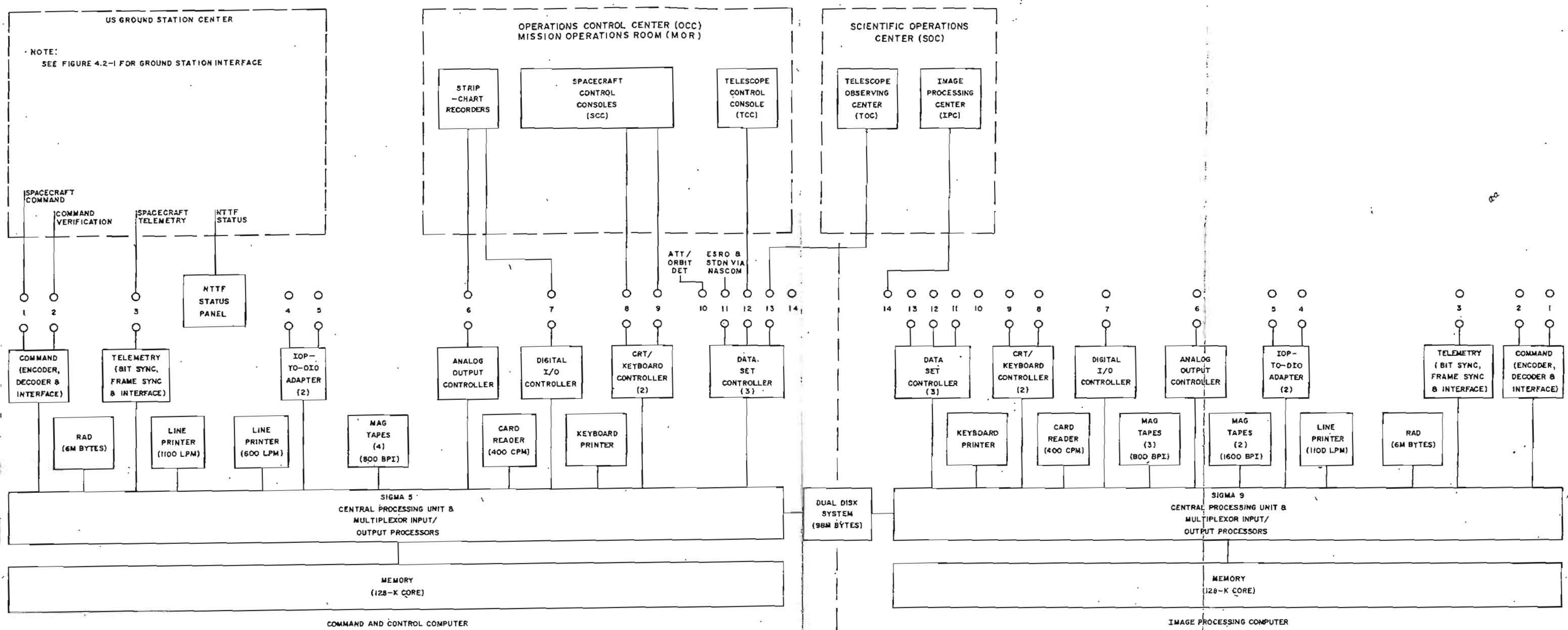

Figure 5.2-1. U.S. Ground Observatory Block Diagram

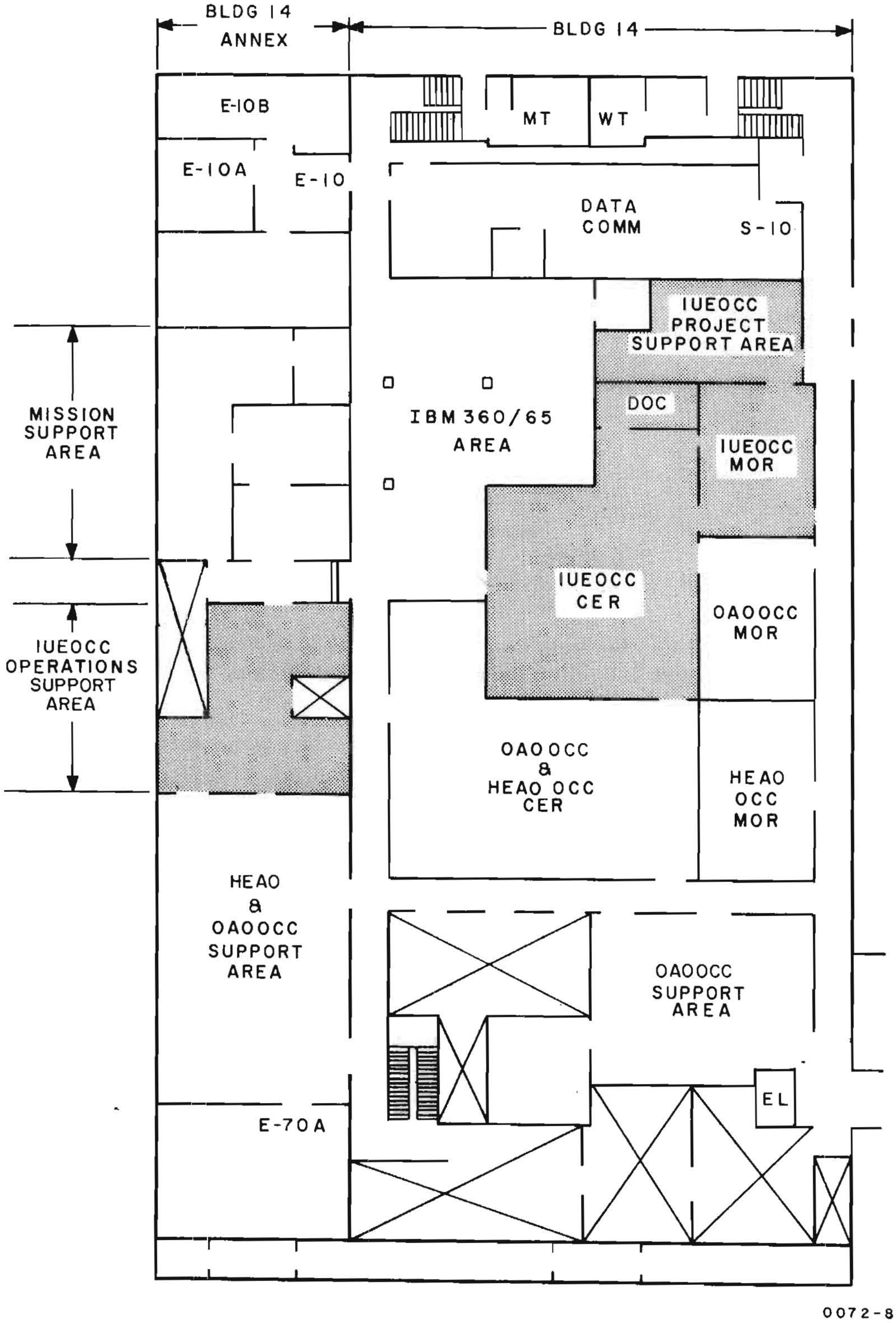

Figure 5.2-2. Operations Control Center Floor Plan

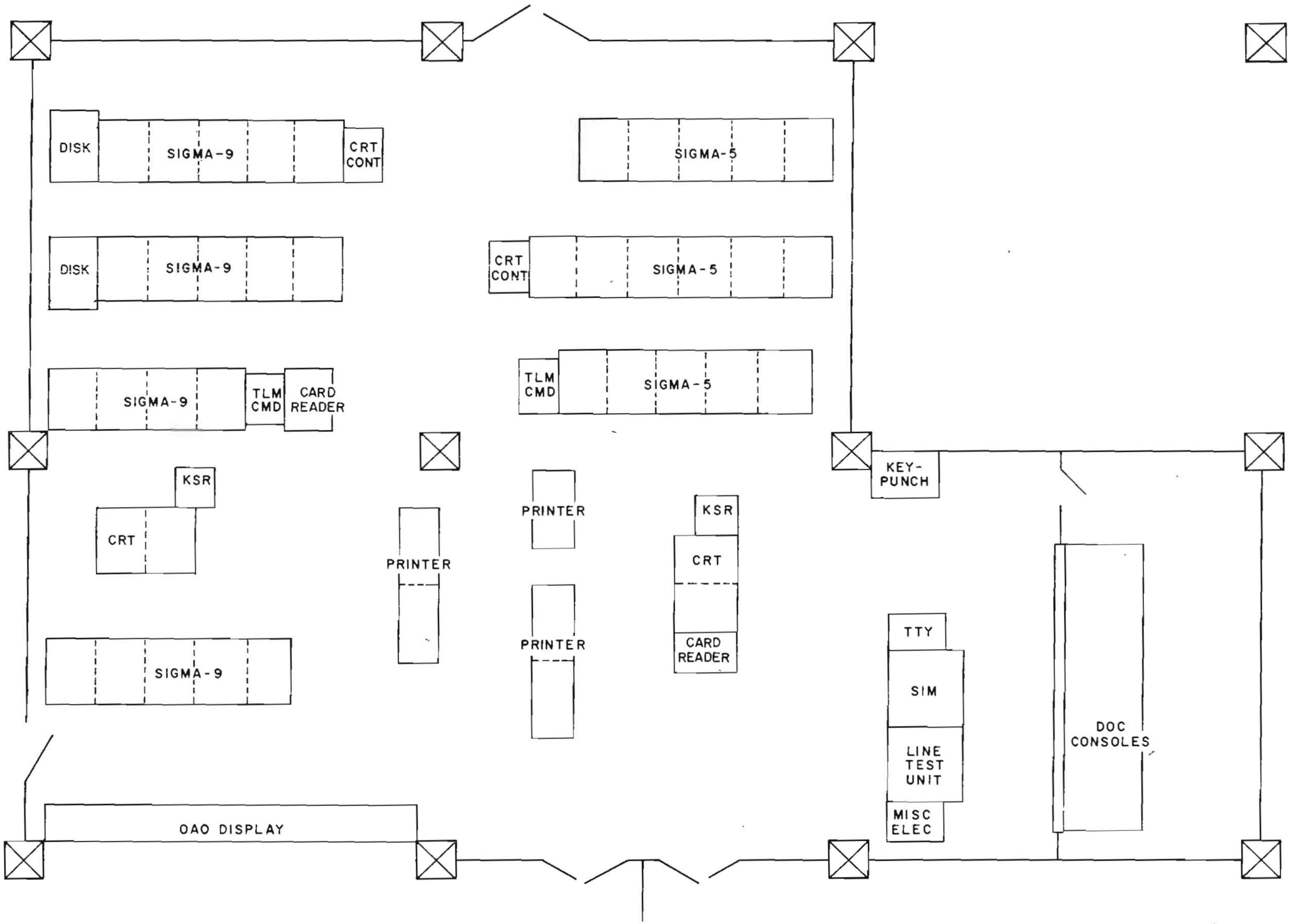

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Figure 5.2-4. IUEOCC Computer Equipment Room

5.2.3 COMMAND AND CONTROL COMPUTER

The Sigma 5 computer system (Figure 5.2-5) will fulfill the requirements anticipated for the IUEOCC. An equipment list is shown in Table 5.2-1. This system will have an average instruction execution time of 3 to 4 microseconds and a high input/output capacity designed to satisfy real-time operating requirements. The following are the primary requirements for the OCC command and control processing functions:

a. Provide the capability for concurrent real-time processing of spacecraft housekeeping and control data, and provide the capability for the collection and handling of experiment data.

b. Provide the capability to convolutionally decode the telemetry data as required.

NOTE

Redundant hardware sequential decoders will be provided in the OCC for this function.

c. Provide the capability of real-time control of telemetry processing (for display purposes) and spacecraft command verification.

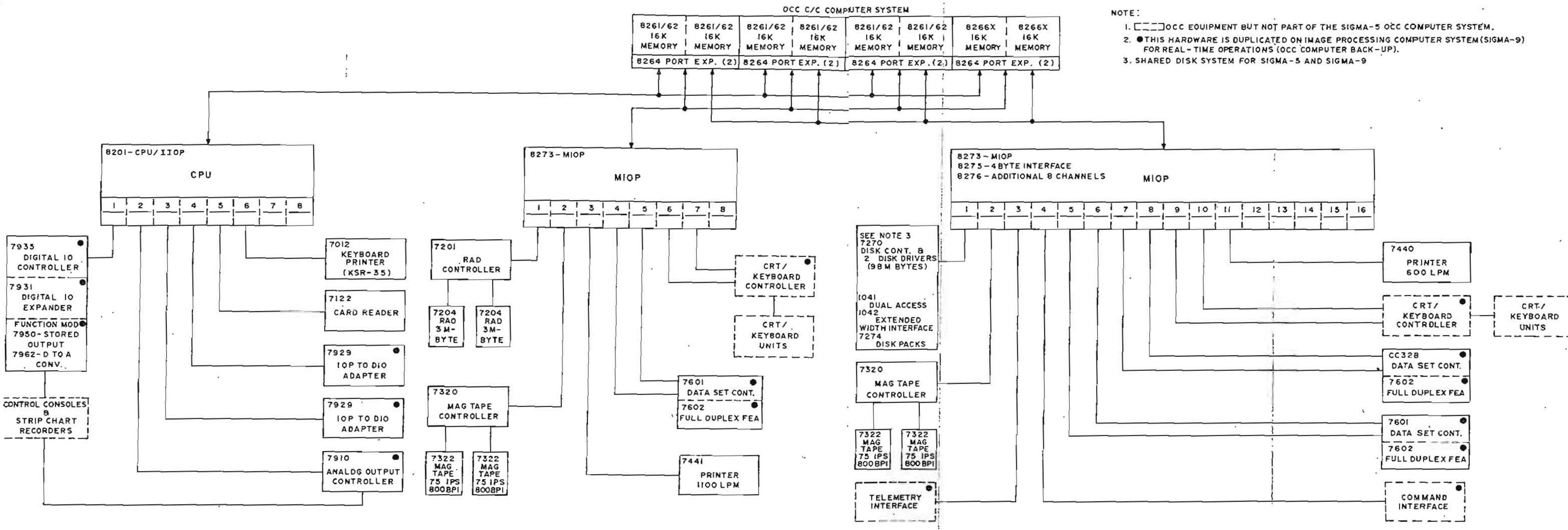
d. Receive the telemetry input, calibrate and convert the spacecraft housekeeping data values to engineering units, and display them on various devices.

e. Provide the capability for three-axis attitude determination to be used for spacecraft slewing maneuvers and spacecraft station-keeping.

f. Generate bit-structured commands and format the data for output to the command encoder for transmission to the spacecraft.

g. Provide the software necessary for preobservation planning and routine daily operational planning, such processing being accomplished as required by the mission analysis and control group for the generation of spacecraft commands.

h. Provide a command and control backup software system for the IP computer.



NOTE:

1. [dashed box] OCC EQUIPMENT BUT NOT PART OF THE SIGMA-5 OCC COMPUTER SYSTEM.
2. ● THIS HARDWARE IS DUPLICATED ON IMAGE PROCESSING COMPUTER SYSTEM (SIGMA-9) FOR REAL-TIME OPERATIONS (OCC COMPUTER BACK-UP).
3. SHARED DISK SYSTEM FOR SIGMA-5 AND SIGMA-9

Figure 5.2-5. OCC Computer System Block Diagram

Table 5.2-1
IUEOCC Sigma 5 Command and Control Computer
Component List

Description	Model	Total Req.
Sigma 5 central processor W/integral IOP, two real-time clocks, control panel, and power supplies	8201	1
Real-time clock	8211	1
Power fail-safe	8213	1
Memory protect	8214	1
Additional register block	8216	1
Floating-point arithmetic	8218	1
Interrupt control chassis	8221	3
Priority interrupt, two levels	8222	24
Memory bank, 8 K words	8261	6
Memory incr., 8 K words	8262	6
Port expansion	8264	8
Memory bank, 16 K words	8266X	2
External interface feature	8270	1
Multiplexer I/O processor, includes eight multiplexer channels	8273	2
4-byte interface	8275	1
Additional eight multiplexer channels	8276	1
Keyboard/printer and controller (KSR 35)	7012	1
Card reader	7122	1
RAD controller	7201	1
RAD storage unit, 3.0 M-bytes	7204	2
Disk controller and 2-49 M-byte disk drivers (see note)	7270	1
Disk, dual access	1041	1
Disk, extended-width interface (see note)	1042	1
Disk pack (see note)	7274	3
Magnetic tape controller	7320	2
Magnetic tape unit, 60 kb	7322	4
Buffered line printer, 600 lpm	7440	1
Buffered line printer, 1100 lpm	7441	1
Data set controller	7601	2

Table 5.2-1
IUEOCC Sigma 5 Command and Control Computer
Component List (Cont)

Description	Model	Total Req.
Full-duplex feature	7602	3
Analog output controller	7910	1
IOP to digital adapter	7929	2
Digital I/O expander	7931	1
Digital I/O controller	7935	1
Stored-output module	7950	2
D/A converter	7962	19
Communication controller	CC32B	1

Note: The disk system will be shared between the image processing computer system and the OCC command and control computer system for experiment data storage, data base, and bulk data storage.

i. Develop the command and control computer software such that it can be adapted for use in the European Ground Observatory computer.

j. Provide an I/O handler and routines to service a data line to the European Ground Observatory. This line will be used to transmit software system updates from the U.S. to the European Ground Observatory, and to transmit operational continuity data in both directions to assure smooth turnover.

k. Provide the software necessary to receive an observer request, via an interactive terminal, calculate the slew, display the acquisition image for target identification, process acquisition image and calculate accurate stellar locations, process and display the quick-look spectrograph data for data validation, and transmit the data to one of the experiment display consoles.

l. Provide operational test programs and diagnostic programs.

m. Simulate the spacecraft for test and training purposes.

NOTE

> The spacecraft simulator will be located in the 360/65 computer located in building 14.

5.2.3.1 Central Processing Unit

The central processor used to support the IUE spacecraft real-time command and control function will have the following general capabilities:

a. Memory of 131, 072 32-bit words (128 units of 1024 words).

b. Memory speed of 1 microsecond to meet the requirements of the real-time tasks with a margin for additional tasks.

c. Real-time clocks will be used by the control task to monitor activity of the special I/O devices which are necessary to meet the command and control real-time requirements.

d. Memory protect feature will guard against the possibility of a program malfunction altering the content of the data base or destroying critical real-time programs because of concurrent program checkout.

e. Memory parity protection will be used so that immediate action can be taken in the event a computer error is detected and to reduce the possibility of erroneous commands being sent to the spacecraft.

f. Power fail-safe will permit orderly computer shut down; this will permit restart of operations with a minimum loss of data and time.

g. Principal control and priority of computer tasks will be based upon a computer interrupt system. Forty-eight levels of interrupt will be provided and assigned as the operational software is developed.

h. The CPU will offer a variety of instructions which permit efficient processing of real-time telemetry. This will include logical operations, shifting, and powerful I/O commands. Floating-point hardware will provide the capability to perform the calibration and conversion to engineering units calculations and the slew maneuver calculations.

5.2.3.2 Peripherals

A number of peripheral devices will be used to meet the requirements of the OCC as follows:

a. Mass storage will be provided for the operating system, application programs, experiment data, and experimenter support. Two types of mass storage will be provided:

- A rapid access device (RAD) will be provided for the operating system and application programs frequently accessed by the CPU. Six M-bytes of RAD storage will be provided for this purpose.

- A dual-spindle disk system, 98 M-bytes of storage, will be provided. The disk system will be shared with the image processing computer, basically 49 M-bytes of storage each for the command and control and image processing computers. The command and control computer will strip image data from the spacecraft telemetry data and place it on the disk; the image processor will then access the disk for the image data; therefore, the disk will serve as the experiment data exchange device for the two computers.

b. Two digital magnetic tape controllers will be provided, each with two tape units. Each tape unit will be an 800 bpi IBM-compatible nine-track tape drive with a transfer rate of 15,000 words per second (60,000 bytes per second).

c. Three full duplex data set controllers (DSC) will be used in the system to meet the communication requirements. These data set controllers will have bit rates in the range of 50 to 230,400 bits per second with simultaneous two-way transfer. The data set controllers will be used to interface with standard communication lines to transfer data to and from remote locations. These units will be patched by the DOC to provide communications with the following:

- Experiment displays.

- European Ground Observatory.

- STDN stations via NASCOM during prelaunch, launch, and early mission phases.
- Attitude and orbit determination and control computers.
- Integration and test facility.
- Kennedy Space Center (KSC) during prelaunch spacecraft checkout.

d. Two 132-characters-per-line printers will be provided to log events, to print spacecraft data for spacecraft controllers, and record snapshots (a snapshot will be one CRT page of data). These printers will also be used for utility runs, compilations, assemblies, system testing, etc.

e. The keyboard/printer (console typewriter) will be used for rudimentary control of the system and will be required to support most manufacturer-supplied software.

f. The card reader will be used in support of operations and to aid in software development.

g. The analog output controller and digital-to-analog converters will be used to interface with the strip-chart recorders to display spacecraft parameters.

h. The digital I/O adapter and expander will be used to interface the computer with general-purpose function modules, e.g., stored output modules for discrete special-purpose control console functions and 8-bit digital-to-analog converters to drive general-purpose analog recorders.

i. Special-purpose command equipment will be provided to interface the computer with the ground station. This equipment will convert 8-bit parallel data from the computer to 800-bps serial command data and encode it for transmission to the spacecraft by the ground station. Command verification receiver output will be returned via cable from the ground station for verification by the command encoding/decoding equipment.

j. Special-purpose telemetry decommutation and conditioning equipment will be provided to receive and condition data prior to its transfer to the command and control computer. This equipment will operate up to 40,000 bits per second (split phase). Convolutional decoding equipment capable of decoding the sequentially encoded data from the spacecraft will be provided for both the command and control and the image processing computer.

k. Display controllers for the interactive CRT units will be provided for the mission operations and planning activities. These devices will have the ASCII code with a 9600-baud transfer rate. There will be eight of these devices in the system. The operator will make inputs into the computer by using a keyboard. The displays and keyboards will be contained in consoles for use of the Project Operations Director, command controller, data operations controller, computer systems operator and spacecraft subsystem engineers.

5.2.4 IMAGE PROCESSING COMPUTER

The Sigma 9 Model 3 image processing (IP) computer will be located in the Computer Equipment Room of the IUEOCC in building 14 adjacent to the command and control Sigma 5. The IP computer is scheduled to be delivered by December 1974. The computer will be located in building 11 until May 1975 and used to support spacecraft and experiment testing. At that time it will be moved into the OCC.

Figure 5.2.6 is a block diagram of the proposed IP computer system, a Sigma 9, Model 3. Computer speed requirements are described in Appendix D.

5.2.4.1 Image Processing Task

Image processing covers the conversion of raw image data obtained from the spacecraft into a form that is of scientific value to the observer using the telescope. It is intended that the astronomer should not have to be concerned with the mechanics of spacecraft operation, so products available to him will typically be spectra (intensity as a function of wavelength), rather than partially processed images.

Image processing can be characterized by its inputs, outputs, and its processing tasks:

Inputs are:

a. High-resolution echellograms (HRE) consisting of a 768 square matrix of picture elements (pixels), each digitized to 8 bits. The HRE contains 51 distinct spectral orders.

b. Low-resolution spectrograms (LRS) consisting of a 96 x 768 rectangular matrix of pixels, each again digitized to 8 bits. The LRS contains a single spectral order.

NOTE

Nine each HREs and LRSs are expected as an average during each 16-hour observing period.

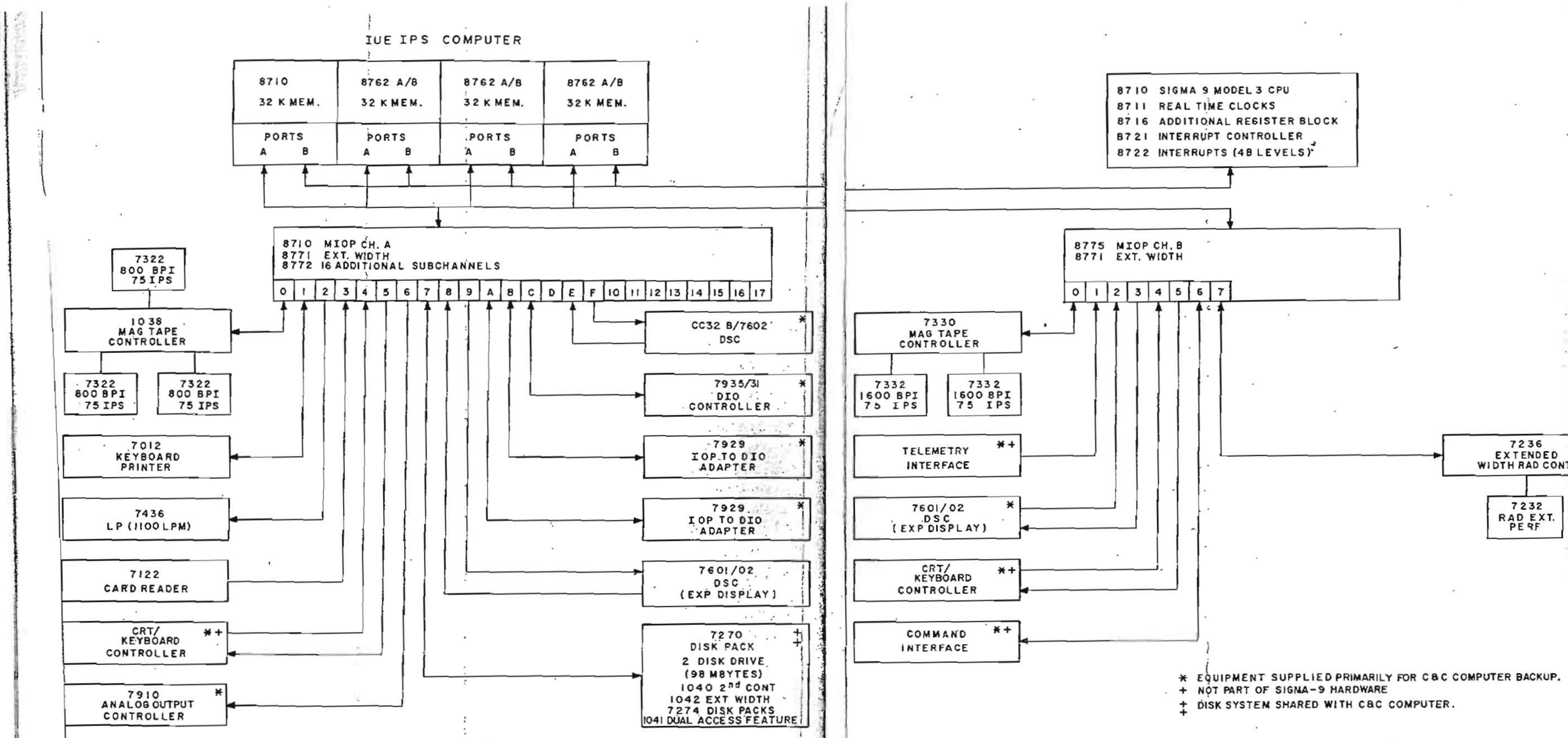


Figure 5.2-6. IP Computer System Block Diagram

Outputs are selected by the observer during his image processing session from the following:

a. Raw data frame, or intermediate processed data frames.

b. Final corrected spatial intensity distribution (I (x,y))

c. Final corrected intensity as a function of wavelength (I (λ))

d. An error analysis considering the following points:

(1) Periodic disturbance effects

(2) Photon Noise

(3) Resolution

(4) Wavelength accuracy

e. A spacecraft log, covering date, time, star name, etc.

All this data is to be provided in a choice of three outputs:

a. Digital magnetic tape with a further choice of two packing densities:

- 800 bits per inch
- 1600 bits per inch

b. Either as a strip chart record or as a digital plotter output.

c. An accurate black and white photograph that is digitally produced.

The image processing function can be broken down into a succession of not necessarily reversible transformations. These are:

a. Remove noise due to camera, spacecraft, data transmission, and background intensity.

b. Remove distortion due to camera and optics.

c. Enhance resolution.

d. Rough wavelength determination.

e. Photometric calibration.

f. Precise wavelength determination.

Many of the image processing tasks rely for their inputs on mathematical or algorithmic models of various effects in the telescope/spacecraft system. Each of these models requires recalibration while the spacecraft is in orbit. Until then, however, it is difficult to say how frequently recalibration will be required. Calibration observations will be scheduled as a regular observation. As such they will not represent an appreciable increase in the workload of the IP computer. However, it is recognized that a large amount of calibration observations would necessarily decrease the amount of obtainable science.

5.2.4.2 Use of Image Processing Computer as OCC Computer Backup

The image processing system is intended to supply full operational backup during launch, transfer orbit, and on-station mission operations. The image processing computer is configured to contain, as a subset, the command and control system. This requires a high degree of hardware commonality with the OCC computer system. A copy of all spacecraft command and control software will be stored on magnetic tape. The OCC computer will maintain a log of essential spacecraft data on a shared disk file. Should the OCC computer fail, the image processing computer would terminate in a timely manner any on-going image processing. The OCC software would then be loaded into the image processing computer so that it could take over the spacecraft control task. It is assumed that the spacecraft can be uncontrolled by either computer for up to 10 minutes.

5.2.4.3 Image Processing Computer Description

5.2.4.3.1 Mainframe. A Xerox Sigma 9 Model 3 computer system (Figure 5.2-6) has been chosen to fulfill the requirements anticipated for IUE image processing, and as a backup to the IUE OCC computer. This computer has an average instruction execution time of between one and two microseconds and a memory access time of less than one microsecond. The computer has a memory size of 128K 32 bit words.

Principal control and priority of computer tasks is based upon a computer interrupt system. Forty-eight levels of interrupt are provided and will be assigned as the operational software is developed. An anticipated assignment of priority interrupt is:

Operational software modules		16
Hardware dedicated functions		24
Spares		8
	Total	48

5.2.4.3.2 Software. The software system will be structured around Xerox's standard CPR operating system.

5.2.4.3.3 Input/Output Structure. The computer has the capability of performing I/O on several devices concurrently, and performing I/O concurrently with the execution of programs in the central processing unit.

I/O devices on the Sigma computers are interfaced via a multiplexing input output processor (MIOP). One MIOP and one bus sharing MIOP will handle the anticipated requirements. I/O operations can be programmed simultaneously with instruction execution, provided that the data transfer and instruction execution are not from the same 16K word block of memory. The two MIOP's will share the same port to memory.

5.2.4.3.4 Non-Core Storage

a. Magnetic Tape Drives

The magnetic tapes will be used as follows:

(1) Bootstrapping of system

(2) Preparation of end product magnetic tape for astronomers.

(3) Storage of calibration data sets for photometric calibration.

(4) Safe storage of backup data sets, including programs under development and complete operational systems.

(5) Preparation of magnetic tape to drive off-line grey scale photographic hardcopy device.

(6) Preparation of magnetic tape to drive off-line plotter for spectrum presentation.

(7) As a buffer device for I/O spooling.

(8) For archiving of raw and processed data as required.

(9) Loading of control computer backup system.

The computer is configured with both 800 and 1600 bpi tape units. The 800 bpi tape units provide:

(1) Magnetic tape interchange between image processing and command and control computers.

(2) Data transfer to an existing off-line grey scale photographic output device.

(3) Data transfer to experimenters with no 1600 bpi tape equipment.

The 1600 bpi tapes on the system provide:

(1) Data interchange with mainframe vendor and other 1600 bpi tape users.

(2) Data transfer to experimenters with no 800 bpi tape equipment.

(3) More compact data storage (for archiving).

(4) The inherently higher reliability of phase encoding over the NRZI used on 800 bpi tapes.

The system has been configured with two 1600 bpi tape drives and three 800 bpi drives. More 800 bpi tape drives are attached to the system than 1600 bpi since the 800 bpi drives are prime for the OCC backup task.

b. Rapid Access Device (RAD)

Fixed head disk storage with its attendant fast (average 17 ms) access times is required to provide residence for:

Operating system including utility programs such as compilers and loaders.	2.5 MBytes
Applications programs (for IP)	1.0 MBytes
Data base storage	2.0 MBytes
Total	5.5 MBytes

The unit selected has a capacity of 6.2 MB which exceeds the amount anticipated by 0.7 MB.

c. Moving Head Disk (Disk Pack)

Data transfer between the IP computer and the OCC computer is via a pair of shared moving head disks. The shared disk serves as an image buffer between the two computers and in times of heavy workload may contain up to about 20 images (about 12 Mbytes). The shared disk has space available for any other random access storage requirements (possibly involved in calibrating the telescope) that are required.

5.2.4.3.5 Other Peripherals. A 132 character line printer is required for utility runs, compilations, assemblies, system testing, and for synopses of the image processing carried out for astronomer use. While the image processing computer is being used for spacecraft command and control, the line printer will log events and record snapshots. A snapshot will be one CRT page of data. The unit selected operates at 1100 LPM.

The keyboard/printer is used for rudimentary control of the system and is required to support most manufacturer supplied software and diagnostic programs.

The card reader will be used as an aid in software development and in support of operations. The unit was selected from the estimated work load and has been found very reliable in use at GSFC.

The following devices are required to support backup of the command and control computer.

a. Three data set controllers (7601/02 and CC32B) will be used in the system to meet the communication requirements of the control center backup. These data set controllers have bit rates in the range of 50 to 230,000 bits per second with simultaneous two-way transfer. The data set controllers will be used to interface with standard communication lines to transfer data to/from remote locations. These units will be patched to provide communications with the following:

   - The experiment display in the OCC.
   - Two experiment displays in the SOC.
   - The European Ground Observatory.
   - STDN stations via NASCOM for prelaunch, launch, and early mission phases.
   - Attitude and orbit computer.

b. The analog output controller and digital to analog converters are used to interface with strip chart recorders.

c. The digital I/O adapter and expander will be used to interface the computer with general purpose function modules, e.g. stored output modules for discrete console functions and 8-bit D to A converters to drive general purpose analog recorders, etc.

d. Command equipment will be provided to interface the computer with the ground station. This equipment will convert 8-bit parallel data from the computer to 800 bps serial command data and encode it for transmission to the spacecraft via the ground station.

e. Sequential decoding, telemetry decommutation, and conditioning equipment will be provided to enable the IP computer to back up the command and control computer.

f. Alphanumeric display devices with controllers will be used by the mission operations, mission analysis and planning activities. These devices operate at a 9600-baud transfer rate. There will be up to 8 of these devices in the system. These will have a means of input into the computer by way of a keyboard, functional switches, etc. The displays, keyboards, and special purpose panels will be contained in consoles for use of the Project Operations Director, Command Controller, Computer Systems Controller, and for overall spacecraft status.

5.2.5 DATA COMMUNICATIONS INTERFACES

Data transfer with remote locations will be provided in support of the IUE spacecraft. Primary communication requirements are as follows:

a. Incoming telemetry from the spacecraft via the ground station will be at the spacecraft telemetry rates, normally 40 kbps information rate. When the spacecraft telemetry data is convolutionally encoded (this is the backup mode) the corresponding symbol rate is 80 kbps. The data will be received via a cable from the ground station.

b. Outgoing commands from the OCC will be transferred to the ground station via a cable at a command bit rate of 800 bps. These commands will be returned from the ground station via cable, as transmitted to the spacecraft, for verification.

c. NASCOM data links will be used during the launch, transfer, and drifting orbit phases between the OCC and participating STDN stations for transmission of telemetry, command, and command verification data.

d. A full-duplex, 7.2 kbps or 9.6 kbps data link between the U.S. OCC and the European Ground Observatory will facilitate spacecraft handover and the transmission of scientific data. A 27.6-kbps data link between the U.S.

OCC and the European Ground Observatory will be used between June 1976 and January 1977 for checkout of the European Ground Observatory System.

e. Stripped telemetry data for attitude and orbit determination and control will be transmitted from the OCC to the IBM 360-95 and IBM 360-75 computers via data links during the transfer orbit phase.

f. Two 230.4 kbps communication links will be provided between the OCC and the SOC for experiment control and data display and image processing. Cables between the OCC and the SOC will also be provided for the TV monitors.

g. Communication links will be provided between the OCC and the integration and test facility to support spacecraft testing.

h. Two NASCOM 7.2-kbps or 9.6-kbps data links plus a wideband link capable of handling 40-kbps data will be provided between the OCC and KSC for prelaunch checkout of the spacecraft.

5.3 SCIENTIFIC OPERATIONS CENTER

When the initial spacecraft checkout phase of the mission has been completed, operation of the spacecraft and the experiment will be switched to the Scientific Operations Center (SOC) for the normal scientific operations. During this phase of the mission the spacecraft and the experiment will be operated from the SOC through the command and control computer system. The function of the OCC then becomes one of spacecraft performance monitoring and general support to scientific operations. The normal SOC functions will be as follows:

- The preobserving run preparation, planning, training, and scheduling of guest observer programs.
- The selection of target stars.
- The display and identification of targets and star fields on the target acquisition and observation console (TAOC).
- The initiation of spacecraft slews and experiment exposure sequences.
- The reduction of all scientific data both in quick-look display and in final reduced form.

The SOC will be designed to allow a guest observer with no previous experience in making orbital observations to exercise control over the orbiting telescope and make real-time judgements pertaining to the execution of his observing program. Experienced resident observers will support the guest observer throughout all phases of his program.

The SOC support functions are carried out in three main areas: the Telescope Observing Center (TOC), the Image Processing Center (IPC), and the Guest Observer Support Area. A floor plan of the SOC, which will be located in Building 21, is shown in Figure 5.3-1. TV monitors of the alphanumeric CRT display will be provided in the TOC and IPC.

5.3.1 TELESCOPE OBSERVING CENTER

The TOC is the place where the observer interfaces with the telescope when he is making observations in real-time. The physical interface is an interactive console/display called the target acquisition and observation console (TAOC).

This display console will enable observers to: (1) make star selections from a list of possible targets, (2) direct the star recognition process during attitude maneuvers, (3) observe and assist final observatory lock onto the target star, and (4) evaluate quick-look data. The spectrum display will provide the observer with the first look at his unprocessed data after the exposure period so that he may determine if additional exposure is necessary.

The actual display will be a high-resolution color TV picture of the spectrum of the stellar object or the field of view of the star acquisition camera according to which display function it is serving. The unit will provide flicker-free image presentations of digitally encoded data in either black and white or pseudocolor. The latter will be used to make the observer's decision process easier by highlighting or emphasizing star images, decision points, subtle data variations, etc. The gray or color scales will be at least 16 levels of intensity and the screen size will be at least 12 by 12 inches. The display system will interface with the C & C Sigma 5 computer located in the OCC in building 14 as shown in Figure 5.2-1. The TAOC also provides training/simulation aid or image processing backup during the off shift. TV monitors located in the SOC that display the TAOC output will also be used for guest observer training.

An interactive capability will exist consisting of a keyboard and a lightpen or internally positioned cursor. These will provide unambiguous positioning for selection of stars or spectrum data during the decision processes. The keyboard will contain a full ASCII character set for interfacing through the display system to the operations and data processing computers. A memory will exist for storing two full resolution images of 768 by 768 data points (8 bits per data point).

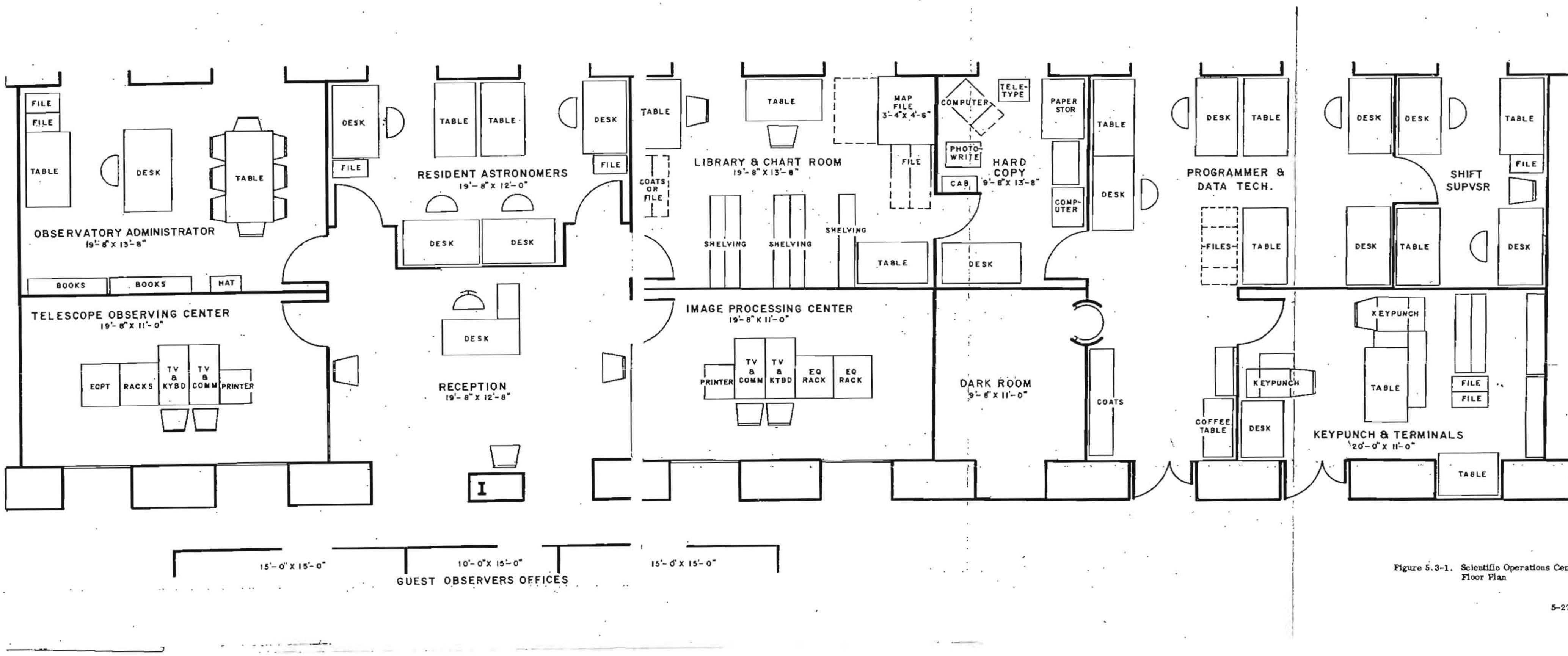


Figure 5.3-1. Scientific Operations Center Floor Plan

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5.3.2 IMAGE PROCESSING CENTER

The Image Processing Center (IPC) is the place where scientific data reduction is carried out by image processing personnel. The controlling console is an interactive color TV display terminal remoted to the image processing computer located in the OCC in building 14. This console called the spectrograph image processing console (SIPC) is identical to the TAOC. The SIPC is a backup to the TAOC when the image processing computer is in control of the spacecraft, or when the TAOC is down. The SIPC will normally be used for one 8-hour image processing shift per day, 7 days per week. During this shift, image processing specialists will control the reduction of the past 16 hours of accumulated spectra and technicians will assemble the hardcopy and tape output package for each guest observer.

5.3.3 SOC SUPPORTING HARDWARE

Hardware for the SOC includes finder field chart copy equipment, programmer support area, keypunch and computer terminals, and hardcopy and dark room equipment, which support the production of scientific data output.

Finder fields are required at the TAOC to assist the observer in the identification of his targets. Finder fields are generated as hard-copy photographic 4 by 5 prints, 12 by 12 transparencies and as computer-compatible digital images on tape.

The hardware which generates these finder fields will be Polaroid camera and optical image digitizers with tape or disk output. Observatory scheduling programmer support hardware consists of keypunches and computer terminals which are used to develop, debug, and run programs on the C&C or IP computer. A Calcomp type plotter provides hard-copy of the IUE sky maps for the guest observer's planning functions.

Scientific data will be output in several hard-copy forms as well as computer-compatible formats on tape. Strip-chart data is plotted by Calcomp-type hardware. Photographic reproductions of quick-look as well as processed spectrographs will be made with Photowrite-type hardware and dark-room processing. Target acquisition images can be generated from the computer digital image data or by Polaroid snapshots of the acquisition display. Keypunches and computer terminals support program runs and development of image processing software on the IP computer.

5.3.4 GUEST OBSERVER SUPPORT AREA

The Guest Observer Support Area includes guest observer offices, chart room and library, and observatory staff offices.

SECTION 6
OBSERVATORY SOFTWARE

6.1 GENERAL

This section presents the functional requirements for software to be implemented on both the command and control and data reduction computers. The major categories of software discussed are command and control, integration and test, observatory scheduling, image processing, and ESRO. Each of these software components is discussed in a separate subsection.

6.2 COMMAND AND CONTROL SOFTWARE SYSTEM

It is possible to define the project requirements for the Operations Control Center command and control (C&C) processing as follows:

a. Provide the capability for concurrent real-time processing of spacecraft housekeeping and control data and provide the capability for the collection handling of experiment data.

b. Provide the capability of real-time control of telemetry processing (for display purposes) and spacecraft command verification.

c. Receive the telemetry input, calibrate and convert the spacecraft housekeeping data values to engineering units, and finally, display them on various devices.

d. Provide the capability for three-axis attitude determination to be used for spacecraft slewing maneuvers and spacecraft station-keeping.

e. Generate bit-structured commands and format the data for output to the command encoder for transmission to the IUE spacecraft.

f. Provide the software necessary for routine daily operational planning, such processing being accomplished as required by the mission analysis and control group for the generation of spacecraft commands.

g. Provide a C&C backup software system for the IP computer.

h. Develop the C&C computer software such that it can be adapted for use in the European Ground Observatory.

i. Provide an I/O handler and routines to service a data line to the European Ground Observatory. This line will be used to transmit software system updates from the U.S. to the European Ground Observatory, and to transmit operational continuity data in both directions to assure smooth turnover. Scientific data may also be transmitted between the two observatories.

j. Provide the software necessary to receive an observer request via an interactive terminal, calculate the slew, display the acquisition image for target identification, process acquisition images to accurately measure the position of the target star and calculate slews to center the target star in the aperture, process and display the quick-look spectrograph data for data validation, and transmit the data to the IP system.

k. Provide operational test programs and diagnostic programs.

l. Simulate mission operations for test and training.

There are three interfaces between the C&C and IP systems. These interfaces are all technically feasible and have been implemented on other computer systems.

The system data base disk file will be shared by both processors. This will facilitate transmission of large files such as images from one computer to the other, and also will make possible the rapid switchover to the backup computer if the C&C computer goes down.

A direct intercomputer communications line may be implemented. This would provide a real-time capability for notifications between systems. These notifications may be necessary for several requirements.

The color graphics terminals will be shared by both processors. In this way, any of the terminals can be used to interact with any graphics software on either processor. This capability is essential to provide redundancy without buying unnecessary additional units.

6.2.1 COMMAND AND CONTROL COMPUTER OUTPUT FOR MISSION CONTROL

The C&C computer will provide the following outputs for real-time data for the mission controllers:

a. Hard-copy outputs, such as high-speed printer pages, for mission planning as well as spacecraft operation. Some types of data for output on these devices include:

   (1) Snapshots of data displayed in more volatile form.

   (2) Recording of events which occur during the observation.

   (3) Quick-look data for spacecraft engineering status.

   (4) Contents of data base and data files available to the control center computer.

   (5) A log of activity in the system.

b. Strip-chart recorder outputs to monitor variables, such as those found in the thermal, power, and control subsystems.

c. Alphanumeric CRT display devices which present data to the mission and experiment controllers for monitoring total system performance. There will be eight of these devices in the system. The operator will make inputs into the computer by using a keyboard and function switches. The displays, keyboards, and special-purpose panels will be contained in consoles for use of the Project Operations Director, command controller, data operations controller, computer systems controller, and spacecraft subsystem engineers. Fifty CRT display pages are estimated as required to support the IUE spacecraft; estimated page requirements are as follows:

(1)	Experiment status	5
(2)	Spacecraft health (power, comm, thermal, out of limits, alarms, etc.)	18
(3)	Displays for Project Operations Director	2
(4)	Raw data (general checks)	1
(5)	Onboard computer	5
(6)	Overall spacecraft status (orbit number, attitude, orbit, GMT)	1
(7)	Command	2
(8)	System log	1
(9)	Display directory/operations procedures	10

(10) Ground system status 2

(11) Unassigned spares 3

A "page" as used here means the display of a number of variables. Each variable will be updated by the computer within 2 seconds after it has been identified as having changed. The computer must hold in memory and continuously update data for eight of these pages and switch from one display page to another within 3 seconds, on operator command.

d. High-resolution TV displays with at least 16 levels of intensity of pseudocolor will be provided for performing the star acquisition and the spectrograph data display.

e. Outgoing stripped data for orbit and attitude determination and control will be transmitted to the IBM 360-95 installation via duplex data lines during the transfer orbit. Backup support will be performed on the IBM 360-75.

f. Communication links will be provided to the SOC for experiment control and data display.

g. Communication links will be provided to the integration and test facility to support spacecraft testing.

6.2.2 SOFTWARE REQUIREMENTS

This section covers the functional requirements for software to be implemented on the C&C computer. The C&C computer software system encompasses the computer operating system; telemetry, command, and control software; observatory control software; and spacecraft integration software.

A continuing need for software development will exist in the OCC, such that all available computer time more than that required for operations and maintenance will be devoted to this effort. This continuing need further implies a duality of use of the computer, where a processing task and program development can be taking place simultaneously. Provision for compilers, assemblers, loaders, etc. as part of the control center computing system must be made.

6.2.2.1 Operating System

The operating system (OS) needed to support the IUE mission will be the dominant software for controlling the computer facility, particularly with respect to utility functions such as input/output, language translations, etc. The OS will provide the division of memory into real-time and batch structures, with priority given to the real-time region.

One or more user-supplied supervisor modules will be located within the real-time partition of memory. These will interact with the OS to control the utilization of the real-time region. Each of the user-supplied supervisors of the real-time region will interact with the OS to load and execute submodules in response to cataloged lists or operator requests.

The OS selected will have to be modified, at least to the extent of providing some I/O handlers for specialized I/O requirements (such as image handling) and perhaps modifying the vendor-supplied criteria for scheduling, priorities, etc. Such modifications must be supported at least to the standard obtained with vendor-supplied software.

To meet the requirements of the IUE mission, the OS, as modified, will provide the following:

- Optimal use of asynchronous operations, particularly with respect to I/O.
- Small size (20 K words or less).
- Memory protect features, particularly between the foreground (real-time) and background (batch).
- Background checkpoint capability.
- Foreground and background concurrent operations.
- An extensive user-controllable task priority interrupt facility.
- Master/slave modes with master state available to selected users.
- Device-independent I/O facility.
- Concurrent peripheral processing.
- Mass storage random (nonsequential) data accesses.
- Variable-length file capability (desirable but not essential).
- Comprehensive file management for tapes, disks, RAD, etc.

- System utility and mathematics libraries, etc.
- System loaders, link editors (particularly overlay capabilities), language translators, etc.

6.2.2.2 Telemetry, Command, and Control Computing Requirements

This software will consist of several interrelated functional subsystems. The PCM subsystem will process the real-time telemetry data as it is received and determine the status, health, and performance of the spacecraft and scientific instrument. The results of this processing will be displayed online for command and control operations. Selected command and telemetry data will be made available to the observatory control software.

The status data control and display subsystem consists of software necessary to present, maintain, and update the mission system and spacecraft system status data essential to flight operations. This software will interact with operations consoles, CRT devices, strip charts, timing units, etc.

The command generation subsystem will operate in conjunction with the PCM and status data control and display subsystems to afford the complete capability for command compilation, display, transmission, and verification. During the real-time acquisition, the command messages will be checked against a list of restricted commands and normally transmitted automatically, but under command operator surveillance. The major source of these commands will be from the observatory control software.

The operations control center software subsystem will consist of the following software elements which will be independent of the other subsystems but necessary to their operation: (a) system backup, (b) data base generation and maintenance, and (c) test, diagnostic, and simulation. In the design and implementation stages of the flight software, maximum use will be made of programs developed for spacecraft and experiment integration and test and programs and routines previously developed for other control centers.

The following software modules will satisfy the requirements for these functional subsystems.

6.2.2.2.1 System Executive Module. The executive module will consist of the following two areas of application software designed to augment the vendor-supplied operating system:

a. Operator Interpreter. Operations personnel will interface with the computing system via keyboards. This program will interpret the request through dialog with the operator and trigger other modules (display, command, printout, etc.) as required. The module will also interpret requests from function keys, switches, and command function groups if required. Requests having a higher priority than the function currently being performed will cause that function to be suspended and placed in an interrupt queue. If the request is of a lower priority than that currently being performed, it will be placed in the request queue for later processing. As each request is satisfied, the interrupt and request queues will be interrogated to determine the next processing task.

b. Interface Control. This software will handle the interface between applications programs, the computer vendor-supplied operating system, and the special OCC equipment (nonstandard peripherals, devices, etc).

6.2.2.2.2 Data Acquisition Module. All input/output of spacecraft telemetry and command data will be handled by this module. It will accept serial telemetry data from a frame synchronizer, decommutate the telemetry words, extract selected words, and output these words for display at strip-chart recorders. It will also make the decommutated data available to the processing programs. The module will accept data from the station unblocked or in the standard format. The standard format contains NASCOM header data and source/destination codes, followed by telemetry data and flag bits. The header will be checked to determine if the data is legitimate. The flag bits will be checked for the presence of command status information, such as command number, time of transmission, and command message disposition. Any command status information will be given to the command management module to provide feedback to the command operator. The telemetry data in the blocks is handled in the same way as the serial data described above. The module will accept data from the spacecraft history tape and provide all of the capability described for serial data. When operational control of the spacecraft is transferred from the U.S. Observatory to the European Observatory, it will be necessary to transfer representative samples of latest housekeeping data and other vital information such as experiment pointing status.

This data will be placed in storage by the appropriate processing modules during the wrapup phase. The module will handle the input/output, timing, and any interrupts associated with sending and receiving the data over this special interface. Additional capabilities of the module are as follows:

- GMT input to the computer.
- An option to record all raw data on a storage device.
- An option to dump all selected data on the printer.
- Status indicators on control and display consoles.

6.2.2.2.3 Command Management Module. The command management module will provide for the creation, transmission, verification, and display of all prestored command sequences and real-time commands. The sources of these commands are: (a) operator interpreter (via command panel or keyboard), (b) star acquisition and other observatory control software, (c) memory loader for the onboard computer, (d) operations scheduling, and (e) automatic test programs during environmental testing. Upon receipt of the commands, the command management module will present these to the display module for presentation at the command operator's console. All critical commands will be flagged and the command operator at any time may add or delete commands by editing the command display. When the operator initiates transmission, the commands will be assembled into the proper format and transferred to the primary ground station or to other STDN stations during the transfer orbit. The commands, as transmitted to the spacecraft, will be returned to the OCC for verification. The management module must verify this data and cause retransmission of commands found to be in error. The results of commanding (acknowledge, reception, uplink complete, and telemetry verification via the real-time processor) will be presented to the command operator via a CRT display, so that the current status of the spacecraft is known.

This module will also provide for the input of spacecraft computer memory loads via cards or preformatted images on high-speed external storage. The critical parts of the memory load will be displayed at the operations console CRT for verification and initiation of the transmission to the station. The memory load will be put in proper format and sent to the station for uplink to the spacecraft. The spacecraft will be commanded to dump the new memory load via telemetry matrix readouts for verification purposes. A bit-by-bit comparison between the transmitted and received memory loads will be made and any discrepancies displayed at the operations console CRT. If discrepancies are present, the entire sequence of commands must be repeated.

6.2.2.2.4 Real-time Processing Module. The real-time processor will take decommutated data from the telemetry buffer and perform limit checking, status determination, calibration, and command verification. The transformed quantities will be left in common areas for use by the processing modules.

a. Limit Checking. Spacecraft housekeeping parameters will be tested against predefined upper and lower limits to alert the operator to abnormal conditions. Parameters may have more than one set of limit values, depending on the spacecraft status.

b. Status Determination. The spacecraft status will be described by determining the operating mode of each status item. In order to determine the mode of each item, its associated functions will be range checked, that is, compared against predefined values to determine in which range the sample lies.

c. Calibration. All functions will be converted from PCM counts into engineering units and formatted into various subsystem displays for presentation at the operations consoles.

d. Command Verification. Each command sent to the spacecraft by the command management module will be transferred to the command verification module. For each command input, the module will predict the status change that should occur and check the telemetry data to determine if the desired response has occurred. The command will be reported to the command management module as verified if the status change is found within a prescribed period of time. All the status changes are identified and reported.

All of the transformed quantitites will be formatted for presentation at the operation console CRT or on the line printer.

6.2.2.2.5 CRT Display Module. The CRT displays will have at least 40 characters per line and 20 lines per page for an adequate presentation of the data. In addition, pages being displayed on a CRT will reside in the CRT display memory. The results of processing by the command management and the real-time processor modules, involving as many as 50 different preformatted reports (pages), will be presented in real-time at the console CRT displays at operator request. The module will accept keyboard operator inputs for constructing new pages, freezing pages, scrolling, report request, and printing hard copies. Pages in the CRT memory will be kept current at the telemetry rate. Copies of any CRT pages will be provided by the system line printer.

6.2.2.2.6 Experiment Image Processing Module. This processor will supervise all experiment image data processing. Specifically, it will handle input/output, module interfaces, and any interrupts. The acquisition image data will be routed to the acquisition display processor for display purposes to assist in star acquisition, and the spectrograph image data will be routed to the spectrograph data handler for reformatting and transferring to the data processing computer for in-depth processing.

a. Acquisition Display Processor. This processor will accept image information from the data acquisition module and reformat the information onto a disk file for storage and display, along with other information pertinent to the acquisition process. Modules of the observatory control software will pick up this data and present it in either raw form or as a coded, calibrated image to be used for fine acquisition slewing.

b. Spectrograph Data Handler. This handler will accept spectrograph image information from the data acquisition module, reformat it, and write it in a file on the shared disk along with other data pertinent to the spectrogram. A rudimentary display option will exist such that the spectrograph image can be viewed on the acquisition display in quick-look form. It will be the task of the IP computer to retrieve unprocessed spectrograph data from files on the shared disk-pack device, to process and display such data as the operator wishes, and to produce final reduced data outputs.

6.2.2.2.7 History/Report Module. This module will perform the recordkeeping job in the system. It will record representative samples of telemetry data on magnetic tape for historical purposes and summarize specified housekeeping parameters for statistical reports. In addition, it will maintain spacecraft performance trend values and events for spacecraft, experiment, and system analyses. Some of the outputs will be as follows:

- Subsystem, command, and alarm summary reports.
- Event log.
- Spacecraft history.
- Spacecraft performance trend values.

6.2.2.2.8 Miscellaneous Software Module. Other computer software will be developed, as required, to satisfy miscellaneous OCC functions, such as the following:

a. Data Base Generation and Maintenance. This software will store, catalog, and control information for the applications software of the OCC. Computer vendor-supplied routines will serve for storing and retrieving data from the mass storage devices. Special programs will be required for the control, maintenance, and updating of the engineering data such as telemetry ranges, limits, alarms, and calibration logic, status logic, report formats, command data, etc.

b. System Backup. Software will exist for the image processing computer system to provide full backup capability for the C&C computer failure. The software for the image processing computer will be essentially identical to the software for the C&C computer. If the C&C computer malfunctions, the image processing computer will be able to provide backup support within 10 minutes. Additionally, C&C computer software will be provided to store the spectrograph data if the image processing computer fails.

c. Diagnostic, Test, and Utility Programs. Many different types of diagnostic, test, and utility software will be required to support the integration, test, and operation phases of the OCC. These programs will be written as needed and must satisfy the following functions:

- Computer and peripheral tests.
- Special hardware and interfaces (not supplied by computer vendor) tests.
- Application software tests.
- Tests of isolated components of the first two items concurrent with operations.
- Network configuration and validation tests.
- Spacecraft telemetry simulator for OCC tests and operator training. It has not been decided which computer will be used for the spacecraft simulator.
- Utility programs for miscellaneous data management functions.

d. Program Developments. This software will support the ongoing development of software systems and will include assemblies, compilations, and support activities. During carefully defined periods there must be sufficient computer resources available to permit some non-operational functions to be performed. These will include support activities such as tape listings, duplications, and generation of system tapes. An operational consideration here, however, would be the exclusion of program checkout or other work where there exists the possibility of interfering with normal real-time control center activities.

6.2.2.3 Observatory Control Computing Requirements

The observatory control software to be developed for IUE will serve as the basic control interface between the guest observer and the observatory. It will be used both in actual online operations and in offline planning support. This software system will interactively analyze the observation requests against constraint data to help ensure spacecraft safety. It will further provide the command sequences required to fulfill accepted observation requests. These commands will then be optionally enabled for transmission to the spacecraft (Figure 6.2-1). Once a given maneuver has been completed, the acquisition image will be displayed in order that the observer might interact by means of slew adjustments needed to center the target star in the spectrograph aperture (Figure 6.2-1). The control software will also provide auxiliary support in the areas of alignment, calibration, three-axis attitude determination and onboard computer backup. Some of the functions to be supported under this software complex are:

- Model the spacecraft and its environment.
- Compute maneuvers.
- Generate command requests for observatory activities.
- Detect constraint violations.
- Process and display acquisition and quick-look spectrograph images.
- Calculate accurate star positions.
- Provide interactive graphics system between observers and observatory.
- Provide basic data management.

EXPERIMENT PERIOD

Acquisition Episode ≈ 30 Min (Note 1)

Coarse slew — ≈10 min	First field camera exposure and readout ≈ 5 min	Pointing identification — 5 min	Fine slews — 30 sec each and concurrent field camera exposures and readout — 20 sec each	Jitter evaluation — 5 min

Observing Episode ≈ 43 Min (Note 2)

Exposure ≈ 40 min. Also observer preacquisition planning period					Readout — 5 min
Pointing calculation #1 — 6.6 min	..	Pointing calculation #2 — 6.6 min	.. etc.		

Notes:

1. Following initial pointing identification by the guest observer, the computer may make fine slew identifications and command field camera exposures continuously to allow visual observation of the star moving into the spectrograph aperture.

2. At the end of the observer's planning period, the next star of interest will have been selected and the present attitude, desired attitude, and sequence of slew commands will be known for use at the end of the readout period.

Figure 6.2-1. Computer Usage During Experiment Period

- Align and calibrate the IRA, acquisition camera, attitude sensors, etc.
- Provide for three-axis attitude determination.
- Select the optimum spacecraft antenna for the telemetry downlink.
- Provide ground software backup to the onboard processor.

All but a small portion of the above software will be used directly by the observer. However, certain software management activities are still required to support mission operations. This operations activity would typically entail the following:

- Maintenance of source/object and program libraries.
- Data management activities.
- System acceptance testing of new software elements.
- Records keeping and computer-use coordination, etc.

The following subsections present the functional requirements for the software to be implemented for IUE operations.

6.2.2.3.1 Spacecraft Environments Module. This module will be used to access spacecraft and celestial characteristics and to perform necessary updates to these data. This module will update program parameters to the current spacecraft state in preparation for processing of spacecraft maneuver requests.

Some of the functions to be performed via this module are as follows:

- Provide a control responsive to various inputs which will initialize commanding and controlling systems for spacecraft maneuvering.
- Accept historical data to initialize program parameters to reflect current spacecraft status.
- Initialize parameters defining spacecraft hardware characteristics such as misalignments, slew rates, etc., and also initialize any operations constraints such as smallest angle permitted between optical axis and sun line, etc.
- Update celestial configurations from standard reference to a current state.
- Provide a capability to automatically redefine the value of all parameters input to this module without requiring an immediate data base update.
- Provide for outputting the results of this module execution.

6.2.2.3.2 Spacecraft Maneuvering Module. The spacecraft maneuvering module will provide the basic functions needed to operate the spacecraft in the experiment mode and to perform a better-beta sequence. The experiment function involves the normal slewing activities needed in going from one target to another. The better-beta function involves slew sequencing in an effort to achieve a better-beta angle for power purposes.

The functions to be performed by this module are as follows:

- Computation of all maneuvers, including large and small slews, and improved power maneuvers, etc.
- The accepting of maneuver requests from interface modules and the computation of the parameters of requested maneuvers on the basis of the updated model data provided by the data management module.
- The fabrication of command sequences as required and the communication of these to the spacecraft controller.
- The providing of information on constraint and failure conditions as they occur.

The maneuver computations will be all made on the basis of standard inputs, normally provided by the output of the astronomer interface display (AID) module. The data base for maneuver computations (episode data base) is the updated model data provided at the output of the initialization phase by the data management module.

The status of the spacecraft will be modeled in the data base in addition to the actual spacecraft. This will allow the observer some freedom in selecting maneuvers for simulation or planning purposes, without changing the status of the model of the actual spacecraft or requiring a command sequence to be fabricated.

Each maneuver requested will be tested against the local constraints (episode constraints) before being executed. If the local constraints are violated, this condition will be reported to the observer. If the observer still wishes to compute the maneuver, the maneuver will have to be validated against the global constraints. If the maneuver can safely be performed, the appropriate commands will be fabricated. Then a new episode will be initiated which centers the postmaneuver conditions in its unconstrained region.

A functional description of each of the submodules is given in the following paragraphs:

a. Maneuvering Driver. Central logic unit for maneuvering. Will accept input arguments and call up the appropriate submodules. The driver supervises operation of the spacecraft in three logically distinct modes — normal operations, inertial initialization, and better beta.

b. Slew Generation Task. Computes large and small slews from current attitude to desired attitude or pointing. Will also compute the time necessary to perform selected slew for comparison with time remaining in the target acquisition sequence (episode):

   (1) Accepts current attitude and desired attitude or pointing.

   (2) Compares desired pointing with episode constraint; returns if constrained.

   (3) Computes optimum roll angle if roll is not specified.

   (4) Determines optimum slew sequence between attitudes. Allows for possibility of defective momentum wheel.

c. Specific Command Task. Given a sequence of specific commands, checks against episode constraints and updates the model appropriately.

d. Constraint Handler. Tests for global (extended) constraints on maneuvering. This submodule is used when a maneuver violates an episode constraint. At the option of the observer, the desired maneuver can then be tested against the global constraints, and if unconstrained, can be commanded. Then a new episode is initialized about the maneuver terminal condition.

   (1) Determines for a given slew sequence whether the spacecraft goes within a prohibited region about the sun, or whether sunlight will enter the experiment optics under static or dynamic conditions.

   (2) Determines similar conditions for lighted moon and earth, if required.

   (3) Computes thermal and power constraints, if required.

   (4) Computes episode space and time constraints for sun, moon, and earth occultation relative to maneuver terminal attitude.

(5) Provides for initialization of new episode upon observer's concurrence.

(6) Selects the optimum S-band antenna for the telemetry downlink.

e. Command Fabricator. Accepts arguments defining a command or command sequence and outputs the corresponding commands in a form suitable for direct communication to the spacecraft controller:

(1) Given a set of arguments, generates the associated commands.

(2) Provides the capability of defining and issuing standard sets of commands from a command pool.

f. Maneuvering Output. Outputs results of spacecraft maneuvering module excution:

(1) Produces printed report of results of execution.

(2) Provides arguments to the astronomer interface display module necessary to communicate with the observer.

(3) Communicates command sequences to the spacecraft controller in a form suitable for immediate use.

6.2.2.3.3 Astronomer Interface Module. The astronomer interface module will perform the following functions:

- Recognize and interpret all observer requests for spacecraft maneuver computations, and inform the observer of the results of these computations.
- Provide visual displays and hard-copy formats of constraint and failure conditions, with respect both to requested maneuvers and to celestial and orbital environment constraints.
- Display the acquisition camera image in a flexible format interactively controllable by the observer, and provide an interpretive data input capability for direct spacecraft control via image manipulation.

The observer will be provided with considerable flexibility in specifying desired maneuvers and commands. The nominal mode for large slews will be to specify 1950.0 right ascension and declination, but roll angle may also be specified or specific slews requested. The nominal mode for small slews will be attitude changes defined by locating a target on the acquisition image display, but any attitude change or slew may be specifically requested.

If a failure or constrained condition occurs, the observer will be notified and his alternative actions will be indicated. He may wish to proceed in violation of the constraint indicated (go ahead with a slew request which violates local constraints but which other computations have shown is globally safe), he may wish to specify a different target, or he may wish to examine the global enviornment and then perhaps reinitialize the episode.

The observer may call, at any time, for a hard copy of visual display of his local or global environments. These will be used for analysis of present or past situations or for planning for future experiments.

The acquisition image display will be the ordinary means by which the target will be located and maintained. Target selection and maintenance will normally be performed using only image parameters defined and selected by the observer, and a direct spacecraft control option (enabled by the command controller) will link certain spacecraft fine maneuvering functions directly to the image manipulations under control of the observer.

A functional description of each of the submodules is given in the following paragraphs:

NOTE

> Beyond the level of functional requirements is the software required to interface the module I/O to the display devices I/O. This software may be all or in part vendor supplied.

a. Driver. Central logic unit for display handling. Responds to various inputs to determine which page is to be displayed at any time, and to call up submodules as required to support and maintain the display.

b. Maneuver Request Table. Provides a menu of maneuver formats for selection and completion by the observer. Some prompting and editing capabilities are included. Large slews, search and dither patterns, and improved power maneuvers can be requested via this submodule.

c. Spacecraft Command Table. Provides a menu of activities enabling the observer to select an activity which causes a sequence of commands to be transmitted to the spacecraft under command operator surveillance.

d. Timeline Display. Displays target viewing and spacecraft constraints in a timeline format, and provides input capability for observer response. These constraints may include, but are not necessarily restricted to:

- $\pm 43^{o}$ cone around the sun
- Anti-sun (Thermal B angle)
- Earth occultations
- Sunlit earth or moon
- Antenna nulls
- Gyro update

e. Acquisition Camera Image Manipulator. Displays the acquisition camera image in a variety of formats. Contains provision for inputs via light pen, function key, and keyboard. Input requests are dynamically interpreted and arguments are computed if necessary and passed to the operating modules for execution. Results of the execution may then be displayed in appropriate form and a response awaited. Individual routines will provide image manipulation services as required, as directed by a driver:

(1) Driver. Logic unit; interprets acquisition image display requests and calls up routines as needed.

(2) Disk-to-core Format Converter. Reads from the interface disk the telemetry data representing a single raw image, converts it to core storage format, and stores it in core. The conversion may involve such techniques as data compression, feature identification and coding, etc.

(3) Core Image Display Routine. Displays the core format image on the CRT, with option to display or suppress fiducial marks and nominal aperture.

(4) Star Identification and Location Routine. Accepts display positional input to identify star (target image), and computes center-of-light and local coordinates (relative to core image). Accepts 1950.0 (or other) right ascension and declination celestial reference location of target.

(5) Image Regularizer. Regularizes acquisition image by means of linearizing transforms, intensity conversions, etc., as required. This routine is simply a driver to load arguments and call the alignment and calibration module driver to direct the actual computing.

(6) Celestial Coordinate Grid Generator. Overlays a celestial coordinate grid on regularized acquisition camera image. This is done by fitting best (least-squares) transformation of local coordinates to celestial reference locations for all stars identified (minimum = 2).

(7) Image Manipulator. Provides translation, rotation, and zoom capabilities, as well as more specialized image manipulation functions (for example, intensity clipping).

(8) Command Interpretation and Response Routine. Accepts various forms of commands to slew to target star (fine slew), reexpose acquisition camera, etc. Status of request and commands sent will be indicated on CRT.

A detailed list of functional requirements desired by the observer will be incorporated into the astronomer interface display and spacecraft maneuvering modules. These requirements are as follows:

a. Commandability. Call up, display, and execute experiment-related commands or command groups.

b. Experiment Status Data. Access and display experiment-related status data from the status data set maintained by the spacecraft control center.

c. Target Lists and Star Field Displays

(1) Access and display a list of targets.

(2) Display sky charts of target stars.

(3) Access and display a log of past operations.

d. Target Selection. Select and identify by console positional input, a single target or a sequence of targets.

e. Target-related Orbital Information

(1) Compute and display slews and slew time to a single target or through a sequence of targets.

(2) Display celestial coordinates, roll angle, sun angle, etc., for each target.

(3) Display target viewing and spacecraft constraints in a timeline format.

f. Large Slews

(1) Select new target from listing or star chart with light pen.

(2) Check new attitude for long-term stability.

(3) Display constraint violations (if any).

(4) Initiate start of slew from console. (All spacecraft maneuvers and experiment commands initiated from the astronomer interface display will be supervised by the computer for safety considerations and may be flagged, delayed, or inhibited according to procedures specified by the command controller.)

(5) Display maneuver status.

g. Finder Chart Display. Display finder chart overlays for the acquisition and fine guidance fields.

h. Acquisition Camera Display

(1) Perform image corrections in computer prior to display.

(2) Display camera image and finder charts simultaneously.

(3) Optionally suppress star images below a specified magnitude limit on both acquisition and finder field images.

(4) Perform small rotations and translations of finder chart.

(5) Display calibrated location of spectrograph slit.

i. Target Acquisition

(1) Accept light-pen identification of the target to be placed in the slit.

(2) Accept light-pen or computer-generated (pattern recognition) identification of offset guide star.

(3) Verify target identification.

(4) Calculate target location.

(5) Compute small slew to place target in slit.

(6) Compute fine error sensor offset.

(7) Initiate small slew from keyboard.

(8) Initiate fine error sensor tracking.

(9) Initiate fine error sensor control.

(10) Update acquisition camera image as necessary.

(11) Display star presence signal and fine guidance errors.

j. Exposure Setup

(1) Display current experiment status.

(2) Execute experiment commands from keyboard and display new status.

(3) Execute commands to start exposure.

k. Observation Monitoring

(1) Read out acquisition camera or check fine guidance errors as often as necessary to verify proper pointing stability.

(2) Optionally repeat small slew acquisition procedure to keep star in slit.

In addition the following functions will be performed as required:

a. Focus Telescope

(1) Select suitable focus star from listing.

(2) Execute steps f, g, h, and i from preceding paragraph.

(3) Initiate focus measurement procedure.

(4) Display focus data.

(5) Change telescope focus from console.

(6) Repeat steps 3, 4, and 5 as required.

b. Calibrate Acquisition Camera

(1) Select suitable star field from listing.

(2) Execute steps f, g, and h from preceding paragraph.

(3) Expose calibration lamp.

(4) Process acquisition image to calculate image distortions, accurate locations of all spectrograph slits, and accurate locations of fiducial lamps.

(5) Store calibration data for use in processing subsequent acquisition images.

c. Track Moving Targets (for solar system observations).

6.2.2.3.4 Data Management Module. The data management module will be used as follows:

- To access the data base to obtain spacecraft, celestial, and orbit characteristics, and the historical data from the previous episode.
- To perform necessary updates of this data to the current state in preparation for processing by the operating modules.
- To write out these updated data to a main storage common area for use directly by the operating modules without need for further preprocessing.

The episode for which the updated data will be considered valid is defined by time and position boundary conditions which will be continuously monitored by the operating module drivers to ensure the validity of the computations. Selected submodules of the data management module will also be used to maintain the data base (display, modify, and create data) and to provide for the orderly storage of historical data at the conclusion of each episode.

A functional description of each of the submodules is given in the following paragraphs:

a. Initialization Driver. Central logic unit for initialization. Determines which initialization functions have to be executed and calls them in order as needed.

b. Historical Data Task. Retrieves stored continuity data and writes these data into common area to represent current status. Includes such items as spacecraft attitude, sensor status, etc. Also writes historical data onto data set during and after episode.

c. Spacecraft Data Task. Initializes parameters defining spacecraft hardware characteristics such as misalignments, slew rates, etc. Also initializes any constraint parameters relating to spacecraft operations, such as smallest angle permitted between optical axis and sunline, etc.

d. Celestial Data Task. Updates celestial configurations from standard references to a current state. This involves updates of sun and moon orbits and possibly bright planet and stellar positions. Also spacecraft orbit is updated to current time.

e. Ground System Staff Input. Provides capability to quickly redefine value of any parameter in common area without requiring data base update.

f. Initialization Output. Outputs results of initialization module execution as descriptive reports.

g. Modify Data Base. Provides for protected, systematic display, modification, and creation of data base elements. Provides descriptive report of changes and full hard copy of data base. Provides test programs with comparison of results as appropriate.

6.2.2.3.5 Initial Acquisition Module. Once the gyro hold mode is achieved on the sunline, the initial acquisition module will provide the automated assistance needed to search for a second stellar reference. This reference then establishes the three-axis attitude of the spacecraft. The major functions of this module are as follows:

- Provide requested yaw slew commands.
- Provide requested displays of the acquisition field.
- Aid in the identification of selected candidate guide stars from an acquisition display.
- Once a candidate guide star has been been identified, commands the spacecraft to slew such that the star is put into the fine error sensor (FES) field of view on the acquisition image.

6.2.2.3.6 Alignment and Calibration Module. The alignment and calibration module will be an offline function performed only when the alignment and calibration parameter values change significantly enough to degrade observatory performance. Its basic functions will be as follows:

- Estimate the alignment and slew angle scale factors of the inertial reference assembly gyros.
- Align and calibrate attitude sensors as necessary.
- Align entrance aperture to acquisition camera image fiducial marks.
- Calibrate brightness, distortion, and other features of acquisition image necessary to specify regularizing transformations.

6.2.2.3.7 Three-axis Attitude Determination Module. The attitude determination software will be required for both normal operational activities as well as for periodic station-keeping functions. The station will be maintained using this software in conjunction with the OCC command system.

The major functions of this module will be as follows:

- Accept sensor readings.
- Perform any conversions needed to relate sensor readings to directions.
- Calculate reference vectors as a function of the current environment (position of sun, earth, stars).
- Determine the relationship between the vector directions generated from the sensor output and the reference vector, which determines the attitude required.

6.2.2.3.8 IUE Simulator. The IUE Simulator resides in an IBM 360-65 and will provide a software model of the IUE spacecraft. The major functional objectives of the simulator will be to provide:

- Training for dynamic commanding of the IUE spacecraft.
- Dress rehearsal capability for the guest observer to help familiarize him with the mechanics of observatory procedures prior to his own allotted experiment time.
- A checkout and debug capability for the OCC software.
- A mechanism for verifying the adequacy of the OCC hardware/software configuration for carrying out normal operations.
- An aid in developing adequate operations procedures.
- A means for evaluating the sufficiency of displays and other informational aids in the operations environment.

6.2.2.3.9 Ground System Software Backup to Onboard Processor. The ground support computers will have the responsibility for providing software programs to backup the onboard processor aboard the IUE. The onboard processor will be capable of commanding any spacecraft system if programmed to do so. This includes the capability of issuing stored commands on a time delayed or event dependent basis. The basic onboard processor task is one of attitude control. The ground based software will interact with telemetry, execute prescribed programs, and issue commands. Currently it is planned that the onboard processor execute the attitude control laws for attitude hold and slew modes. The onboard processor will get both IRA and FES inputs and address commands to the reaction wheels. The onboard processor will also provide software redundancy for the hardwired control modes such as nutation control, initial sun acquisition, etc.

The extent of ground system backup, while not yet detailed, will nonetheless be quite extensive and probably include the following:

- Execution of the control laws.
- Model delayed mode execution.
- Model sun acquisition.

6.2.2.4 Integrated Telemetry, Command, and Control/Observatory Control Requirements

The computing resources required to accomplish the total spacecraft and experiment control tasks were investigated from two basic points of view; viz., core storage size and execution throughput time. The maximum use of computer resources will occur during the observing episode illustrated in Figure 6.2-1. Then the telemetry, command, and control functions will require the computer for housekeeping purposes, and observatory control functions will require the computer for experiment control activities. The functional interrelationship of this software is illustrated in Figure 3.3-1.

The computer resources that will be required for telemetry, command, and control and those for observatory control are given in this section. Table 6.2-1 shows the resident functions and corresponding core storage and CPU timing. The total core requirement is shown to be 127 K words. The execution throughput time problem was investigated by quantifying two parameters:

a. The percentage of total computing time which the C&C computer will require to do housekeeping at the expected telemetry rate. These estimates are based upon experience with C&C of the ERTS spacecraft using the ERTSOCC Sigma 5.

Table 6.2-1
Software Mix for Control Center Computer

Resident Functions	Core Required (32-Bit Words)	Time Per Major Frame	Planning Time Per Observation
Operating System			
1. Operating system	15K	10 msec	
Telemetry, Command, and Control Function			
2. System excecutive	5K	10 msec	
3. Data acquisition	10K	100 msec	
4. Command management	11K	50 msec	
5. Real-time processor	14K *	450 msec	
6. CRT Display processor	8K *	50 msec	
7. Spectrograph experiment processor	5K *	85 msec	
8. History/report	2K *	5 msec	
Maximum required core	40K	Total 760 msec	
Observatory Control Function			
9. Graphics support	40K *		1 msec shots
10. Maneuver computations	40K *		30 sec shots
11. Session continuity	10K *		10 sec
12. Executive and common areas	20K		
Maximum required core	60K		
Background			
13. Background processing area	12K		
Total			
Total, maximum required core	127K		

*Items within brackets will be swapped in and out of core one module at a time, as required.

b. The accumulated total computing time which the observatory control task will require during the experimenter planning interval. These estimates are based upon experience with OAO experiment control using the IBM 360-65.

The worst case for item a. above occurs at the normal telemetry, information rate of 40 kbps. At this rate, a subcommutator cycle is received every 1.64 seconds. Table 6.2-1 shows that the total accumulated telemetry, command, and control processing time per major frame is 0.76 seconds; therefore spacecraft housekeeping will consume 0.76/1.64 = 46.3% of the available computer time, leaving 53.7 percent for observatory control support computing in the time-sharing environment.

When this 53.7 percent resource is applied to the 214-second time requirement (see paragraph 6.2.2.4.2), the resulting total time required for the experiment planning per observation will be 214 sec/53.7% = 398 sec = 6.6 min.

NOTE

> These calculations represent the worst case condition; it is anticipated that no more than 3 minutes will be required per observation. The calculations were based on processing every telemetry word. This will probably not be required. In addition, the computer will be performing these computations during the exposure period and therefore should not normally impact the observers sequence.

6.2.2.4.1 Telemetry, Command, and Control Requirement. These software requirements were gathered and documented to size the C&C computer. The software requirement estimate assumes that all housekeeping data from every subcommutator cycle will be processed. The normal processing situation will be a new major frame every 1.64 seconds, based upon a telemetry information rate of 40 kbps. The software system is organized into modules to satisfy the C&C requirements. A functional description of each module is given in paragraph 6.2.3. The memory size and timing of the modules are estimated based upon similar modules existing both in OSOOCC and ERTSOCC on Sigma 5 equipment. Modules 2, 3, and 4 (Table 6.2-1) must be resident in core memory because of the timing constraints, response time, and module interplay imposed upon the system. It is intended to swap modules 5 through 8, thus reducing to a minimum the resident core requirement. Therefore, 55 K memory will be needed with computer time utilization of 0.76 seconds per major frame.

6.2.2.4.2 Observatory Control Requirement. The computer resources required for observatory control during the experiment control interval were determined as follows. The functional requirements for this software were drawn up as listed in paragraph 6.2.3. The core and execution time requirements to perform these functions during a typical experimenter planning interval has been determined. Such an interval involves the investigation and generation of a complete target-to-target slew. The appropriate functions are found in the spacecraft maneuvering module. The specific functions which would be performed by this module during a typical planning interval were broken out in sufficient detail that many of them could be identified as being identical or similar to functions performed by the OAO support computer (IBM 360-65) program system (SPS). The core storage and total time required to perform these functions was estimated on the 360-65 computer now being used to run programs of a similar nature. The resulting estimates were a nominal 40 K words of storage and a nominal 55 seconds of total time.

So that the requirements for core memory and timing shown in Table 6.2-1 are based on a common computer system, the 360-65 estimates were converted to the Sigma 5. The core storage requirements of 40 K words on the 360-65 transforms identically to the Sigma 5. The maneuvering module is expected to require the greatest amount of core. The total core storage requirement for observatory control computing was set at 60 K words (Tables 6.2-1, 40 K words for applications programs plus 20 K words for executive and data). An empirical study of relative throughput time was performed using the ERTS OCC Sigma 5 and the OAO/SCPS 360-65. The resulting relative time factor adopted was the factor 3, the ratio by which the 360-65 was faster than the Sigma 5. Applying this factor to the estimated 55 seconds of 360-65 time results in an estimated 165 seconds of Sigma 5 time to accomplish the spacecraft maneuvering computations. To account for overhead in executive, graphics support, and data communications between modules, this estimate was increased by 30 percent, to 214 seconds.

6.2.2.5 <u>OCC System Requirements</u>

The OCC system must meet the functional and software requirements specified to support the IUE spacecraft. Telemetry and command data processing will be performed and data presented to spacecraft controllers and experimenters in real-time.

Provision will be made for the operators to interact with the OCC systems for real-time spacecraft control.

6.2.2.5.1 Command and Control Computer System. The C&C computer system to support the IUE spacecraft will be especially suited for real-time I/O and will simultaneously perform data processing. The preceding discussion of requirements permits an evaluation of system characteristics. The requirement for the major components of the computer system are described in the following paragraphs.

a. Core Storage/CPU Utilization. Based upon the OCC processing requirements S/W functional modules were identified and sized to estimate the core storage requirements. The total core requirement will be 127 K 32-bit words.

   The maximum demand for CPU utilization will occur during the 40-minute observing period, when housekeeping processing and observatory slew processing proceed concurrently. The telemetry, command, and control function will require approximately 50 percent of the computer time, leaving 50 percent for the observatory control function.

b. Mass Storage. Rapid access device (RAD) storage (4.6 M bytes) will be required for the operating system and application programs frequently accessed by the CPU. Disk storage (24.9 M bytes) will also be required for the operating system, application programs, experiment data, and experiment support. The following is an estimate of mass storage requirements by function:

	Mass storage (M Bytes)	
Observatory Control	Disk	RAD
Acquisition images (4 images)	2.0	0
I/O and module storage	3.5	1.5
Source/object storage	4.4	0
Miscellaneous mission support	5.0	.4
Total	14.9	1.9

Operating System	Mass Storage (M Bytes) Disk	RAD
RBM operating system (2 copies)	1.5	1.5
Telemetry, Command, and Control		
Spectrograph data storage (4 images)	3.0	0
I/O and module storage	2.0	1.0
Source/object storage	2.5	0
Miscellaneous mission support	1.0	.2
Total	8.5	1.2
Grand Total	24.9	4.6

c. Magnetic Tape Storage. Magnetic tape units will be provided for the C&C computer. The tape units will use the 800 bpi, nine-track, IBM-compatible format widely used at GSFC, so that tapes can easily be transferred between GSFC computer systems. This will permit some offline processing to be performed on other computer systems and the tapes easily transferred to the C&C computer. Two digital magnetic tape controllers will be provided, each with two tape units. The magnetic tape units will be required for:

- A history tape of selected spacecraft data.
- A command history.
- A star catalog, star field overlays, and other experimenter data needed for target identification and acquisition.
- General-purpose background processing.
- Backup to the disk storage for image data.
- Short-term record of housekeeping telemetry data.

6.2.2.5.2 CRT/Keyboard Interactive Display System. CRT/keyboard interactive displays will be used to provide real-time alphanumeric data to the spacecraft controllers and permit the controllers to provide inputs to the computer system. The keyboard will have a full ASCII character set and will provide capability for the operator to interact with the computer to update the displays and control operations.

Eight of the displays will be required for the Project Operations Director, command controller, data operations controller, computer system controller, and spacecraft subsystem engineers.

6.2.2.5.3 Experiment Display System. An experiment display will be provided in the MOR for performing star acquisition and spectrum data display. The C&C computer will provide real-time data to the star acquisition display for experimenter operational control of the spacecraft and initial viewing of spectrum data. This display will be located in the MOR for launch and early mission support, special operations, emergency operations, and backup to the experiment display in the SOC.

The actual display will be a high-resolution TV picture of the spectrum of the stellar object or the field of view of the star acquisition camera. The unit will provide flicker-free image presentations of digitally encoded data in pseudocolor. The color scale will provide at least 16 levels of intensity and the screen size will be at least 12 by 12 inches. The star identification and spectrograph image displays will be greatly enhanced by using color. An interactive capability will exist consisting of a keyboard, a lightpen, or internally positioned cursor. These will provide unambiguous positioning for selecting stars or spectrum data during the decision process. The keyboard will contain a full ASCII character set for interfacing through the display system to the C&C computer. A memory will exist for storing two full resolution images of 768 by 768 data points (8 bits for each data point). A TV monitor capable of displaying the output of the alphanumeric CRT's will be provided at the experiment displays in the MOR and SOC.

6.2.2.5.4 System Backup Requirement. The OCC C&C computer will be a critical element in the controlling and monitoring of the IUE spacecraft. Backup for the C&C computer will be provided to avoid a potential single point failure. Spacecraft C&C software will be available in the backup computer so it can be switched on line within 10 minutes after the failure of the prime C&C computer. Full backup capability will be provided so the backup computer will have the capability described for the prime C&C computer. The full backup capability will assure that normal operation of the spacecraft will continue and valuable experiment data and observing time will not be lost.

The CRT/keyboard system will be switchable to either the prime C&C computer or the backup computer.

The experiment display in the MOR will provide backup to the experiment display in the SOC. The GSFC Operations Control Center will serve as the backup to the ESRO Observatory Control Center; it will assume control of the spacecraft in case of emergency.

6.2.3 ESTIMATING REQUIREMENTS FOR COMPUTER CYCLE TIME AND CORE STORAGE CAPACITY

6.2.3.1 Observatory Control Software

The support computer program system (SCPS) currently supporting the OAO-C spacecraft has been examined to identify the functions similar to those which will be required for IUE support; Table 6.2-2 lists these functions. Those IUE functions which have no direct OAO counterpart are not discussed here. Of these, the simulations and training module has not be sized.

Based upon an investigation into the coding of the OAO target module, it appears that the IUE maneuver module would be approximately two-thirds as involved as the OAO target. This factor is then applied to the OAO table (Table 6.2-2) to generate the IUE table (Table 6.2-3). The onboard processor backup sizing is based on an assumption of backing up at least one-third of the 12 K capacity of the onboard processor memory. Table 6.2-3 is thus a summary of the IUE computer requirements for the mission software.

Approximately 20 K words of resident core memory will be required for a small (order of 1 K) executive program and 19 K words of common resident core. This root segment of all observatory control software then directs the operation of the astronomer interface, environments, maneuvering, and attitude determination functions. These modules themselves require 14, 22, 32, and 38 K words of core, respectively. It thus appears that the observatory control software will require about 60 K words of core storage for its inline experimenter support. The offline data management, initial acquisition and alignment, and calibration functions also appear to fit into this 60 K core size.

Table 6.2-2
OAO-C Observatory Control Functions on IBM 360-65

	Module Size[1]				Aux Storage[1]		
	Execution Core Requirements	Number of Overlays	Instruction Length	Common/Buffer Size	Nominal CPU Time	I/O and Module Storage	Source/Object Storage
1. Environments Module (OAO Intitial)	85 K	0	35 K	50 K	15 sec	100 K	82 K
2. Maneuvering Module (OAO Target)	100 K	30	138 K	50 K	60 sec	400 K	347 K
3. Astronomer Interface Module (Profile OAO System)	30 K	13	100 K	10 K	10 sec	134 K	400 K
4. Data Management Module (OAO ICPS)	40 K	35	120 K	20 K	2 sec	150 K	340 K
5. Initial Acquisition Module (OAO Star Search)	150 K	15	118 K	50 K	135 sec	160 K	145 K
6. Alignment and Calibration (OAO Mess)	100 K	8	110 K	20 K	180 sec	108 K	210 K
7. 3-Axis Attitude Determination (OAO Attd)	88 K	0	58 K	30 K	65 sec	66 K	54 K
8. Simulation and Training Module							
9. AOP Ground Backup Module							

[1] 32 bits per word

Table 6.2-3
IUE Observatory Control Functions on IBM 360-65

	Module Size[1]				Aux Storage[1]		
	Execution Core Requirements	Number of Overlays	Instruction Length	Common/Buffer Size	Nominal CPU Time	I/O and Module Storage	Source/Object Storage
1. Environments Module (OAO Initial)	56 K	0	26 K	34 K	10 sec	66 K	54 K
2. Maneuvering Module (OAO Target)	66 K	20	92 K	34 K	40 sec	266 K	232 K
3. Astronomer Interface Module (Profile OAO System)	20 K	8	66 K	6 K	6 sec	90 K	266 K
4. Data Management Module (OAO ICPS)	26 K	24	80 K	14 K	1 sec	100 K	226 K
5. Initial Acquisition Module (OAO Star Search)	100 K	10	78 K	34 K	90 sec	106 K	96 K
6. Alignment and Calibration (OAO Mess)	66 K	6	74 K	14 K	120 sec	72 K	140 K
7. 3-Axis Attitude Determination (OAO Attd)	58 K	0	38 K	20 K	44 sec	44 K	36 K
8. Simulation and Training Module							
9. AOP Ground Backup Module	6 K	2	6 K	1 K		6 K	12 K
[1] 32 bits per word							

6.2.3.2 Telemetry, Command and Control Software

The statistics in Table 6.2-4 were arrived at by direct comparison of IUE modules with similar modules existing both in OSO and ERTS operational control centers on Sigma 5 equipment. Although in a few cases significant differences exist, a large degree of confidence is assumed in the overall results.

6.3 OBSERVATORY SCHEDULING SOFTWARE

Preobservation planning and scheduling of the IUE observatory consists of estimating guest observer's required telescope time, calculating target availability dates, scheduling guest observer visits and daily observing shifts, verification of target guide-star availability, and generation of target finder fields and other acquisition aids.

The software system which aids the SOC staff to plan and schedule consists of five main subsystems programs or modules: (a) The exposure time module estimates exposure times for specified magnitude, spectral type, and signal-to-noise ratio. It calculates the required exposure time for each observation requested in a guest observer's program. (b) The target availability module calculates the percentage of targets of each program which are accessible throughout the scheduling period. This data is used to optimize the number of targets per visit. (c) The IUE sky constraint map generates plots which graphically display the viewable and restricted areas of the sky for a particular date and set of guest observer targets. These plots which are produced for each guest program at various dates during the scheduling period will be sent to each guest observer to aid him in his planning. (d) The schedule module works out a schedule of dates and length of stay for each guest observer. This program will probably be interactive to provide manual input and control for time-dependent and other special observing constraints which can not be handled in the automatic scheduling mode. (e) The guide star selector module examines a 15-arc-min field surrounding each guest observer's target to select or varify suitable stars for offset guidance. This program obtains its guide star input data from star catalogs on tape. Stars identified as suitable guide stars are listed in the output of this program which will be maintained for use in the acquisition phase of operations.

The IUE observatory scheduling software system is currently run offline to the IUE computers. It runs on the Code 600 360-75 computer. If some spare time is available on the IUE-dedicated computers it will be desirable to include these programs in the total IUE software system.

Table 6.2-4
IUE Telemetry, Command, and Control Functions on Sigma 5 Computer

	Module Size[1]				Aux Storage[1]		
	Execution Core Requirements	Number of Overlays	Instruction Length	Common/Buffer Size	Nominal CPU Time	I/O and Module Storage	Source/Object Storage
1. Real-time Batch Monitor (RBM)	15 K	—	—	—	10 msec	380 K	—
2. System Executive Module	5 K	2	6 K	1 K	10 msec	8 K	13 K
3. Data Acquisition Module	10 K	10	9 K	6 K	100 msec	120 K	100 K
4. Command Management Module	11 K	5	16 K	5 K	50 msec	125 K	200 K
5. Real-time Processor	14 K	0	11 K	3 K	450 msec	150 K	250 K
6. CRT Display Module	8 K	20	12 K	2 K	50 msec	50 K	34 K
7. Spectrograph Data Processing Module	5 K	2	3 K	3 K	85 msec	8 K	7 K
8. History/Reports Module	2 K	10	10 K	1 K	5 msec	30 K	20 K
9. Background Processing	12 K	—	—	—	—	—	—

[1] 32 Bits per word

6.4 INTEGRATION AND TEST SOFTWARE

The software required to support IUE integration, environmental testing, and prelaunch checkout consists of the following three groups:

a. The vendor-supplied operating system (RBM).

b. The foreground tasks which acquire telemetry, operate special input/output devices, and process telemetry.

c. A set of automatic test programs which run as background tasks but make use of the services and data provided by a and b.

These three areas are described in detail.

6.4.1 VENDOR-SUPPLIED SYSTEM

The vendor-supplied system performs the following functions:

a. Accomplishes all input and output operations to standard peripheral devices (tapes, printers, disks, etc.).

b. Accomplishes file management operations (allocate, deallocate, compress, copy, etc.) on the RAD storage devices. Files are logically equivalent to input/output devices and are created and used via system I/O calls.

c. Interprets incoming control statements which initiate foreground and background tasks.

d. Maintains a program library and overlay loader.

e. Provides proper handling of trap conditions, such that programming errors do not cause system crashes.

f. Provides the allocation of common storage (memory) as requests are received from tasks.

The operating system input/output services should be device-independent and such that input/output functions can be assigned to a wide variety of devices and files at run time without reprogramming. Thus, in the event of failure of a particular peripheral device, the functions assigned to that device may be reassigned to another device.

6.4.2 FOREGROUND TASKS

The set of foreground tasks consist of the following:

a. Telemetry Acquisition Module. Inputs PCM telemetry from either a PCM data channel or from an XDS 7601 data set controller. The actual source should be invisible to programs using the data.

b. Command Transmission Module. Accepts command sequences from calling programs and supervises their transmission through the local command generator or through the XDS 7601 data set controller. Calling programs should be oblivious to the destination.

c. Special Device Input/Output Handler. Accomplishes all data transfers to and from nonstandard peripheral devices, such as keyboard/CRT displays, digital-to-analog converters, the spacecraft control and display console, etc.

d. Set of Control Tables. Provides for the selective display or printout of groups of functionally related parameters.

e. Engineering Data Processor. Converts performance parameter data into engineering units and places these parameters in common storage for access by other programs. It also tests the selective output tables and generates the requested output formats relative to performance data.

f. Control Message Processor. Accepts operator key-ins and performs associated functions. The control message processor is the means of controlling the foreground and background tasks which are initiated by the operating system. For example, this processor recognizes operator requests for command transmission and calls the command output handler with the appropriate arguments.

6.4.3 AUTOMATIC TEST PROCEDURES

Automatic test procedures are sequences of control statements written in the test procedure language. The language consists of all directives which are recognized by the foreground system, as well as a set of statements which control the execution of the procedure. These control statements may specify loops, test and branch, communicate with a test conductor, or specify timing for various operations. This enables rapid execution of long sequences of control statements.

The set of automatic test procedures consists of one procedure for each major spacecraft subsystem. Automatic test procedures execute as the lowest priority task in the system. They typically initiate the transmission of commands, check incoming telemetry for correct response, and notify the test conductor via this terminal in the event of test failure or in requesting operator participation. Hence, the automatic test procedures need access to data acquired by the foreground telemetry processors and the use of services rendered by both the foreground and the operating system.

6.5 IMAGE PROCESSING SOFTWARE

Image processing covers the conversion of raw image data obtained from the satellite into a form that is of sceintific value to the observer using the telescope. It is intended that the astronomer should not have to be concerned with the mechanics of spacecraft operation, so products available to him will typically be spectral intensity as a function of wavelength, rather than partially processed images. Image processing can be characterized by its inputs, its outputs, and its processing tasks. Inputs are either of the following:

a. High-resolution echellograms (HRE) consisting of a 768 square matrix of picture elements (pixels), each digitized to 8 bits. The HRE contains 51 distinct spectral orders.

b. Low-resolution spectrograms (LRS) consisting of a 96 by 768 rectangular matrix of pixels, each again digitized to 8 bits. The LRS contains a single spectral order.

Outputs are selected by the observer during his observational period from the following:

a. Raw data frame or intermediate processed data frames.

b. Final corrected spatial intensity distribution (I (x, y)).

c. Final corrected intensity as a function of wavelength ($I(\lambda)$).

d. An error analysis considering the following points:

(1) Periodic disturbance effects.

(2) Photon Noise.

(3) Resolution.

(4) Wavelength accuracy.

e. A spacecraft log, covering date, time, star name, etc.

All this data is to be provided in a choice of three outputs:

a. Digital magnetic tape with a further choice of two packing densities: 800 bits per inch or 1600 bits per inch.

b. In chart fashion, or as a digital plotter output.

c. An accurate black and white photograph or negative that is digitally produced.

The image processing function can be broken down into a succession of not necessarily reversible transformations as follows:

a. Remove noise due to camera, spacecraft, data transmission, and background.

b. Remove distortion due to camera and optics.

c. Enhance resolution.

d. Rough wavelength determination.

e. Photometric calibration.

f. Precise wavelength determination.

Many of the image processing tasks rely for their inputs on mathematical or algorithmic models of various effects in the telescope/spacecraft system. Each of these models requires recalibration while the spacecraft is in orbit. Until the spacecraft is in orbit, however, it is difficult to say how frequently recalibration will be required. It should be remembered that in most cases a considerable computational effort is involved in performing such calibrations. In the estimation of required computer time presented in this study computer time to perform calibrations has been ignored. Should by mischance any of the calibrations be required every one or two images, the required computer load would rise by a significant percentage. In some cases it would literally double.

In the following paragraphs estimated times are for an HRE image on a Sigme 9, Model 3, computer. Core memory requirements (except for I/O buffers) are similar for both types of image.

Estimated timings and core requirements have been based on work done at the Jet Propulsion Laboratory (JPL) to process Mariner '69 and '71 TV images. This work was done on an IBM 360-75. Some timing tests conducted at GSFC have indicated that for CPU-bound jobs the Sigma 5 is four times slower than the 360-75, and the Sigma 9 is 1.9 times slower than the 360-75. I/O-bound tasks are assumed to run at the same speed on all the machines considered.

Bear in mind that it is not any easy task to make strict timing comparisons between two different computers. A comparison of instruction timings is not conclusive, because these timings can vary depending on system architecture and configuration. The only way to make a conclusive comparison is to run identical programs on both computers where the configurations are functionally identical. Such criteria is difficult to satisfy since, in general, no two computer configurations are alike.

In the specific case of comparing an IBM 360-75 to an XDS Sigma 9, the greatest difference is in the execution times of the floating-point arithmetic instructions. The 360-75 is about 2.5 times faster than the Sigma 9. However, the nonfloating-point instruction timings compare more favorably. In this case, the 360-75 is about 1.2 times faster than the Sigma 9. The results of the timing tests specified earlier in this section represents a weighted average of bench mark tests run on both types of computers; however, the computers were not configurated identically. As expected, the bench mark tests involving a lot of floating-point manipulation show the Sigma 9 to be much slower than the 360-75. The comparison is much more favorable when non-floating-point manipulation bench marks are used.

6.5.1 VICAR SYSTEM

It is intended that programming for image processing should be done following the VICAR system as a pattern. The VICAR system was developed by JPL for processing images from the Mariner satellites. The system essentially consists of three parts:

a. A command translation program, VTRAN.

b. A control program, VMAST.

c. A set of problem programs.

The command translation program translates commands for the execution of problem programs. The commands can be given in a fairly free format. VTRAN produces a set of job control language statements to control the running of problem programs, and a set of "reduced commands" in a rigid fixed format.

The control program essentially supervises the execution of the problem programs. Its job is to initiate the problem programs and to simplify the complex, and potentially inefficient, image input/output tasks that any problem program must perform. In the original VICAR system (written for the IBM 360-44), core storage was at a premium, and VMAST also provided simplified (and thus more compact) input/output facilities for all peripherals. In the IUE image processing system (IPS), where core storage is not at a premium, input/output will be by means of normal, vendor-supplied operating system calls. This approach renders the image processing system more flexible towards peripheral equipment at the expense of some core storage.

A VICAR system set up to process images for a particular application would have a unique set of problem programs. Many of the problem programs would be unique to the application; others would not. A major goal of the VICAR system design was to insulate problem programmers from system programming considerations, and leave them free to devote their energies to the application. Simplified and efficient image input/output (courtesy of VMAST) and a rigid "reduced command" format (courtesy of VTRAN) help to fulfill this goal. Most of the problem programs needed for the IUE image processing will have to be newly written, and in most cases this can be done in FORTRAN. Programming problem programs in FORTRAN has the following advantages:

a. Programs are readily transferred from any available computer to the final operations computer.

b. Programming effort is minimized.

However, input/output efficiency is not affected where it matters, because of the I/O facilities offered by VMAST or its equivalent.

The original VICAR system was intended to be used in a batch processing environment; VTRAN produced a JCL deck and a data deck. These decks were submitted as a second batch program. IBM JCL is of limited use for interactive work, because an entire job deck needs to be passed through a syntax analyzer before the first command can be executed. Interaction with VICAR on IBM machines has not been conveniently implemented. The approach that will be taken in the International Ultraviolet Explorer Spectral Image Processing System (IUESIPS) will be different in that a dedicated online system will be used. Thus VTRAN will be a command interpreter which will accept free-form commands and then communicate directly with the operating system via internal system calls. The two-pass system whereby JCL statements are first generated and then processed will be eliminated. Any sequencing of system calls and application program calls will be handled by a VMAST equivalent program. The IUESIPS version of VICAR will be a less general, fully interactive, image processing system.

6.5.2 INPUTS TO IMAGE PROCESSING

While the formats of the raw images are well defined their arrival rate is not. This is a fundamental uncertainty due to the freedom allowed to the observer in determining his observing schedule and exposure times.

It has been necessary to make some assumptions concerning arrival rate of images in order to estimate the required power of the image processing computer. It should be emphasized that the assumptions are based on a rather low image arrival rate and that this is one factor affecting the rather large contingency margin in the required computer performance. The assumptions are as follows:

a. Average exposure time for an HRE or LRS image is 40 minutes.

b. Slewing time from one star to another is 10 minutes.

c. Acquisition time, target identification, and fine slewing takes 5 minutes.

d. Readout time for HRE is 2.67 minutes.

e. Readout time for LRS is 0.33 minutes.

f. Readout time plus quick-look display time is 5 minutes.

g. Readout period is 55 minutes.

Based on these assumptions, during an average 16-hour observing shift 17.5 images will be produced. It is planned that GSFC will be observing for 16 hours of every 24 (the European Observatory will use the other 8 hours).

6.5.3 OUTPUTS FROM IMAGE PROCESSING

The output list is given in paragraph 6.5.

The philosophy of the data reduction system is that the guest observer will be given a few options to choose from. The actual data reduction will be done by the resident observer for scientific data reduction who, sitting at a computer terminal, will choose, based on the guest observers requirements, one of a few paths through the data reduction system. The path chosen (and hence the processing time) depends on the guest observers requirements and on the type and quality of the data.

A fairly full image processing scheme is described here, but with operational experience it may be possible to avoid or compress some of the steps. This uncertainty reflects the novelty of the IUE concept.

Requests for data reduction beyond that described in paragraph 6.5 will not, in general, be accommodated. It is felt that to allow for this would involve a large and unpredictable computer load on the image processing system. Should a guest observer wish to perform such reduction he must do it on his own computer.

6.5.4 NOISE REMOVAL

Types of noise which must be considered, if not corrected for are as follows:

a. Random spikes or missing portions of lines.

b. Target and cathode blemishes.

c. Background intensity level.

d. Periodic noise.

Random spikes are typically caused by data loss from individual picture elements. Missing portions of raster lines are likely to be caused by loss of sync on a telemetry frame (which contains 96 picture elements or 1/8 of a raster line). Both of these errors can be detected since affected elements differ from their neighbors by more than some margin. The errors can be masked by replacing affected pixels with a suitable weighted average of surrounding pixels.

Target or photocathode blemishes are likely to cause permanently unusable areas of the image. The problem is likely to become more acute as the imaging system decays with age.

Two kinds of image blemishes are considered. These can appear as white spots or black spots. Black spots are detected by reading out the image tube after the image has been exposed to an erasure lamp flown inside the telescope. White spots are detected by reading out the image tube with the telescope shutter closed. Using these techniques a map of affected pixels can be built up to help in masking the effects of the blemishes.

Masking of the effects of blemishes is similar to masking of random spikes provided the images do not spread into more than several adjacent pixels. If blemishes do spread into adjacent pixels, then the affected pixel map will have to be used to avoid erroneous judgments during subsequent image processing.

The background intensity level itself has a number of sources, for example, image tube dark current, scattered light due to earth, moon, or sun (fortunately the image is comparitively insensitive to visible light), and bias in the electronic readout circuitry. Background intensity level will be a function of many spacecraft parameters, especially temperature, and may have to be estimated on an image-to-image basis.

Another potentially serious dark current source will be that of galactic background radiation. With the telescope shutter closed, charge will not accumulate on the image in a linear fashion with time. Consequently dark current levels will not be a linear function of exposure time. It is expected that knowledge of the dark current/exposure time law can be built up prior to spacecraft launch. A few critical parameters can then be estimated periodically while the spacecraft is in orbit using sample exposures with the telescope shutter closed. The noise sources arising in the equipment (as opposed to noise in transmission, etc.) are all of the form $(a+bt)$ where t is exposure time. Complications arise because $\underline{a}$ and $\underline{b}$ are not necessarily constant, but may be functions of many variables such as temperature, B-angle, age, etc.

The level of background intensity in any image could also be estimated by using the intensity levels between the echelle orders and assuming that the background is a simple, continous function over the whole image. In either event the form of correction for the background is a subtraction performed on each picture element.

Periodic noise has two major sources:

a. Harmonic interference between the video readout and any other time-varying signals in the spacecraft.

b. Microphonics in the TV tubes which result from mechanical vibration introduced during readout. Careful spacecraft design and operating procedures can minimize this problem. Any residual noise, however, can be treated using a general-purpose periodic noise removal algorithm.

Periodic noise can be corrected by subtracting a Fourier transform of the noise source from a Fourier transform of the image. The noise sources will be characterized either by prelaunch investigations, or in flight by reading images taken with the telescope shutter closed. The resulting Fourier transform of the image is reverse transformed back into the X-Y space. The result is a noise free image.

If all periodic signals in the spacecraft are derived from a single clock (which they are not) and if they remained in phase, then noise would appear in a constant position in the X-Y plane of the image. It could be corrected for (after characterization) by a simple subtraction without performing a time consuming Fourier transform. A compromise solution may be possible in which the noise appearing in successive pictures is assumed to change only slightly. The noise would then be characterized in the X-Y plane every few images and subtracted without Fourier transforming the image.

The CPU time and core storage required to produce a two-dimensional fast Fourier transform (FFT) of every image is considerable. Unfortunately, the need to correct for periodic noise in this way may not be apparent until the spacecraft is in orbit. Certainly it would be difficult to make a decision prior to integration and test of the complete spacecraft.

JPL found that Fourier transform noise removal was necessary to obtain really good pictures from Mariner '69 and '71 TV images. Considerable effort is being made to ensure that the IUE spacecraft is considerably more noise-free than Mariner. In this study, a worst case assumption is made that periodic noise removal using a Fourier transform of each image will be necessary.

Noise removal and processing summary:

NOTE

> Random spikes, missing portions of lines, cathode blemishes, and background intensity level can be treated as one item.

a. Inputs: Image to be processed
   Background level image
   Blemish map

b. Outputs: Cleaned up image

c. Estimated program size (less buffers): 20 K words

d. Estimated processing time: 1 minute

e. Periodic noise (using FFT)

f. Inputs: Image to be processed
Filter (same number of elements as image)

g. Outputs: Cleaned up image
Estimated program size (less buffers): 77 K words
Estimated processing time: 7.6 minutes

6.5.5 DISTORTION REMOVAL

This task is intended to model or remove geometric distortion due to nonlinearities in both camera and optics.

In the general case, a two-dimensional deformation model is constructed. The model is an array of vectors modelling the magnitude and direction of geometric distortion at each pixel. This model may be used to construct intensity levels on an undistorted matrix, or the model may be stored to apply an undimensional distortion removal to the final spectrum.

Estimation of the distortion present during orbital operations is a considerable problem. Distortion arises both in the optical system and in the camera tube itself. Unfortunately, distortion in the camera tube is a function of intensity and pixel location.

Prior to launch, ray tracing experiments on the optics of the instrument and experiments using reseau marks on the face of the image tube should allow the system to be characterized with a few parameters, including image intensity. Such calibration parameters can be calculated in flight using the reseau marks on the faceplate of the tube and the spectrum from a hollow cathode discharge lamp (flown inside the telescope), which should produce an image in a fixed position.

Distortion modelling using an image which should appear in a fixed position is essentially a correlation problem between small areas of the actual and ideal image. It is thus a time consuming task and hopefully will only be required at infrequent intervals.

To give an idea of how time consuming this task can be, the distortion removal for Mariner TV pictures involved a 17-coefficient polynominal applied at each image point. It can be seen that distortion removal is also a heavy computing load.

In many cases distortion removal will not be necessary until the spectrum is being reduced to one dimension. It will be necessary, however, for astronomers involved in stellar classification who need rectified uniform images to be able to judge similarities by eye. Fortunately such astronomers are few and will in general be working with LRSs rather than HREs. Despite this, the estimates of time and core storage given here are for characterization and removal of distortion from all HREs and LRSs since there is the possibility that this would be needed on every image.

Distortion Removal Summary:

a. Inputs: Distorted image
Deformation model and deformation versus intensity law.

b. Outputs: Corrected image

c. Core size (minus buffers): 60 K words

d. Run time: 12 minutes

6.5.6 RESOLUTION ENHANCEMENT

Both camera and optics combine to produce a smearing of what should be a single point on the image. Ray tracing of the optical system produces a theoretical point image occupying an area 1.5 by 1.5 pixels. Jitter in the pointing of the telescope will make this an area of about 3 by 3 pixels.

Assuming that telescope pointing jitter is Gaussian, a point spread function can be derived for each pixel. This point spread function could be used as a basis for a bidimensional deconvolution of the image.

On a practical basis, such a deconvolution would at the same time be an improvement of the spectral resolution of the instrument in one direction, and a rejection of contamination of one order in the spectrum by its neighbors in the other.

Telescope jitter may not, however, even be statistically constant, let alone Gaussian. The point spread function of the instrument could well change during launch because of acceleration as well as during flight as a result of thermal effects.

Resolution enhancement using deconvolutions could be destructive to the science since, not only does it require technical judgment, but it may also drastically alter relative spectral line widths and spectral line lengths. Bearing this in mind, it is probable that the majority of guest observers would prefer to accept the resolution limitations of the instrument (0.1 Å for HRE and 6 Å for LRS both using the 3-arc-second entrance aperture) rather than have their data interfered with.

An attempt will be made on most images to remove interference between one order and its neighbors by applying a one-dimensional deconvolution at right angles to the spectral orders. Characterization of interorder interference produced by the instrument would be by using the hollow cathode discharge tube flown inside the telescope. The image produced by this tube would be compared with the image produced by the tube in an ideal instrument, and the spatial point spread function deduced.

The instrument point spread function may well be worse than expected, and if this were the case, deconvolution would be necessary on a routine basis. Estimates given below are for a worst case, bidimensional deconvolution using the closest five points in each dimension.

Resolution Enhancement Summary:

a. Input: Image to be enhanced
   Deconvolution matrix

b. Output: Enhanced image

c. Estimated program size (less Buffers): 60 K words

d. Estimated run time: 12 minutes

6.5.7 ROUGH WAVELENGTH DETERMINATION

This process is equivalent to the location of the echelle orders within the image. It is required to obtain geometrical information sufficient to traverse each order and extract the spectrum.

The spacing between the echelle orders is not constant, but follows a mathematical law. The program will attempt to detect the boundaries between orders and background at the center of the image. Using the distortion model, the program will also attempt to find the ends of orders. The search for these boundaries would proceed from a predicted order edge position. Having detected all possible boundaries between orders and background, the program would attempt to fit the measured spacing to the known mathematical model. This fit would be on the basis of the predicted position of the orders. Since the orders must be stable on the image plate by more than one plane to avoid smearing during exposures, the determination will usually be correct on the first or second try. In a few case, where the spectrum is very sparse and much of it differs negligibly from the background, it may be necessary for the data reduction operator to identify certain orders at the computer terminal, using some interactive mechanism.

Rough Wavelength Determination Summary:

a. Input: Image
   Mathematical model of echellogram

b. Output: Pixel numbers sufficient to trace each order

c. Estimated core size (less Buffers): 40 K words

d. Estimated run time: 2 minutes

6.5.8 PHOTOMETRIC CALIBRATION

This task converts the charge distribution on the target into the number of photons that excited each pixel during the exposure period.

The task can be performed most simply by holding a calibration table that relates charge to intensity for each pixel in the image. Strictly speaking, the calibration is also dependent on the wavelength of the incident energy.

Fortunately, the image is unlikely to move much; therefore, a given wavelength will fall approximately in the same place each time. Furthermore, sensitivity as a function of wavelength is unlikely to change with time.

Corrections for echelle and grating ripple which cause light intensity fall-off along the orders can also conveniently be corrected during this task since the correction also implies a calibration table for each pixel.

Tables for both these functions can be combined into a single table which would need up to 16 points for each pixel. Intensity at each pixel is then determined by interpolation using this table.

The photometric calibration tables themselves will be constructed prior to launch using the camera tube without spectrograph. The modification to the table to account for echelle and grating blaze will be made on the basis of measurements coupled with a mathematical model.

It is likely that the calibration tables will need to be changed in flight because of aging of the tube and mechanical distortion of the optics. Should this be the case, the tables would be modified using images of known stars and images of the erasure lamps taken with various short exposure times.

Photometric Calibration Summary:

a. Input: Image to be calibrated
   Calibration table (10 million bytes, probably from mag tape)

b. Output: Calibrated image

c. Estimated program size (less buffers): 30 K words

d. Estimated Run Time: 4.5 minutes

6.5.9 PRECISE WAVELENGTH CALIBRATION

This task is performed when all other tasks have been completed. Its input is a clean image with all intensity and geometric distortion removed (or at least modeled). The image consists of a number of orders of the spectrum, the wavelength scales of which overlap each other to some extent.

The output from this task is a wavelength scale for the entire spectrum.

In most cases it will be possible for the data reduction operator to identify several lines in the image. The identity of these lines, together with a mathematical model of the echellogram format will allow a precise wavelength determination to be made for the entire spectrum. The wavelength overlap of the orders of the spectrum will make registration of consecutive orders considerably easier.

In cases where insufficient recognizable data is included in the image, a cruder method will have to be used. The wavelength of the spectrum will be assumed invariant on the image tube over two images. An exposure will be made with the calibration light source to determine the spatial position of significant lines. This would be done immediately after the astronomer's image has been transmitted and without changing the pointing of the telescope. Such a calibration would minimize shifting of the image due to time and temperature.

Precise wavelength determination is another task which critically affects the validity of the astronomical data. To minimize this effect, it is proposed to produce, with the wavelength determination, an error boundary for each value of wavelength determined. In this way uncertainties due to gaps of several orders between identifiable spectral lines can be simply explained to the astronomer.

Precise Wavelength Calibration Summary:

a. Inputs: Cleaned, but not calibrated image
   Calibration image (possibly)

b. Outputs: Calibration for image (possibly)
Spectrum as I (λ) table

c. Estimated program size (less buffers): 60 K words

d. Estimated run time: 2 minutes

6.5.10 IMAGE PROCESSING FINAL OUTPUT PRODUCTS

The observer will have several choices of final output format. It is intended that these outputs would be complete and would not require any further data processing.

a. Magnetic Tape Output. Several forms of magnetic tape output will be available. The simplest form will be a digital tape image of the final corrected image (8 bits per pixel). Several forms of I (λ) or I (X, Y) are possible using as many data points as there are resolution elements. The guest observer will be able to request that the value of intensity be given in units of ergs, photons, or magnitude relative to a specified wavelength, and that the argument be given per unit wavelength or unit frequency.

b. High-Quality Photograph. The final corrected image of the data reduction system will be converted to a photographic negative with at least as many resolution elements as the original raw data. Prints of this negative, nominally of size 8 by 10, are also available to the guest observer.

c. Printed Output. A summary of the data reduction procedure applied to each image along with the relevant spacecraft and experiment status data will be provided. Estimates of the errors remaining in the data and how they were determined will also be included.

d. Digital Plotter Output. (Intensity versus wavelength)

6.5.11 SUMMARY OF COMPUTER RESOURCES REQUIRED BY IMAGE PROCESSING APPLICATIONS PROGRAMS

Table 6.5-1 gives a summary of the estimated resources required of the IP computer in order to reduce one high-resolution echellogram. (The time needed to reduce one low-resolution spectrum is 20 percent of that needed for an HRE.)

Table 6.5-1
IP Computer Estimated Resources

Task	Type	Core Required	Time
Noise removal (random)	CPU	20 K words	1.0 min
Periodic noise removal	CPU	77 K	7.6
Distortion removal	CPU	60 K	12.0
Resolution enhancement	CPU	60 K	12.0
Rough wavelength determination	I/O	40 K	2.0
Photometric calibration	I/O	30 K	4.5
Precise wavelength			
Calibration	I/O	60 K	2.0
Final output preparation	I/O	3 K	2.0
Graphics support package	I/O	5 K	2.0
			45.1 min

6.5.12 CALIBRATION REQUIREMENTS

As a statement of the current understanding of calibration requirements, a report from the IUE Calibration Subcommittee is provided in Appendix B.

The execution times stated in the table are estimates based on work performed at both JPL and GSFC on an IBM 360-75 and then converted to Sigma 9, Model 3, estimates based on the discussion in paragraph 6.5. However, it is anticipated that as the application programs are converted to run on the IP Sigma 9, Model 3, a significant amount of software optimization will be performed. Therefore, the estimates in Table 6.5-1 are considered worst case figures.

6.6 ESRO SOFTWARE

The IUE is an international satellite program with operations to be shared between ESRO and NASA. International agreements have been made which will minimize duplication of effort between ESRO and NASA. The following excerpt, from the memorandum of understanding (dated March 21, 1974), shows the anticipated ESRO/NASA agreements which affect the OCC implementation.

"3. To carry out this project ESRO will use its best efforts to fulfill the following responsibilities.

"(d) Establish a European-based integrated ground station/observatory for command, control, operations, and use of the IUE spacecraft. The computer in this facility will have a common identity with the computer in the U.S. observatory and the overall operating system will create an identical computing environment for the computer applications programs.

"(e) Make ESRO personnel available for training in spacecraft operations at the U.S. ground facilities.

"4. NASA will use its best efforts to carry out the following responsibilities.

"(f) Integrate and test the spacecraft.

"(k) Provide an integrated ground station/observatory for command, control, operation, and scientific use of the IUE.

"(l) Assume responsibility for orbit determination, station-keeping, and for a period of up to 30 days, complete checkout of the spacecraft and scientific instrumentation. Establish procedures for orbital operations. Conduct orbital operations, as mutually agreed.

"(m) Provide software for the European-based ground station/Observatory, as mutually agreed.

"(o) Provide training for ESRO personnel, as mutually agreed, in spacecraft operations.

"(p) Make available and update as necessary calibration of the scientific instrument."

The agreement quoted will avoid the duplication of software development effort by NASA and ESRO, since similar computers will be used in both observatories. NASA will develop and supply ESRO with the software for conducting normal IUE operations. In cases where NASA and ESRO software must be different, it will be necessary to identify highly visible, independent modules which may be implemented differently by NASA and ESRO. In these cases, tight interface and test specifications must be prepared and rigorously enforced to assure system integrity.

Therefore, ESRO software will consist of the subset of NASA software which is used to conduct normal mission operations. The remaining NASA software, which NASA uses for integration and test and for initial mission phase and emergency operations, is not intended to be duplicated in Europe.

It is firmly intended that ESRO software be identical to corresponding NASA software. This is clearly an achievable objective for the overwhelming majority, if not all, of the software, in view of the hardware identicality requirement.

A data line will be provided between the NASA and ESRO control computers. This line will be used to transmit software and data base maintenance updates from NASA to ESRO, and to transmit operational continuity data in both directions to assure smooth turnover.

SECTION 7
ORBIT AND ATTITUDE SYSTEM

7.1 GENERAL

An integrated Flight Dynamics System (see Figure 7.1-1) will be used for orbit and attitude determination and control of the spacecraft during the transfer orbit. The five distinct functions which are performed by this integrated computational system are as follows:

a. The processing of tracking and telemetry data for use by the applications programs in the system.

b. The determination of an orbit for use by the attitude determination, orbit maneuver, and station prediction programs.

c. The computation of the time and attitude of apogee boost motor (ABM) firing and hydrazine orbit maneuvers.

d. The determination of spacecraft attitude required by the orbit and attitude control programs.

e. The computation of attitude reorientation and spin control maneuvers.

The system will operate primarily in a launch support environment but its components can be used in an off-line stand-alone mode for prelaunch and postlaunch studies and operations.

7.2 FLIGHT DYNAMICS SYSTEM

The Flight Dynamics System (FDS) is not a system but a mechanism by which a mission-dependent set of stand-alone programs can execute in the same computer and can communicate with each other. Probably the most important feature of this system is the intersystem communication and interaction. Although the various subsystems may be executing simultaneously, they also may pause, change functional direction, terminate or perform any other logical sequence depending on requests and information from other subsystems of the FDS. In order to accomplish the basic functions of this system, the FDS uses interactive graphics devices.

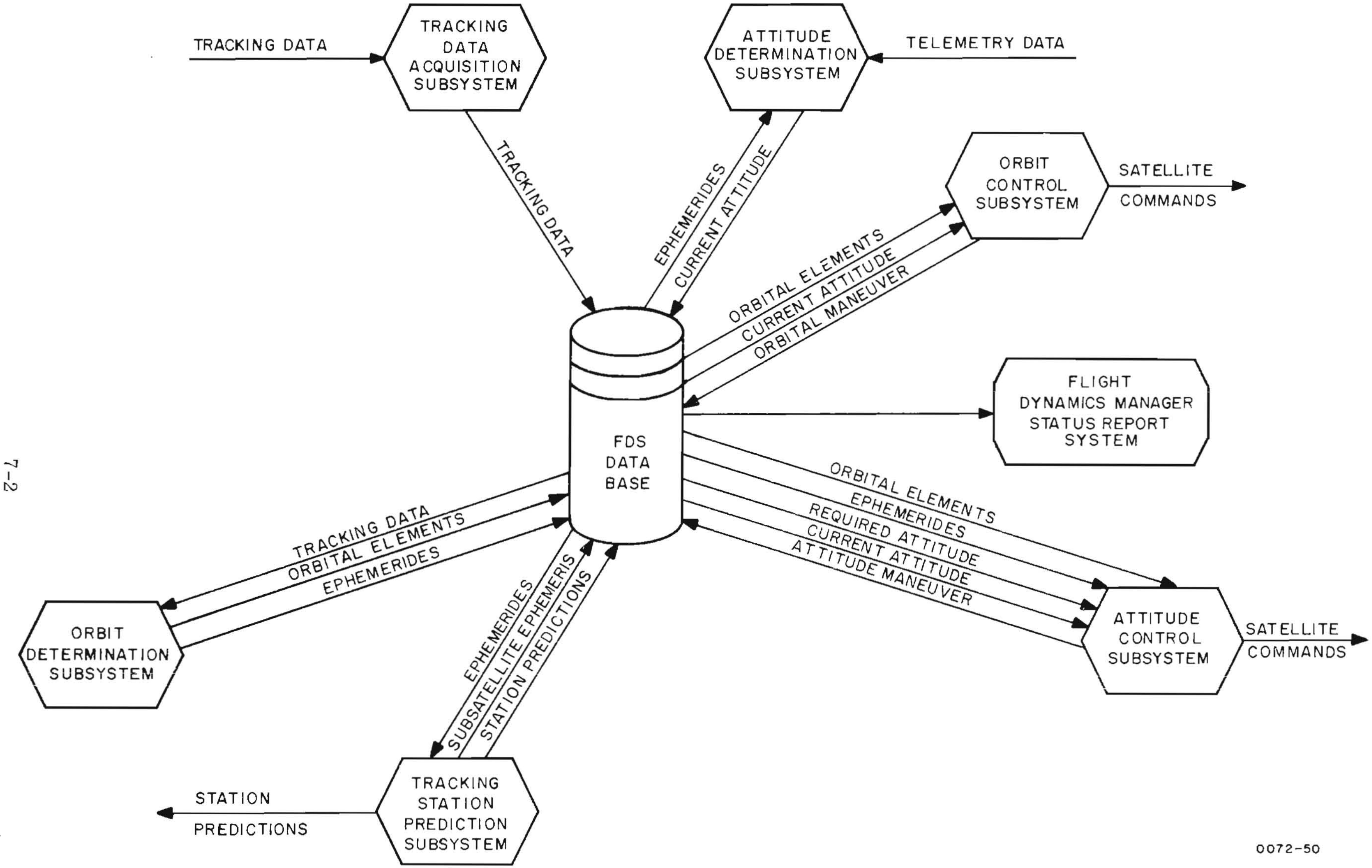


Figure 7.1-1. Orbit and Attitude Determination and Control System

The components of the FDS are sets of software which enable the entire orbital analysis system to function. The most common components are the following programs:

a. Tracking and attitude data acquisition

b. Orbit determination

c. Attitude determination

d. Attitude control

e. Orbit control

f. Station predictions

Other programs may become part of the system to perform specialized tasks.

Not only do these various subsystems transmit information to each other, but major portions of required data bases and program modules may be shared by the various system components. This fact minimizes the number of peripheral programs required and facilitates system consistency.

The design of FDS depends on extensive usage of interactive graphics terminals with one of the terminals controlling the initialization and priority setting of the various subsystems. Another terminal is used to facilitate the Flight Dynamics Manager (FDM) in the review of summary status reports from all of the individual subsystems. Although it may be desirable to allocate individual terminals to each of the subsystems, it may be necessary to share one device between several programs. The most likely candidates to share one device are generally the system controller, FDM, and maneuver control programs.

Once the various subsystems are initiated by the FDS controller and once their individual priorities are set, communication between subsystems is then either automatically controlled by the data flow or controlled by the operator of the particular subsystem through the interactive graphics device.

The entire function of the FDS is activated during critical real-time support operations. Since the primary objective of the system is quick response, non-real-time support is generally not a function of FDS. For non-real-time support, each of the FDS subsystems may function as a stand alone program and provide its own output to other subsystems in a non-real-time fashion.

7.3 ORBIT DETERMINATION AND CONTROL

The orbit determination and control of IUE is separated into three support phases: transfer-orbit phase, drift-orbit phase, and mission-orbit phase. The transfer-orbit phase commences with separation of the spacecraft from the launch vehicle and terminates with ABM firing. The drift-orbit phase begins with ABM firing and ends when the spacecraft has been placed above the designated on-station longitude. The mission-orbit phase extends from placement on-station throughout the remainder of the mission.

7.3.1 TRANSFER-ORBIT PHASE

During the transfer-orbit phase the Minitrack Interferometer Tracking System and the Goddard VHF Range and Range-rate System will be scheduled to obtain orbital tracking data from the spacecraft. Radar tracking data on the launch vehicle will also be obtained. Throughout the transfer-orbit phase, the computed transfer orbital elements will be used for generation of an orbit ephemeris which will be used for generating station predictions, scheduling aids, attitude determination, attitude maneuver planning and operations, and orbit maneuver planning and operations. The elements of the transfer orbit will be updated as required throughout the transfer trajectory.

The initial orbit solutions following transfer trajectory injection will be used to compute ABM firing time and attitude using the ABM analysis programs MAESTRO and FUSIT in conjunction with other specialized support software. Following reorientation to ABM firing attitude the final ABM firing parameters will be recomputed using the most current orbit and attitude solutions.

7.3.2 DRIFT-ORBIT PHASE

Following ABM firing the spacecraft will nominally be drifting six degrees per day towards its on-station position over the Atlantic Ocean. Goddard VHF Range and Range-rate data will be scheduled as required in the drift-orbit phase to compute the orbital elements needed for station predictions, scheduling acquisition aids, attitude determination, and orbit maneuver planning. Typically, 24 hours of continuous tracking, consisting of 5 minutes of tracking data every 30 minutes, will be scheduled immediately following ABM firing and at other intervals as required, for example, following orbit maneuvers. Upon reaching the on-station position, the onboard hydrazine propulsion system will be fired to achieve a zero drift synchronous orbit. Maneuver computations in the drift-orbit phase will utilize the PRELUDE and CONTROLF maneuver software.

The normal dispersions of the ABM may result in a drift orbit with an undesirable drift rate. Under this condition it will be necessary to correct the drift rate using the onboard hydrazine propulsion system following ABM firing.

7.3.3 MISSION-ORBIT PHASE

The mission-orbit phase will commence when the spacecraft has been placed at its on-station position in an inclined eccentric synchronous orbit. Goddard VHF Range and Range-rate tracking and/or S-band antenna pointing data will be scheduled to update the mission orbit on a routine basis. Typically, 24 hours of continuous tracking, consisting of 5 minutes of tracking data every 30 minutes, may be required biweekly and immediately following orbit stationkeeping maneuvers. The orbit solutions will be used for station predictions, scheduling acquisition aids, and orbit maneuver planning. Several times yearly stationkeeping maneuvers will be required to compensate for the effect of gravity to pull the spacecraft off its on-station position.

7.4 ATTITUDE DETERMINATION AND CONTROL

The attitude determination and control of IUE (see Figure 7.4-1) will be divided into three different support phases: The transfer-orbit phase, the drift-orbit phase, and the mission-orbit phase. The transfer-orbit phase involves the attitude support necessary to get the spacecraft from the transfer orbit to the drift orbit (after ABM firing). The drift-orbit phase involves those attitude activities which are necessary to place the spacecraft on station. The mission-orbit phase involves the support during spacecraft checkout, experiment data acquisition, and stationkeeping activities.

Throughout the transfer-orbit phase, the orientation of the spin axis of the spacecraft will be determined and the control (maneuver) commands computed in order to achieve the desired orientation for the orbit adjustments. The attitude support will be coordinated with the orbit determination and orbit control support activities to provide a unified support effort using the FDS.

The software will be developed taking advantage of previously developed capabilities where possible. The system will be designed and developed using the functions available in the Multisatellite Attitude Determination (MSAD) system and the Multisatellite Attitude Prediction (MSAP) system.

In addition, analyses will be performed to simulate the launch environment for determining optimal times to receive attitude data and to simulate attitude maneuvers based on nominal and non-nominal launch conditions. These analyses will be instrumental in

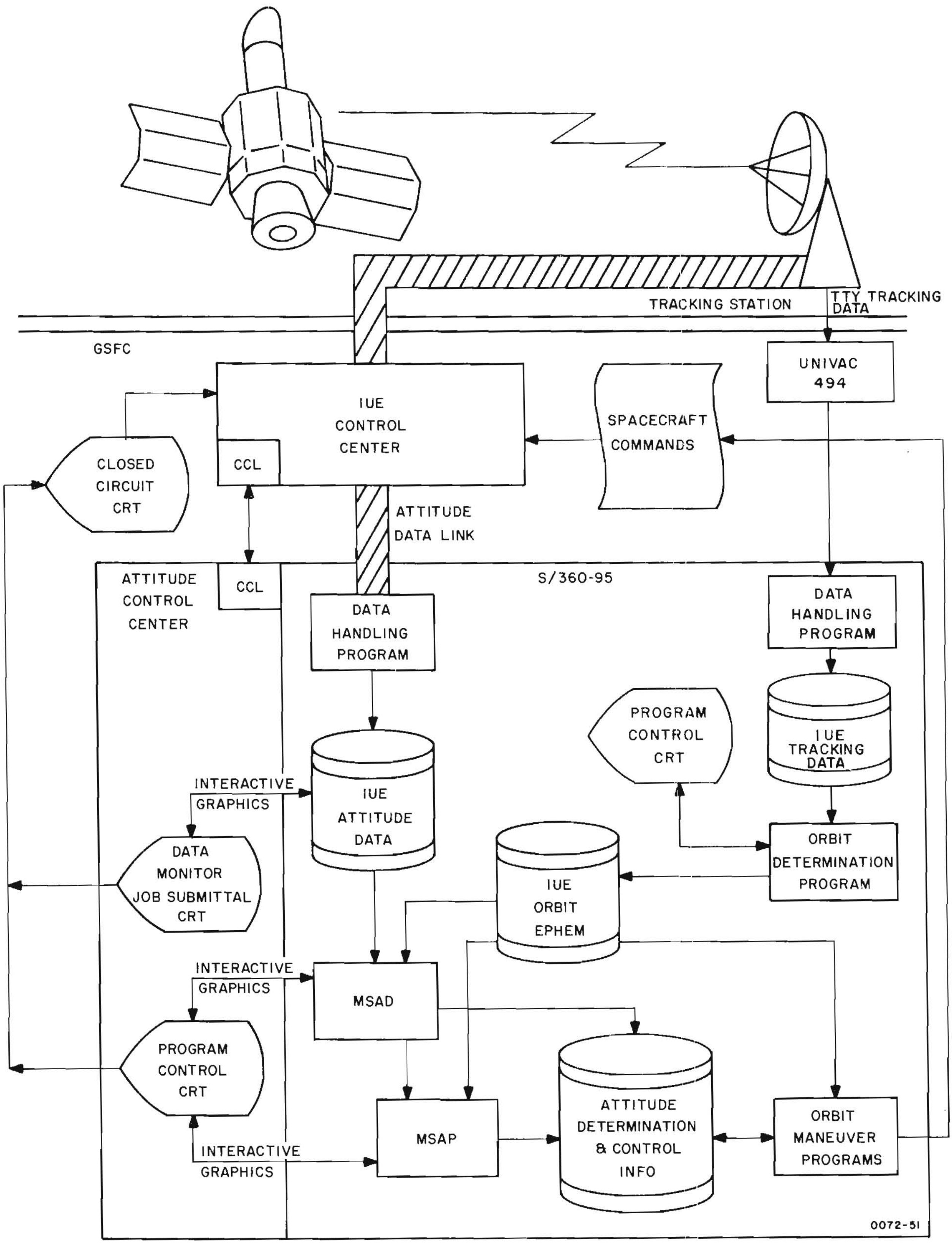


Figure 7.4-1. Attitude and Orbit Determination and Control Flow Diagram

establishing the techniques and procedures which will be used in supporting the critical transfer orbit phase of the IUE mission.

7.4.1 TRANSFER ORBIT

After the IUE launch and injection into the transfer orbit, the attitude and spin rate of the spacecraft will be determined based on the nominal orbit, and as soon as available, the actual orbit. Any changes in attitude data reception or in maneuver plans will be established once the actual attitude has been determined. Once the attitude has been verified, the spin axis will be precessed to the desired attitude necessary for performing the apogee motor burn. This will require at least two maneuvers with the first doing the bulk of the reorientation and the last doing the small final adjustment to bring the spin axis within the constraints for the burn.

7.4.2 DRIFT ORBIT

Following the firing of the ABM and spacecraft despin, it may be necessary to perform additional orbit and attitude maneuvers in order to trim the drift rate of the orbit. At the completion of these maneuvers, if they are required, the IUE attitude determination and control functions will be turned over to the IUE Operations Control Center (OCC). The OCC will have all attitude responsiblities from the time the spacecraft is despun until the spacecraft is ready to be placed on station. Just prior to the latter event, the Attitude Computation Analyst (ACA) will again assume control of the attitude processing functions using OCC three-axis attitude determination and control software and the OCC computer. The ACA will maneuver the Z-axis of the spacecraft to the desired orientation to place the spacecraft on station. Following this maneuver, the spacecraft attitude processing functions will be returned to the OCC.

7.4.3 MISSION ORBIT

During the mission phase, all attitude processing functions related to stationkeeping operations will be performed by the ACA. When it becomes necessary to place the spacecraft back on station, the ACA will become a guest experimenter in the OCC and will use the OCC attitude determination and control software and OCC computer to determine the present attitude, compute the commands necessary to maneuver the Z-axis into position for the stationkeeping motor firing, and recompute the final attitude. After the stationkeeping functions have been completed, the spacecraft attitude control will be returned to the OCC.

SECTION 8
EUROPEAN GROUND OBSERVATORY

8.1 INTRODUCTION

The European observatory for IUE will be integrated with the ground station and will form an independent and project-dedicated part of the ESRO tracking and data acquisition network. Because of the incompatibility of IUE frequencies with those generally allocated for use in Europe, the station will be built in Spain where special frequency allocation rules apply.

8.2 SITE AND BUILDING

The station site is located at Villafranca del Castillo approximately 25 kilometers west of Madrid enroute to El Escorial (see Figure 8.2-1). The site selected for the Observatory extends on a plane west of the creek Guadarrama and east of the ruin of the castle Villafranca.

Preliminary station coordinates are 3 degrees 57.2 minutes west, 40 degrees 26.2 minutes north, at an altitude of 600 meters. The antenna center will be 10 meters above ground level. Tentative station mnemonics are VILFRA (VIL).

Figure 8.2-2 shows the preliminary layout of the IUE building. The control area is occupied by the computer room; the telemetry room, which contains ground station RF equipment; and the spacecraft control room and observatory. Office space for the station manager and astronomers is located next to the observatory, while ESRO support personnel offices are situated in another part of the building with easy access to telemetry, computer, and spacecraft control areas. This design aims at a separation of operational and observatory functions. The total area, including space for storage and air-conditioning machinery, is 1500 square meters.

8.3 DATA ACQUISITION SYSTEM

The data acquisition equipment will consist of the antenna system, the receiver system, the VHF command system, the timing system, and the observatory interface system (see Figure 8.3-1).

8.3.1 ANTENNA SYSTEM

The antenna structure will consist of a parabolic dish of 15 meters diameter on an elevation over azimuth mount for full hemispherical coverage. The antenna will

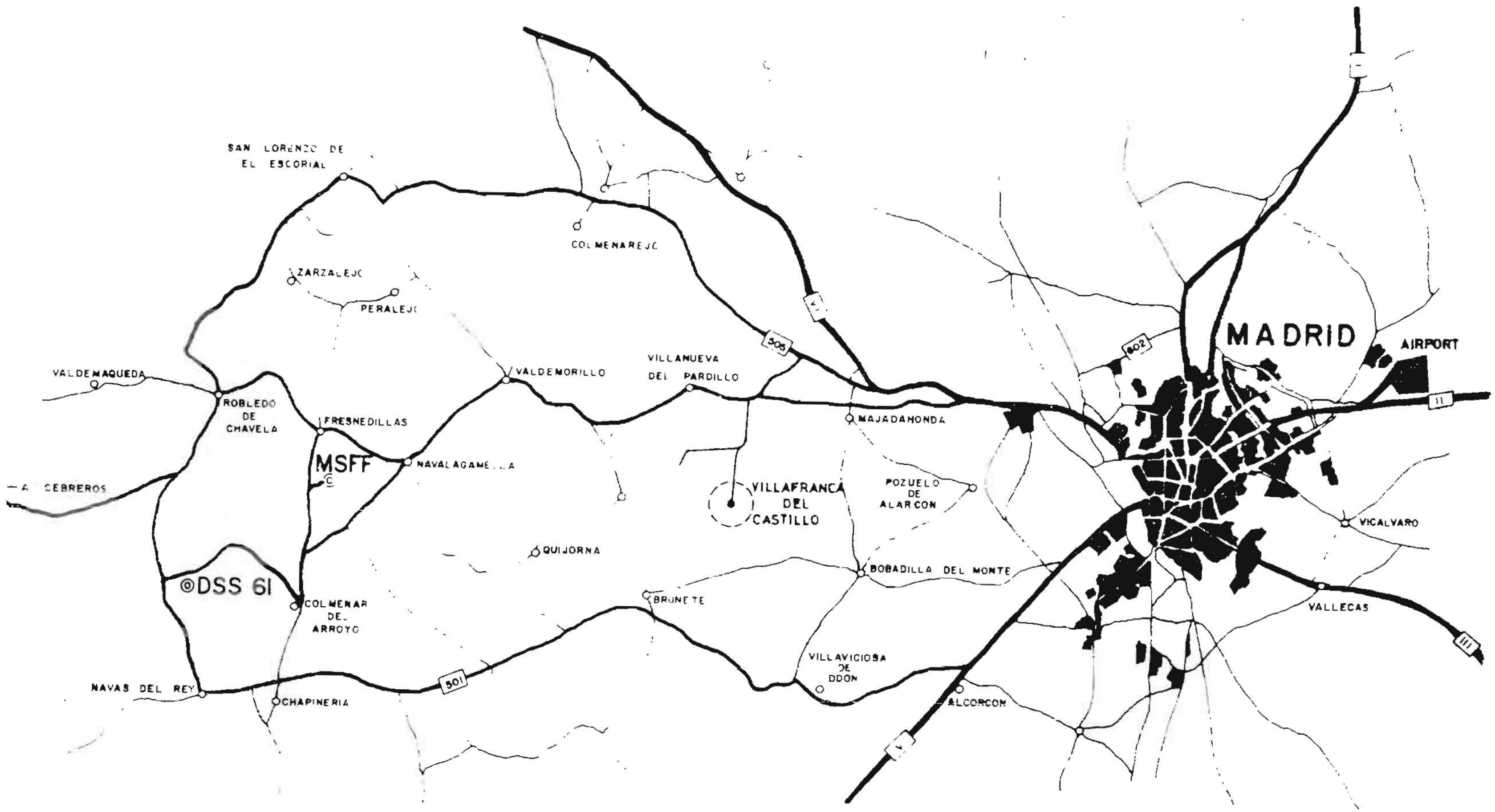


Figure 8.2-1. European Ground Observatory Site Location

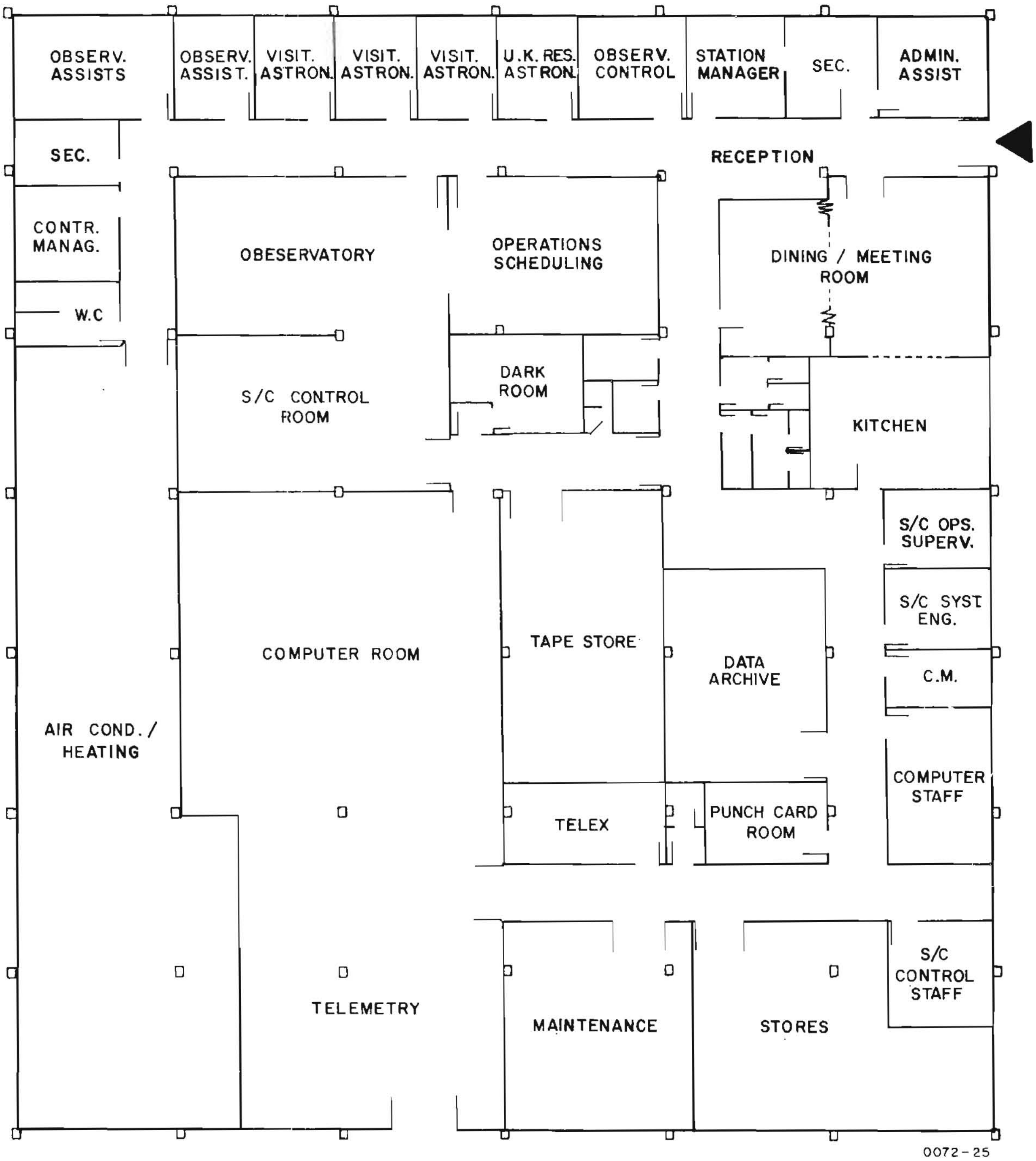


Figure 8.2-2. European Ground Observatory Floor Plan

include servo systems, all autotrack facilities, low-noise preamplifiers, down-converters and IF amplifiers, up-converters and power amplifiers.

8.3.2 RECEIVER SYSTEM

A large part of ESRO's future programs will be devoted to the support of geosynchronous satellites for which new facilities must be provided. These facilities will include the new high stability, low flexibility receiving equipment. As each receiver may be specially configured for a particular mission, it is more economical to provide receivers for IUE from this program, rather than use general-purpose receivers. Only those receivers required by IUE will be provided.

The receiver employs diversity combination at the second IF of 10 MHz. The first IF signal from the antenna at 70.2 MHz is translated down to 10 MHz, and the remnant carriers of the horizontal and vertical signals are each phase-locked to the station 10-MHz reference. The AGC voltages of each channel are then used to determine how the signals are combined. If the two signals are equal or nearly equal, they are summed; if one signal is below a preset threshold, only the stronger signal is used. This scheme provides optimum signal-to-noise ratio for all signal conditions. The combined signal is then coherently demodulated to obtain the baseband output which is applied to a bit conditioner and format synchronizer and then interfaced to the station computing system.

8.3.3 VHF COMMAND SYSTEM

A modified version of the ESRO PCM telecommand system will be provided, and new VHF equipment will be procured and installed at the station. This equipment will be dedicated to IUE.

8.3.4 TIMING SYSTEM

Although the timing requirements for the IUE mission are not severe, an accurate timing system will be installed at the station. This will indicate time to within about 1 ms of universal time coordinated (UTC) and will provide reference frequencies for carrier generation. The basic clock will utilize a rubidium frequency standard, with dividers to provide standard frequencies, followed by a time code generator.

8.3.5 OBSERVATORY INTERFACE SYSTEM

All displays and controls in the observatory will be interfaced to the station computing system which will route data within the ground station/control center to meet the

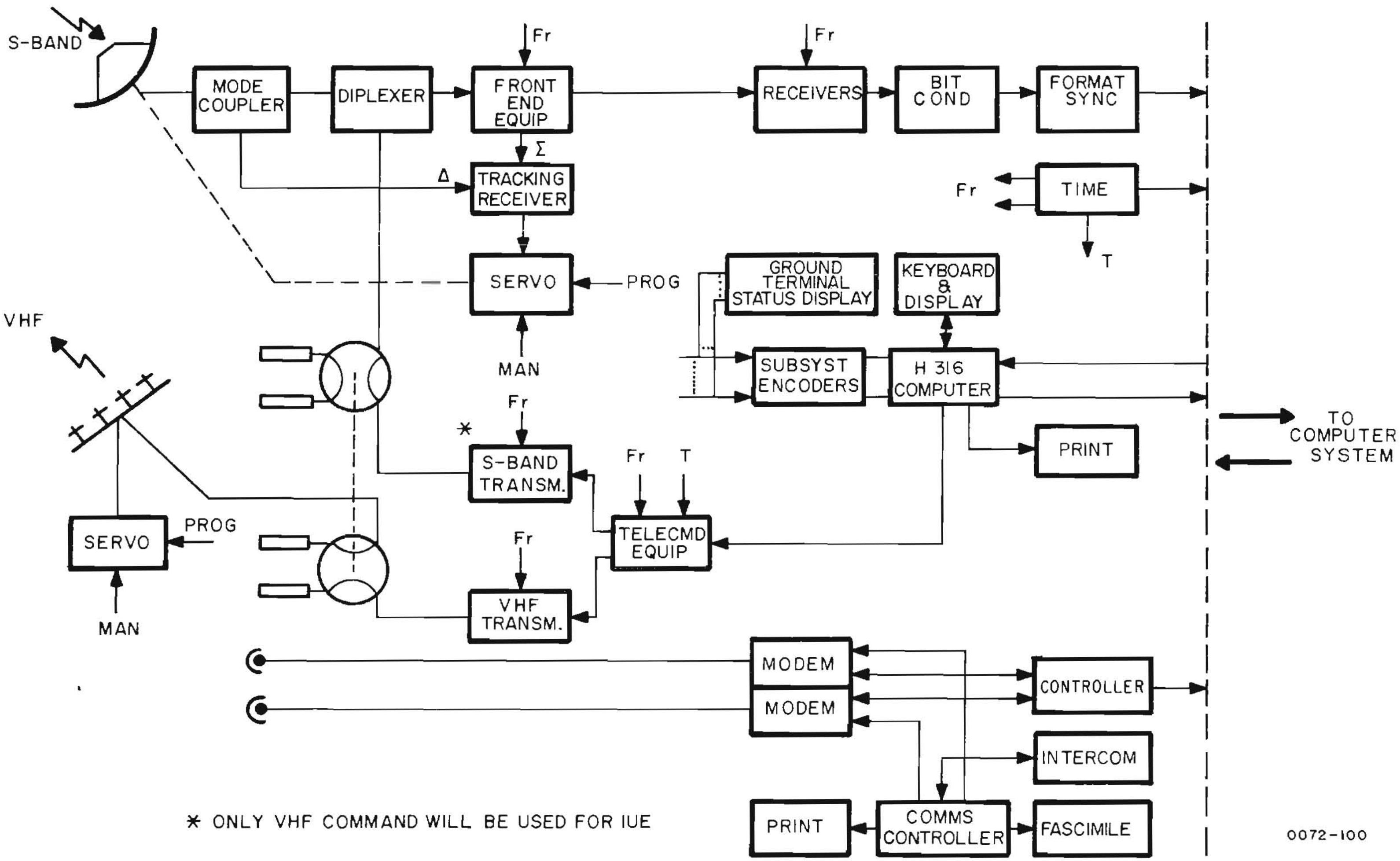


Figure 8.3-1. Data Acquisition Equipment Block Diagram

requirements of the project. It is anticipated that some of the software to accomplish this will be developed during the equipment integration phase.

8.4 COMPUTER SYSTEM

The computer system will be based upon a single RXDS Sigma 9. This computer is very similar to the GSFC IPS computer. The GSFC IPS computer will perform spacecraft control in the backup mode. Consequently, installation of GSFC applications software (both spacecraft control and image processing) on the ESRO ground station computer is expected to proceed with minimum difficulty.

8.4.1 COMPUTER CONFIGURATION

The configuration of the ESRO ground computer is shown in Figure 8.4-1. Table 8.4-1 is a list of components.

Significant differences between the GSFC IPS Sigma 9 and ESRO computer system are as follows:

a. The ESRO system has provision for only one alphanumeric display controller. Only four alphanumeric displays will be attached to this unit. These alphanumeric displays (to be procured) will be similar but not necessarily identical to their GSFC counterparts.

b. The tape units connected to the ESRO machine are slightly different. The RXDS 7315/7316 replaces the RXDS 1038/7322 of the GSFC system. The function and speed capabilities of the two units are identical, and full compatibility is maintained.

c. An extra line printer (RXDS 7440) is included in the ESRO system to improve its availability.

d. Two experiment displays (to be procured) will be attached to the Sigma 9 via RXDS 7601/02 data set controllers. One of them is intended primarily as backup for the other. These displays are being procured to be physically compatible with those of GSFC. The displays will be supported by a minicomputer, and software for this minicomputer will only be specified when GSFC's display support software is defined in mid 1975. In this way a high degree of compatibility can be achieved between the experiment displays of ESRO and GSFC.

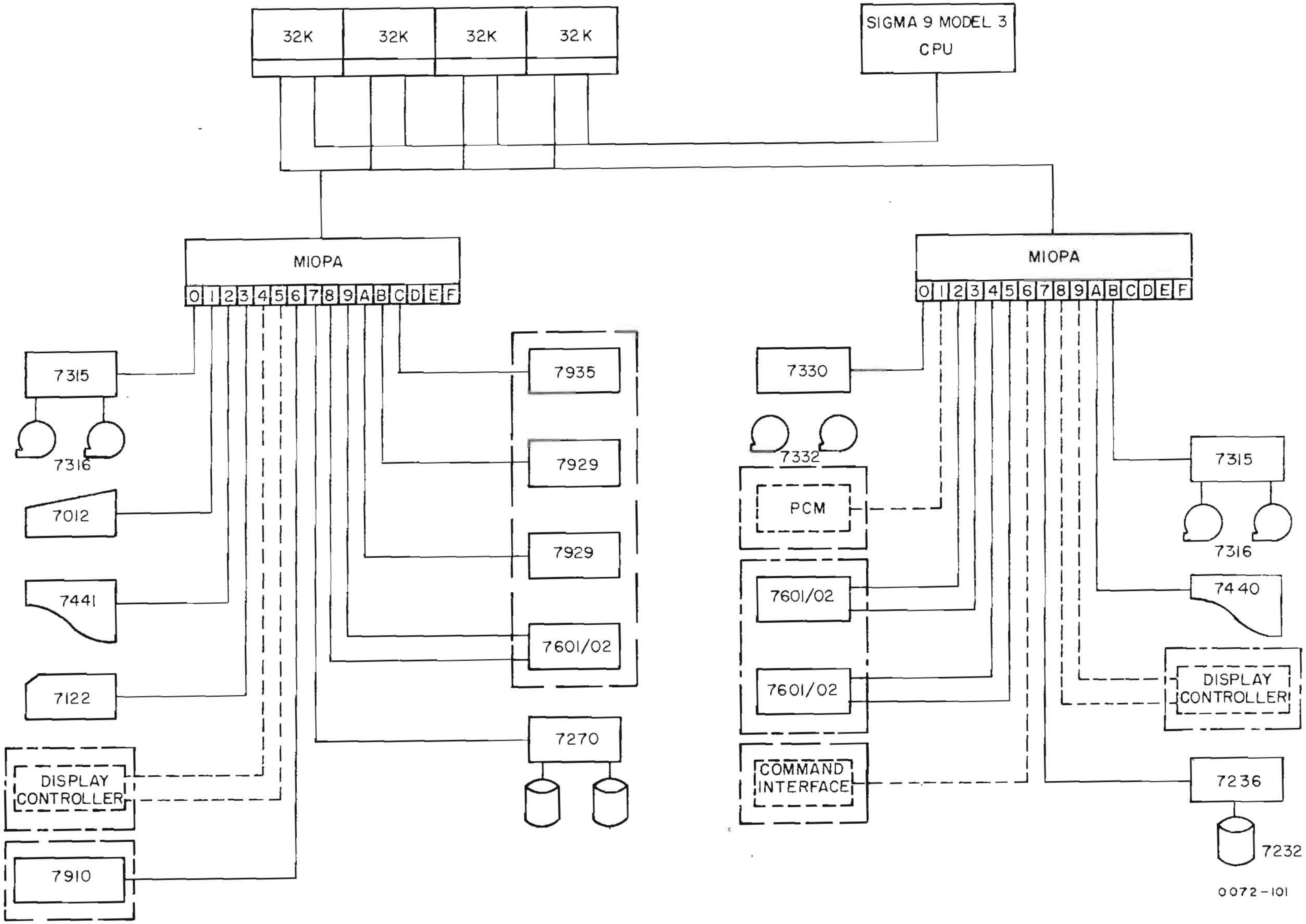


Figure 8.4-1. ESRO Ground Computer Configuration

Table 8.4-1
ESRO Ground Computer Sigma 9 Model 3 Component List

Model No.	Quantity	Description
8710	1	Sigma 9 model 3 CPU + 32K memory
8711	1	Two additional real-time clocks
8716	1	Additional register block
8721	2	Interrupt controller
8722	23	Priority interrupts, 2 level
8762A	3	Memory with 2 parts 16K words
8762B	3	Memory increment 16K words
8773	1	Memory to memory move
8775	1	MIOP - channel B
8772	2	Additional 8 subchannels
8771	2	4-byte interface
7012	1	Keyboard printer, KSR 35
7122	1	Card reader, 400 cpm
7441	1	Line printer, 1100 lpm
7440	1	Line printer, 600 lpm
7935	1	Digital I/O controller
7931	1	Digital I/O expander
7950	1	Stored output function module
7962	18	D/A converter
7315	2	Magnetic tape controller plus 1 drive, 800 bpi, 60 kb
7316	2	Add-on tape drive
7330	1	Magnetic tape controller, 1600 bpi
7332	2	Tape drive, 1600 bpi, 75 ips
7601	3	Data set controller
7602	3	Full duplex feature
7910	1	Analog output controller
7929	2	IOP to DIO adapter
7270	1	Disk controller and 2 disk drives, 49 M bytes
1042	1	Extended-width interface
7274	3	Disk pack
7236	1	Extended-width RAD controller
7232	1	Extended performance RAD, 6.2 M bytes

e. An additional NASCOM modified RXDS 7601/02 full duplex data set controller is attached to the Sigma 9 for communication with GSFC.

8.4.2 PROCESSING CAPACITY REQUIREMENTS

The processing capacity required in the observatory can be divided into three requirements: for spacecraft command and control; for maintenance and software updates; and for image processing.

Processing capacity requirements for spacecraft command and control are identical to those of GSFC except that the spacecraft will only be controlled for 8 hours per day from the European Ground Observatory. A period of time each day may be required for handover of the spacecraft. An additional 4 hours a day will be needed on the computer for maintenance, installation of system software, reruns because of operator error, etc.

The image processing workload has been estimated on the basis of initial observation requests from European astronomers. An average of 60 percent of exposures are expected to be high-resolution spectograms and 40 percent should be low-resolution spectra. The following distribution of observations as a function of required exposure time is expected:

Exposure Time	Percentage of Exposures
1—10 min.	40%
10—20 min.	16%
20—30 min.	15%
30—40 min.	12%
40—50 min.	11%
50—60 min.	6%

During a normal day, between eight and ten spectrograms of each type are expected. The computer system will be able to process this average load within slightly less than 24 hours. In addition, the system will be able to process data from peak-load days in less than a month. For example, peak loads will occur when observers wish to study the variability of a bright object, in which case a large number of short exposures will be obtained during an observing day.

8.4.3 SOFTWARE

Rank Xerox will supply all standard XDS software within the computer, including the operating systems RBM and CPR.

Application software will be supplied by GSFC, but ESRO will have to make modifications to account for some or all of the following possible differences:

a. Different ground station telemetry equipment.

b. Different ground station command equipment.

c. Different time input mechanism.

d. Different alphanumeric displays for spacecraft control.

e. Different experiment displays.

ESRO will communicate essential features of special ESRO equipment to GSFC, so that GSFC can make the I/O handlers for GSFC analogs to these devices as modular as possible. In this way, it is expected that the unique requirements of ESRO can be satisfied by module replacement.

ESRO will begin designing any special I/O modules in May 1975, when detailed design documentation for the GSFC applications software will be available.

GSFC software will be delivered to ESRO in two phases; in January 1976, a preliminary version of both image processing and command and control software will be delivered. In July 1976, GSFC will deliver working versions of image processing and spacecraft command and control software.

A configuration control board will formally control all IUE ground station software changes. Its terms of reference will be drawn up by representatives of both GSFC and ESRO, and representation of both GSFC and ESRO will sit on it. The configuration control board will be in operation by July 1, 1975.

Initial software delivery to ESRO will be on magnetic tape. Any software update package will consist of the following:

a. Source code for the change (cards or tape or possibly NASCOM transmission).

b. Source listing for complete module with change indicated.

c. Test and test results for the change.

d. Updates to all relevant program documentation.

e. Object code (optional).

ESRO personnel will visit GSFC to obtain on-the-job experience of GSFC software prior to its initial delivery to ESRO.

8.5 COMMUNICATIONS

Besides public telephone and teleprinter lines, the NASCOM switching center at Robledo will be connected to the station to allow for simultaneous communications and data exchange between the European IUE station and GSFC.

8.6 OPERATIONS

An average of 8 hours observation time per day will be allocated to guest astronomers using the European observatory. Short handover periods will precede and succeed the observation period. Because of the different computer configuration at the European observatory, the operations and data reduction tasks will be carried out sequentially; that is, data reduction can commence only after the observation period has been completed and the spacecraft operations have been handed back to GSFC. The remaining part of the day will be allocated to maintenance tasks.

During the observation period, spacecraft operations will concentrate on observations and routine spacecraft health monitoring. In case of spacecraft anomalies, spacecraft control tasks will be limited to simple anomaly procedures which may result in switching the spacecraft into a safe mode before handing it back to GSFC for detailed fault analysis and corrections.

SECTION 9
PREMISSION PHASE OPERATIONS

9.1 INTRODUCTION

This section provides a description of the ground system activities during the period that starts with spacecraft integration and test (I&T) and finishes with the start of mission operations with the spacecraft on station in a geosynchronous orbit.

9.2 SPACECRAFT INTEGRATION AND TEST OPERATIONS

The IUE integration phase will be performed in a clean room at GSFC. Primary I&T support will be provided by an I&T Sigma 5 computer located in Building 11. Additional support will be provided by the OCC command and control Sigma 5 computer. Communications between the spacecraft and Building 11 or the OCC will be either by direct radiation or by hardwire. The I&T or OCC Sigma 5 computer will receive and process the telemetry data in real-time. Remote presentation of processed data will be provided for the engineers at the spacecraft. A CRT display and a hard copy device will be provided by the project in addition to a remote keyboard to allow the integration crew to select processing options, cause commands to be transmitted, and conduct programmed test procedures. Communications between the remote terminal and the computer used for I&T will be implemented with serial data communications equipment operating over audio lines. Voice communication will be provided between the clean room and the I&T test conductor located at the computer. Digital magnetic tapes will be written and line printer outputs will be made during I&T operations.

During environmental testing, a test team consisting of a test conductor and several subsystem engineers will be physically located at the spacecraft control and display console at the I&T Sigma 5 computer or in the Mission Operations Room (MOR). Real-time spacecraft data acquisition, processing, and display will be provided for the test team. The special-purpose displays provided in the spacecraft console will be updated in near-real-time, and switches on the console will be read out by the computer at frequency intervals to control the spacecraft and the execution of automatic test programs. CRT display of processed telemetry data will be provided for the test team and the spacecraft personnel who are remotely located at the spacecraft support equipment. In the event of a test failure, a troubleshooting mode may be instituted. This mode is similar to the integration phase with computer system control being exercised from the remote site via keyboard. When the OCC computer is used to support I&T operations, the operator interface with the OCC will be via CRT keyboard.

A full-duplex data communications link separate from the one serving the remote terminal will be provided to allow the command and control computer to interrogate and control the ground support equipment controller within the spacecraft support racks. This link provides the means by which automatic test programs running in the computer can operate and read out spacecraft sensor exciters, solar power simulators, etc.

9.3 TRAINING

Starting 18 months before launch and continuing up to the launch of IUE, selected ground system personnel will be extensively trained at a subsystem and system level.

a. Digital magnetic tapes containing actual and simulated spectra will be used to train telescope operators and image processing specialists. The data from the tape will be presented on the observer's graphics display. This will enable the resident personnel to gain experience in making decisions as to whether the data is satisfactory and should be processed or destroyed. When the images are selected for processing, digital magnetic tapes containing the reduced data will be generated. This will give image processing personnel experience in operating the computer and reducing the data and will provide a check of the image processing software. It will also enable prospective guest observers to use the output tapes in checking out their data reduction programs.

   During spacecraft I&T operations, the experiment will be simulated with various sources. During some of these periods, the data will be transmitted via data circuits to the OCC and processed in the image processing computer. This will provide, in real-time, the same type of training previously described for the processing of the tape data.

b. Training will also be provided for the telescope operators, software personnel, and command controllers in pointing the spacecraft. A simulated target list will be input into the command and control (C&C) computer. The list will be checked by the control software to determine if any constraints have been violated. If the target is valid, the computer will display the star field overlays on the observer displays. The telescope operators and resident observer will receive training in recognizing star patterns and positioning the spacecraft.

c. After the problems of the image processing training have been worked out (paragraph a) and the training in positioning the spacecraft has been completed (paragraph b), the two will be combined to train personnel in positioning the spacecraft and processing image data.

d. Tape data will also be used in training the OCC personnel. Digital magnetic tapes containing simulated spacecraft data and actual spacecraft data (with and without experiment data) will be used in training OCC personnel. The data will be processed in the OCC computer to provide familiarization with the CRT displays. This will also provide training in analyzing spacecraft parameters and taking corrective action when required. These tests will also check the software and will enable software personnel to gain experience in troubleshooting and debugging the programs.

Similar exercises will be run on the image processing computer to ensure that it will be an effective backup for spacecraft/experiment control. Included will be exercises requiring a rapid changeover (within 10 minutes) of spacecraft/experiment control from the command and control computer to the image processing computer.

e. The spacecraft I&T period will provide excellent training for the OCC personnel. During portions of the I&T period, the spacecraft and OCC will be connected by data circuits. Spacecraft telemetry data will be transmitted in real-time to the OCC. The data will be processed in the OCC computer (or the image processing computer as a backup). Spacecraft parameters will be analyzed using the CRT and hard-copy displays. Commands generated in the computers will be transmitted to the spacecraft. The dynamic response of the spacecraft telecommunications can be then observed on the displays. This period will also provide an opportunity to work out command sequences to be used during the transfer trajectory and mission orbit and to check the response of the sequences with the spacecraft systems.

f. A dynamic spacecraft software simulator will be located in the IBM 360/65 computer in building 14. The simulator will be used to check out the observatory software and to train OCC and SOC personnel.

g. The Network will conduct a number of tests prior to launch to train Network personnel and to assure their ability to support IUE:

(1) A spacecraft/Network compatibility test will be conducted at least 6 months prior to launch using the Network Test and Training Facility (NTTF) at GSFC to ensure compatibility of the spacecraft and the Network, to generate telemetry tapes for training, and to acquaint Network personnel with the spacecraft.

(2) Tape exercises will be conducted with the IUE ground station and the stations that will support IUE during the transfer trajectory. Tapes generated during the compatibility test will be sent to the stations. The telemetry signal from these tapes will be transmitted using a signal generator. This signal will be received by the station antennas and passed through the receiving chain; critical telemetry words will be decommutated and displayed at the stations. After the Network completes the tape exercise, the data will be transmitted to the OCC where it will be processed in both computers and compared to the data recorded on the test tape.

(3) Additional telemetry tapes showing the anticipated modes of the spacecraft and experiment at different times in the transfer trajectory and the mission orbit will be generated during integration and testing of the spacecraft. These test tapes will be used to provide training for station personnel in recognizing anticipated telemetry outputs and responses to specific commands.

(4) Prior to simulations involving the OCC, the Network will conduct a detailed Network readiness test (NRT) to ensure that all elements of the Network, including NASCOM, are ready to support the spacecraft during all phases of the mission.

h. Prior to launch, the Flight Dynamics Manager and his staff of orbit and attitude personnel will conduct a series of tests of the Flight Dynamics System (FDS). These tests will include trajectory determination, trajectory control, attitude determination, and attitude control. After all parts of the system have been successfully tested, a number of tests on the complete system will be made.

i. During this period, the European Ground Observatory, OCC and SOC personnel will participate in similar training exercises. Later data transmission tests between the two observatories will be conducted.

9.4 EXERCISES AND SIMULATIONS

Extensive exercises and simulations on a subsystem and system level will be conducted prior to launch:

a. Exercises will be conducted in the OCC and SOC to train experiment and spacecraft personnel in the control of the spacecraft/experiment and to check out the OCC and SOC software, hardware, and operations procedures.

b. Exercises will also be conducted with the Network to ensure that all elements of the ground system function properly. Both the transfer trajectory and mission orbit phases will be simulated. Malfunctions will be simulated to test contingency procedures. Some of the malfunctions to be simulated are as follows:

   (1) Communications link outages

   (2) Command and control computer malfunctioning

   (3) Spacecraft and experiment anomalies

   (4) Malfunction of the IUE Ground Station subsystem

c. Exercises with the European Observatory will also be conducted to test out procedures for the transfer of control from one OCC to the other including emergency takeover of control by the U.S. OCC in case a spacecraft or experiment problem arises.

d. Simulations will be conducted with all participants included and operating on a time scale as planned for actual prelaunch, launch, and postlaunch mission operations.

e. Present plans are to connect, via wideband data link, the European Ground Observatory to the spacecraft software simulator located in the IBM 360/65 computer in building 14 at GSFC. The purpose of this connection will be to check out the European Ground Observatory prior to launch. It may also be possible to provide training to European Ground Observatory personnel using the simulator.

9.5 PRELAUNCH OPERATIONS

The prelaunch spacecraft operations will consists of running essentially the same automated test programs which were executed repeatedly during integration and test and evaluation. The telemetry and command links will be via data links between GSFC and the Eastern Test Range (ETR).

Prelaunch test operations will be conducted from the I&T Sigma 5 computer, and processed spacecraft data can be transmitted over a data line to the spacecraft support console at Cape Kennedy. The C&C and IP computers will also be periodically connected to the spacecraft via data links for testing during this phase.

A limited backup telemetry display and command generation capability will be provided at the spacecraft support console for use in the event of loss of communications to GSFC.

9.6 LAUNCH SEQUENCE

The spacecraft is scheduled to be launched from Cape Kennedy in December 1976, on a Delta launch vehicle. This section contains a description of the sequence of events during the premission phase beginning with the injection into the transfer trajectory and the separation of the spacecraft from the third stage of the Delta launch vehicle. The sequence ends with the spacecraft on station in a geosynchronous orbit, checked out, and ready for mission operations.

The transfer orbit phase begins with the Delta third-stage burnout. Figure 9.6-1 shows the subsatellite plot during the transfer trajectory through the first four apogees. It is planned to place the spacecraft into a near-geosynchronous eccentric orbit with the firing of the apogee motor at the second apogee. If it is not possible to do this, the spacecraft will be placed into a near-geosynchronous orbit on third or fourth apogee. The fourth apogee is preferable because the third apogee occurs over Africa. Injection at this point would require that the spacecraft drift for approximately 45 days before it arrives on station.

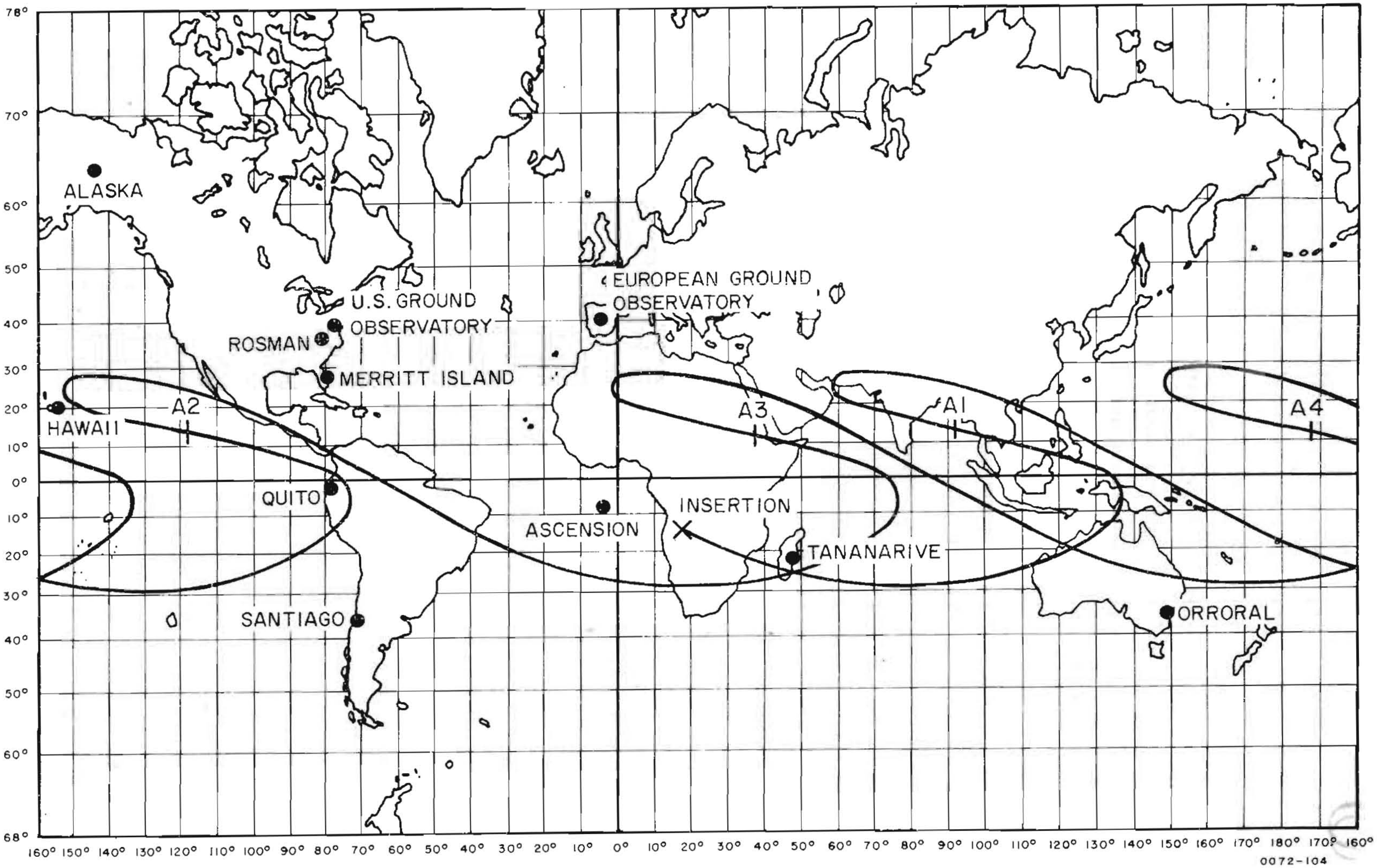


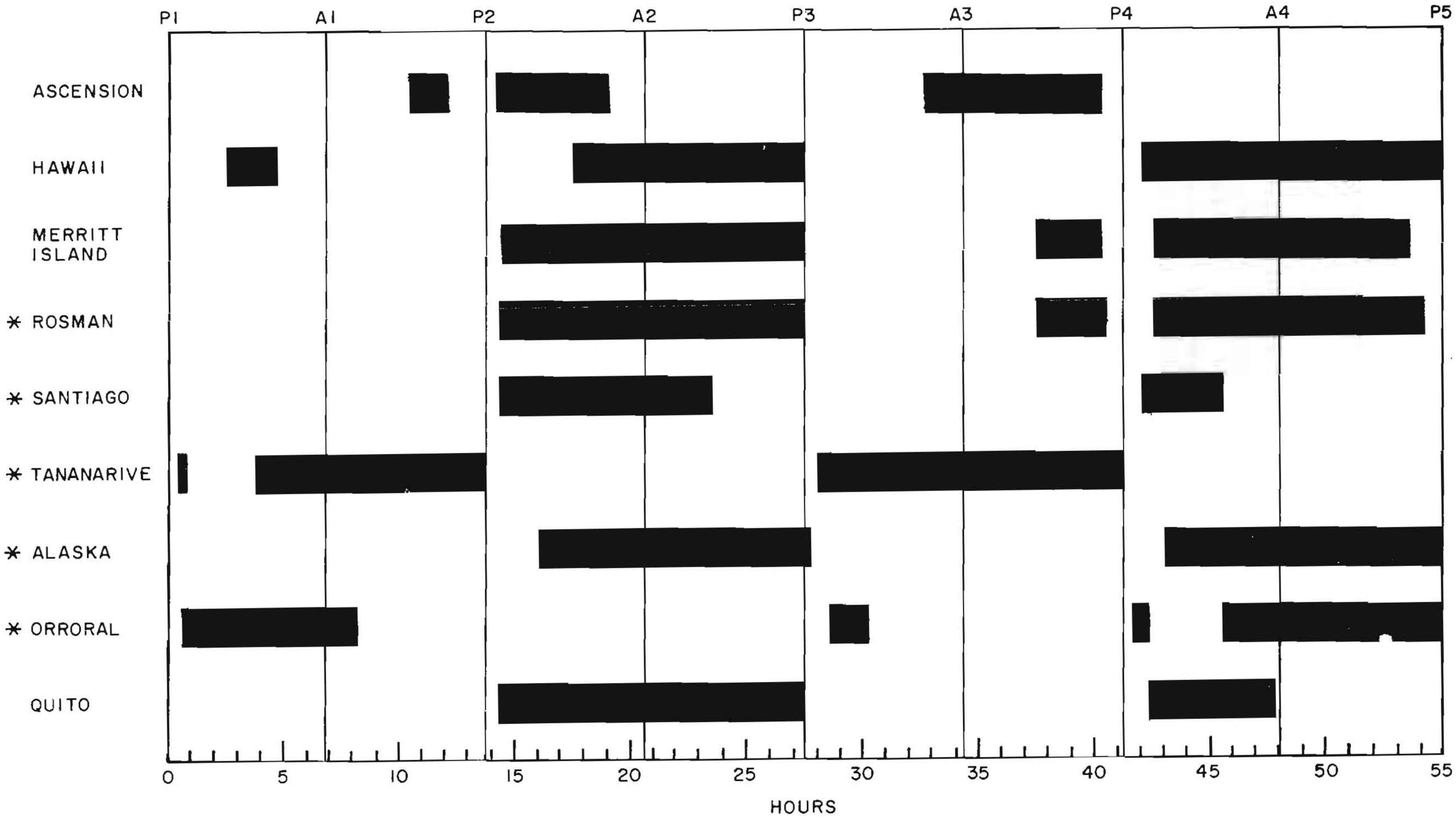
Figure 9.6-1. Transfer Trajectory Apogee Plot

In case of emergency, it may be necessary to fire the apogee burn motor (ABM) on the first apogee. However, the limited amount of tracking and telemetry data makes it undesirable to do this except in an emergency.

During the transfer orbit, the telemetry bit rate will be 1.25 kbps (uncoded). The VHF transponder will be used for range and range rate (RARR) tracking, telemetry data transmission, and command during this period. The VHF transponder will operate in either the telemetry data transmission or RARR mode but not simultaneously in both modes.

The following list describes the anticipated sequence of events from lift-off until the spacecraft is in a geosynchronous orbit on-station. Figure 9.6-2 gives the station coverage through the first few apogees. Appendix D gives the link margins during the transfer trajectory. All margins (command, telemetry, range and range rate) are positive with the exception of the SCAMP command antenna with a 2.5-kw transmitter at maximum range. During these periods, however, a positive command margin can be obtained using the SATAN command antenna systems.

Time	Event	Operations
T+29 min	Third-stage burnout	Vehicle telemetry/radar coverage by a ship or aircraft.
T+31 min	Spacecraft separation	Ship or aircraft will decommutate and display selected spacecraft telemetry words to verify spacecraft separation, spacecraft spin rate, and activation of the nutation control system.
T+33 min	Tananarive AOS	Tananarive will receive and record spacecraft telemetry data and transmit it in real-time to the OCC and will decommutate and display selected spacecraft telemetry words to verify spacecraft separation, spacecraft spin rate, and activation of the nutation control system; station will be prepared to transmit contingency commands if necessary. Between T+37 min and T+42 min, the station will range and range rate (RARR) track the spacecraft and will provide Minitrack interferometer tracking support.



NOTE: ALL STATIONS HAVE VHF TELEMETRY AND COMMAND CAPABILITY. STATIONS MARKED WITH AN ✱ ALSO HAVE VHF RANGE AND RANG RATE CAPABILITY.

0072-105

Figure 9-6.2. IUE Station Coverage Chart

Time	Event	Operations
T+45 min	Tananarive LOS	
T+51 min	Orroral AOS	Orroral will receive and record spacecraft telemetry data and transmit it to OCC in real-time, and be prepared to transmit contingency commands if necessary.
T+56 min		Orroral will terminate spacecraft telemetry data acquisition, and will start RARR tracking the spacecraft and transmit tracking data to GSFC in real-time/near-real-time.
		Note 1
		Until the second apogee, two stations (whenever the spacecraft is visible to two or more stations) will simultaneously receive and record spacecraft telemetry data (for 10 minutes out of each 15-minute period) and transmit it to the OCC in real-time; the stations will transmit commands as received from the OCC. The station will also be prepared to generate commands on station and transmit them upon a voice or teletype request from the OCC. During the other 5-minute period, a RARR station will RARR-track the spacecraft and transmit the data to GSFC in real-time/near-real-time. The RARR stations are Alaska, Orroral, Rosman, Santiago, and Tananarive.
T+1 hour 52 min	Hawaii AOS	Stations will continue to perform alternate spacecraft telemetry data acquisition and tracking operations per Note 1.
T+3 hours 34 min	Hawaii LOS	

Time	Event	Operations
T+4 hours	Spin axis reorientation	Orroral will transmit the commands for spin axis reorientation and transmit spacecraft telemetry data to the OCC in real-time. Note 2 Spin axis reorientation will require approximately 20 minutes. Because of the polarization of the spacecraft antennas it may be necessary for the stations to change the polarization of the command antennas after the spin axis is reoriented. If sufficient data to determine the spacecraft attitude, the spacecraft trajectory, and the required maneuvers is acquired before T+4 hours, the spin axis will be reoriented sooner. After spin axis reorientation, Orroral will receive spacecraft telemetry data and transmit the telemetry data in real-time to the OCC. Orroral will be prepared to transmit contingency commands if necessary.
T+5 hours 9 min	Tananarive AOS	
T+7 hours	Spin axis major trim	Tananarive will transmit the commands for a major trim of the spin-axis orientation. Note 3 Except for the events shown at T+4 hours, and T+7 hours, a STDN station will continue to receive and transmit telemetry data in real-time to the OCC for a 10-minute period out of every 15 minutes. During the other 5 minutes, a station will RARR-track the spacecraft and transmit the tracking data to GSFC in real-time/near-real-time.
T+7 hours 44 min	Orroral LOS	
T+13 hours 39 min	Tananarive LOS	

Time	Event	Operations
T+14 hours 33 min	Santiago AOS	LOS will occur after second apogee.
T+14 hours 42 min	Merritt Island AOS	LOS will occur after second apogee.
T+14 hours 51 min	U.S. Ground Station AOS	Starting at this time the IUE Ground Station will assume control of the spacecraft. A backup station will also be provided. The IUE Ground Station will be referred to as "the station" in the remainder of this sequence of events. LOS will occur after second apogee.
T+14 hours 52 min	Rosman AOS	LOS will occur after second apogee.
T+18 hours	Spin axis minor trim	The station will transmit the commands necessary to make the final adjustment to the spin-axis orientation prior to apogee boost motor (ABM) firing.
T+18 hours 21 min	Alaska AOS	LOS will occur after second apogee.
T+18 hours 26 min	Hawaii AOS	LOS will occur after second apogee.
T+21 hours 8 min	Apogee boost motor (ABM) firing	The station will transmit the apogee boost motor fire command (generated in the OCC) to the spacecraft.
T+21 hours 15 min	Spacecraft despin and sun acquisition	The station will transmit the following commands generated in the OCC. (The backup station will be prepared to transmit the commands upon voice instructions from the OCC, if required.) (1) Disable the nutation control system. (2) Energize three-axis inertial reference assembly (IRA). (3) Enable primary roll jets. (Despin will require approximately 400 seconds.) (4) Enable pitch and yaw primary jets. (Rate about all three axes will be reduced to approximately 0.25 degrees/second)

Time	Event	Operations
T+21 hours 15 min (Cont)		(5) Deploy paddles. (6) Enable attitude information from the summed analog sun sensors to be mixed with the spacecraft rates to initiate sun acquisition hold mode. The primary 0.1-pound thrusters will then orient the solar array normal to the sun line. (7) Disable thrusters. (8) Enable reaction wheels. The spacecraft is now in the sun hold mode controlled by the action of the analog sun sensors, IRA, and reaction wheels. A minimum of 24 hours will be required after despin to accurately determine the orbit and the direction and rate of drift. If required, an altitude and orbit maneuver will be made at that time using the velocity correction jets to correct the drift orbit. Note 4 During this period, the coverage described in Note 3 will be provided.
T+24 hours	Reorient spacecraft (if required)	The station will transmit commands for reorientation and orbit trim. Note 5 For the next 4 hours the coverage described in Note 3 will be provided.
T+28 hours	Additional reorientation of spin axis/orbit trim (if necessary)	The station will transmit commands for reorientation and orbit trim as necessary. Note 6 (1) For the next 4 hours the coverage described in Note 3 will be provided.

Time	Event	Operations
T+28 hours (Cont)		(2) If the apogee motor is not fired on the second apogee, it will be fired on the third or fourth apogee. In this case, the coverage in Note 3 must be extended until the apogee firing. The following times are based on a second apogee firing; third or fourth apogee firing will require adjustment of these times accordingly.
T+21 hours 15 min to T+11 days	Spacecraft drifting eastward at 6 degrees/day (nominal drift rate)	At this point in the flight profile, the spacecraft is drifting toward the station. Attitude is held in this state while experiments are turned on and functionally verified. Drift corrections will be inserted into the computer and the hold-on-gyros mode using the computer and reaction wheels will be verified. This mode will be used during orbit night. The station will receive and record spacecraft telemetry data, decommutate and display selected telemetry words, and transmit telemetry data to the OCC in real-time. During this period, all STDN stations with RARR capability that see the spacecraft will track the spacecraft periodically as required. Tracking data will be transmitted in real-time/near-real-time to GSFC where orbit and attitude will be determined. During this period of approximately 11 days, the spacecraft will be drifting to its station point at a rate of approximately 6 degrees/day. During this period an extensive checkout of all spacecraft systems and the experiment will be made.
T+11 days	Spacecraft placed on station	The station will transmit commands (generated in the OCC) for firing the lateral jets.
	Slew to Initial Guide Star	Under the control of the ground station, the spacecraft will be commanded to acquire the first star. The Panoramic Attitude Scanner and Fine Error Sensor on the spacecraft will be used for this purpose.

9.7 SPACECRAFT AND EXPERIMENT CHECKOUT

Once the spacecraft is on station, additional spacecraft and experiment checkout will be conducted, during which the station will maintain continuous contact with the spacecraft. Commands generated in the OCC will be sent via cable to the station and transmitted by the station to the spacecraft. Command verification information will be transmitted via cable to the OCC. During the checkout period, the station will acquire and transmit spacecraft telemetry data to the OCC in real-time.

APPENDIX A

SIGMA 5 VERSUS IBM 360/65

TIMING STUDY

OPTIONAL FORM NO. 10
MAY 1962 EDITION
GSA FPMR (41 CFR) 101-11.6

UNITED STATES GOVERNMENT

Memorandum

TO : SAS-D Ground Systems Subgroup

DATE: December 14, 1971

Richard desJardins

FROM : Richard desJardins
Spacecraft Control Programming Analyst,
SAS-D Mission Support Study Cadre

SUBJECT: XDS SIGMA 5 Timing Estimate for SAS-D Three-Axis Maneuver Computations

1. Abstract.

An estimate has been made of the total XDS SIGMA 5 core storage and computing time required to perform the basic SAS-D three-axis maneuver computations. Initializing a maneuvering episode will require 20K-40K bytes of core (plus common storage), and will consume 1:50 to 2:30 (minutes and seconds) of time. Once an episode is initialized, the basic computations involved in each complete target-to-target slew will require 100K-150K bytes of core (plus common), and will consume 2:40 to 3:30 of time. (Each pair of figures given above represents nominal and conservative values.)

2. Brief description of functions timed.

Initialization of a maneuvering episode is performed by the Data Management Module. (A functional description is provided in Appendix B.) This module will access the data base and build a system common in core of updated model data. This model will remain valid for operations constrained within some specified time interval and some specified region of attitude space. (This constrained time and space set is called the maneuvering episode.)

Once an episode has been initialized, individual maneuvers may be executed without extensive constraint checks. All computations supporting these maneuvers, including complete target-to-target slews, are performed within the Spacecraft Maneuvering Module. (A functional description is provided in Appendix B.)

Not included in the execution timing was any interface software to communicate back and forth from the Data Management and Spacecraft Maneuvering Modules to the various consoles and graphics terminals assigned to the astronomer, the spacecraft controller and the software analyst.

3. Timing rationale.

Within each of the two modules timed, a complete sequence of activity representing typical utilization of the module was considered.

Within the Data Management Module, all computation necessary to initialize a maneuvering episode was considered. Each function involved was listed, and members of the Spacecraft Control Programming Section estimated the execution time for each such function if performed in high-speed core on the OAO IBM 360/65. (Most functions involved are similar or identical to functions within the OAO Support Computer Program System.) In addition, an estimate of object module core storage requirements (not including common) was made by the same people.

Similarly, within the Spacecraft Maneuvering Module all computation necessary to support a complete target-to-target slew was considered. Each function involved was listed and the execution time estimated for the 360/65. The object module size was also estimated.

Next the attempt was made to determine a relative execution time factor for the SIGMA 5 vs. the 360/65. The resulting study is described in Appendix A. Following that study, in discussions within the SAS-D Ground Systems Subgroup, it was decided to adopt the factor 3 for throughput execution time of the SIGMA 5 vs. the 360/65 for a typical control center system task.

4. Timing and core storage estimates.

The timing estimate computations are presented in the following table.

	Data Management Module (initialization)	Spacecraft Maneuvering Module (complete slew)
Nominal execution time (sec) on 360/65 (technical judgment)	38	55
Nom. time on SIGMA 5 (factor 3 applied)	114	165
Conservative time on SIGMA 5 (30% added)	148	214
Core storage required (bytes) on SIGMA 5 (technical judgment)	20K-40K	100K-150K

Appendix A

SIGMA 5 vs. 360/65 Timing Study

1. Comparison procedure.

Comparing pumpkins and kumquats is rather easier than comparing the ERTS XDS Σ5 and the OAO IBM 360/65. (Five is a greater number of kumquats than three is of pumpkins, etc.) It was therefore arbitrarily decided by analogy to select some unit x of computing "work", and then simply count with a stopwatch (the system clock) the number t of seconds each computer used in performing x. Each computer was run "dry", with no other jobs in execution. Each run consisted of loading a relocatable object module and executing the unit x a number n of times. The number n was varied for different runs on the same computer, thus providing data from which the rate of change of t with respect to the unit x (in units of seconds per x) could be inferred. This method allows possible end-point variations between the two systems (such as program loading time) to be ignored.

Two units of work were selected, each to be used independently to derive an execution rate on each machine.

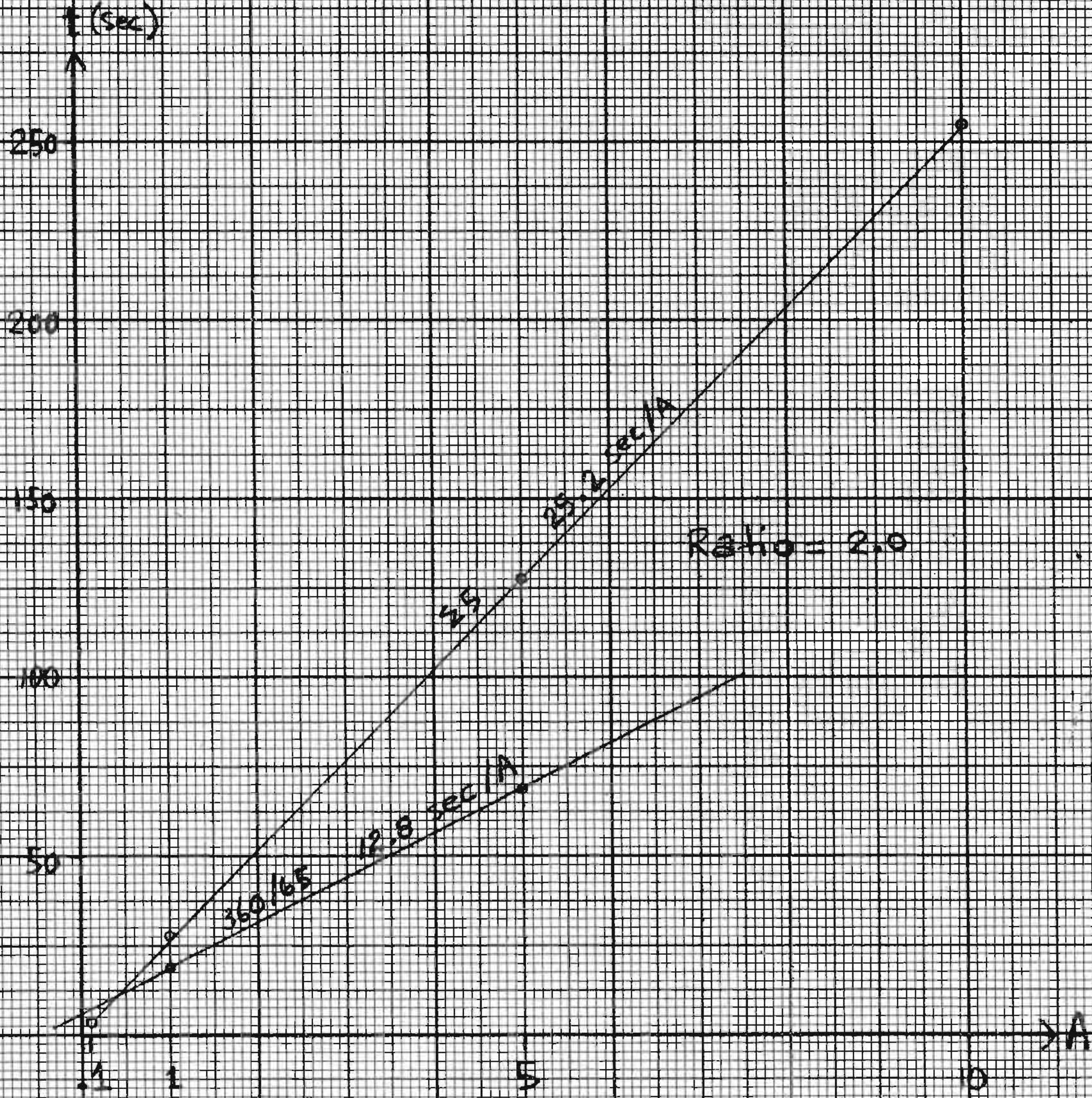
2. Work unit A.

a. Description. Work unit A consists of generating 10000 normal random numbers by successive calls to the IBM SSP subroutine GAUSS. Each such call results in GAUSS issuing 12 calls to the SSP subroutine RANDU (uniform random number generator). Unit A is 100% computation, involving 130000 additions, 130000 multiplications, and the necessary control and memory access operations. The algorithm in FORTRAN source code is given in Appendix A.1.

b. Results. The following table shows the execution times in seconds for each machine for various multiples of A.

Job	Execution time	
	Σ5	65
.1A	4	
A	28	18
5A	128	69
10A	255	

These data are plotted graphically in Figure 1. The feature of interest is the slope of each straight line in the graph, since the slope represents the increment in seconds required to perform each additional unit A of work. The ratio of the slopes is 2.0, which is therefore the measure of the factor by which the 65 is faster than the Σ5 in executing the unit A.



A = 100% computation
= 10000 normal random numbers

FIGURE 1

3. Work unit B.

a. Description. Unit B consists of generating 1000 normal random numbers, each involving the generation of 12 uniform random numbers, as in .1A. Unlike .1A, however, a line of print is written after each of the 13000 returns involved. The unit B thus involves interleaved computation and writing of single records, the efficiency of which depends on things like OS implementation, hardware, block sizes, etc.

b. Results. The following table shows the execution time in seconds for each machine for various multiples of B.

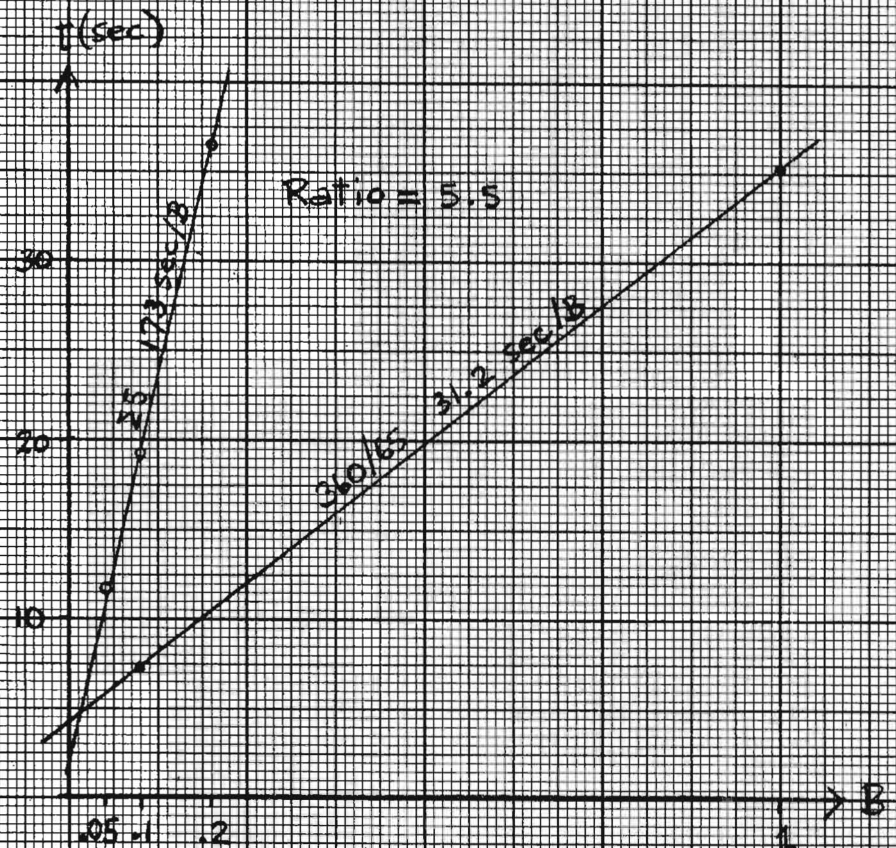
Job	Execution time	
	Σ5	65
.05B	11.8	
.1B	19.3	7.3
.2B	36.5	
B		35.4

These data are presented graphically in Figure 2. As before, the slope of each line represents the time in seconds to do a unit B of work. The data show that the 65 is 5.5 times faster than the Σ5 in executing the unit B.

4. Validity of results.

a. Consistency. The consistency of the Σ5 results is demonstrated by the goodness of fit of the data to a straight line. This goodness was immensely improved by ignoring the value of 348 sec obtained for the entire unit B on the Σ5, presumably caused by filling up the print area on the RAD for some reason, perhaps improper block size.

Consistency among the 65 data is more difficult to establish, since only two multiples of each unit were run. Furthermore, A was run twice on the dry 65, and times of 17.9 sec and 19.8 sec were obtained, presumably due to variation in system condition. (18 sec was adopted because less favorable to the 65, in the sense of resulting in a greater slope.) However the zero-point extrapolations produce values of 5.2 and 4.2 sec for the 65, which are reasonably self-consistent as compared with the consistency of zero-point extrapolations of 1.5 sec and 2.0 sec for the Σ5 data.



B = 50% comp / 50% I/O
= 1000 normal random numbers
with intermediate print out

FIGURE 2

b. Efficiency of FORTRAN object code. The objection may be made that the FORTRAN compilers on the two machines do not produce equally efficient object code. This is undoubtedly true for some programs. However in the two cases studied, the algorithms are so straightforward that such possibility is considered quite remote. Furthermore as a practical matter all the programs which are run on each machine in any operating shop will have been compiled on that machine, so the comparison is actually more realistic rather than less, at least for these algorithms.

The objection becomes problematical when one considers that it is not known which machine the hypothetical variation in efficiency actually favors for these algorithms, and further that it is easily possible that some other algorithm might be compiled with an efficiency variation which favors the opposite machine.

c. Admonition. It must be pointed out that the specific results 2.0 and 5.5, although considered accurate in the empirical sense of repeatable, nevertheless represent particular jobs run on particular system configurations. No claim is made to any generality.

6. Acknowledgment. The source programs were provided by D. Greer. R. Chaplick arranged for the dry execution runs on the OAO IBM 360/65, and P. Merwarth directed the runs on the ERTSOCC XDS Σ5.

Appendix A.1

FORTRAN Source Code

```
LEVEL 19 ( JUNE 70 )                    OS/360   FORTRAN H

COMPILER OPTIONS - NAME= MAIN,OPT=01,LINECNT=58,SIZE=0000K,
                   SOURCE,EBCDIC,LIST,NODECK,LOAD,MAP,NOEDIT,ID,XREF

      S=3.0
      IX=3
      AM=10.
      N=100
      DO 2 I=1,N
      CALL GAUSS(IX,S,AM,V)
      WRITE(06,500) IX,V
  500 FORMAT(T2,'IX=',I10,6X,'V =',E14.7)
    2 CONTINUE
      STOP
      END

      SUBROUTINE GAUSS(IX,S,AM,V)
      A=0.0
      DO 50 I=1,12
      CALL RANDU(IX,IY,Y)
      WRITE(06,500) IX,IY,Y
  500 FORMAT(T20,'IX=',I10,2X,'IY=',I10,2X,'Y =',E14.7)
      IX=IY
   50 A=A+Y
      V=(A-6.0)*S+AM
      RETURN
      END

      SUBROUTINE RANDU(IX,IY,YFL)
      IY=IX*65539
      IF(IY) 5,6,6
    5 IY=IY+2147483647+1
    6 YFL=IY
      YFL=YFL*.4656613E-09
      RETURN
      END
```

APPENDIX B

INITIAL REPORT ON

ANTICIPATED CALIBRATION REQUIREMENTS

FOR IUE TELESCOPE-SPECTROMETER SYSTEM

March 28, 1972

TO: Astronomy Working Group for SAS-D

FROM: SAS-D Calibration Subcommittee:

Members - E.B. Jenkins, Chairman
Princeton University Observatory

D.A. Klinglesmith
Goddard Space Flight Center

L.N. Houziaux
Mons University

R. Wilson
Culham Laboratory

SUBJECT: Initial Report on Anticipated Calibration Requirements for the SAS-D Telescope-Spectrometer System

I. INTRODUCTION

This report summarizes our proposed calibrations to be carried out under the responsibility of the SAS-D operating team. These procedures are intended to fulfill the primary requirements for interpreting the data in a general sense. That is, information derived from the calibrations discussed in this report are considered to be necessary or beneficial to all users of the system. Hence we assume these phases should be defined and executed by resident astronomers and the technical staff as a general service, and oribital time devoted to such operations would presumably not be considered as a part of any observer's (or observing group's) allocated schedule. Special purpose calibrations which only serve the needs of a particular observing program should be the responsibility of the participating astronomer to devise and perform.

II. PARAMETERS DEFINED BY CALIBRATIONS

In considering the scope of problems which need to be defined for the spectrographs and their dectectors, we propose that the following properties must be calibrated in the system:

(1) Detector readout bias (i.e. zero level shift for which we must correct before either a background or actual signal is measured).

(2) Sources of diffuse background (which give rise to a need for an intensity subtraction which probably will vary in a smooth fashion over the face of the detector).

(a) Dark counts inherently registered by the detector tube from

(i) thermal emission of electrons (probably very sensitive to temperature)

(ii) faint discharges from high voltage points inside the tube

(b) Trapped particle radiation, cosmic rays.

(c) Wide angle scattering of star's light by either the echelle or cross-dispersion grating

(3) Contamination illumination passing through the slit (which could superimpose a faint solar spectrum on top of the star's spectrum)

(a) Earth shine or direct sunlight diffracted off the edges of the baffle

(b) Moonlight multiply reflected inside the baffles (we assume the observing constraints do not force us to have the Moon as fully shielded as the Earth or Sun).

(c) Zodiacal light should be negligible: at 40° from the Sun along the ecliptic the illumination passing through a 3 arc sec aperture would be equivalent to viewing a V = 18.25 G2 star.

(4) Diffuse Lyman-α radiation.

(5) Relationship of exposure intensity to the number of electrons read out of each pixel.

(6) Absolute sensitivity versus wavelength. Some factors which influence the sensitivity:

(a) Reflectivity of mirrors and gratings

(b) Blaze efficiency

(c) Overall sensitivity of the photocathode material versus wavelength and also the sensitivity of the individual pixel positioned in the spectrum format for a particular wavelength.

(7) Instrumental profile function and its wavelength dependence. Contributing sources of smearing may be from

(a) finite size of the entrance aperture

(b) optical aberrations

(c) small-angle echelle grating scatter (or ghosts); finite size of the grating or the coherance length of the rulings.

(d) detector tube resolution limit

(e) possible limitation in the bandwidth of the processing electronics

(f) digitization sample interval; possible aliasing effects.

(8) Positions of wavelengths on the detector output format which are influenced by:

(a) the spectrograph's mechanical configuration (and its possible variability with temperature).

(b) geometrical distortion of the image by the detector.

The lettered subcategories describe individual sources which contribute to each of the numbered main problems; in practice we need only to know their combined effect. In a later section (V) we will discuss the implementation of the calibrations.

III. EQUIPMENT

As an aid in carrying out many of the calibration phases, we propose that the following hardware (with appropriate redundancies and safeguards) be on board the spacecraft.

(1) Lamp which floods the detector tube face with an even (or reasonably smooth) illumination. This device has already been proposed as an aid to achieving an even and complete erasure after exposure and readout. It would be preferable to have this tube be an ultraviolet source.

(2) PMT or other reliable photodevice which would monitor some fraction of the illumination lamp's output over the calibration exposure time.

(3) Spectrum calibration lamp which provides narrow emission lines at many wavelengths (such as an Fe - Ne source used in

OAO-C), mounted as shown on p. 4 - 67 of the Phase A Report. Subsequent to the Phase A Report, a decision was made to omit item (3) above. We urge the Astronomy Working Group to reconsider this decision. An emission line source is essential for some calibrations in orbit and useful for other ones, as we shall describe later. It is our opinion that a reinstatement of this device is well worth the additional complexity.

IV. DISCUSSION

For the most part, the measurement of background contamination (for the amount of background subtraction needed) can be done by observing the exposure level between the successive orders from the echelle. Even at the shortest wavelengths, where the cross dispersion is least, there should be a sufficient gap between the lines to measure the fog level. In orbit, it might be wise to occasionally check that the parts of the photocathode which always are exposed to a spectrum are as equally sensitive to background effects as the unexposed gaps. In other words, we should verify that the photocathode has not become "tired" just along the spectrum format. Also we would look for any fine spatial structure in the background pattern. Outside of this occasional check, the background determination could be achieved routinely during each of the data exposures. The readout bias of the zero level can be measured by reading a frame with virtually zero integration time while the telescope is pointed toward a dark spot in the sky.

In listing the individual calibrations (1) through (8) earlier, we differentiated between wide-angle grating scatter, which contributed to problem (2), and small-angle scatter by the echelle, which was placed under (7). What differentiates one from the other is whether or not the light is scattered into the interline spaces. Any light scattered by the cross dispersion grating will fall in between as well as on the spectra. However, if the echelle has irregularities in its rulings, it will scatter some light in a horizontal direction, nearly parallel to the spectra. This scatter will fall between the lines (and hence contribute to the background measurement) only at a distance greater than the spectrum's vertical width divided by its slope on the 2-dimensional format. Smaller angle scatter will fall only on the spectrum and hence should be considered as a weak but very extended contribution to the instrumental profile in wavelength.

The acquisition camera could serve as a monitor for the amount of scattered light contamination in the telescope. The relationship between the relative amount of fogging of the acquisition field, and the amount of contamination of a solar type spectrum on top of the desired spectrum could be established after a series of calibrations in orbit. Such calibrations could also help us define real limits in operating the telescope for various configurations in regard to the positions of the Earth, Moon, and Sun. For a given exposure situation, one must be aware of whether the spectral contamination came primarily from the Sun, Earth or Moon, since the Earth and Moon will have varying albedos as a function of wavelength.

Although we are not certain how strong the geocoronal Lyman-α radiation would be for typical observing situations at geosynchronous altitudes, we suspect it will not be of much consequence. A measurement of non-local Lyman-α glow by OGO-5 shows a maximum of 570 Rayleighs. This corresponds to a flux of 7.5×10^{-3} photons cm^{-2} sec^{-1} within the solid angle that the entrance aperture would accept. By comparison, a 10th magnitude B0 star would give about 2 photons cm^{-2} sec^{-1} $Å^{-1}$ of continuum near 1216 Å. Even if the Lyman-α radiation were distinguishable in the spectrum of a faint object, it would be easily noticed as a narrow spike inside the broad interstellar absorption profile, and hence it could be subtracted from the data by the astronomer. Thus it appears reasonable to disregard item (4) as a potential problem, unless the geocoronal component is considerably stronger in some observing configurations.

The lamp which floods the tube with light could be used to establish, on a regular basis in orbit, the relation between the signal intensity and the integrated exposure. Provided reciprocity effects are unimportant, the relation can be measured for every pixel on the tube by recording the outputs from a succession of exposures of varying duration by the lamp. The actual strength of each exposure would have to be monitored by some independent device (hardware item (2) specified earlier) since we probably could not count on the lamp's intensity to be well regulated.

A rough computation of the time necessary to do a calibration of the tube's intensity response might be as follows: Suppose the dynamic range of the tube is on the order of 256. Then if the successive exposures all differ by a factor of 2, we will need a total of 8 exposures to obtain a satisfactory (logarithmic) calibration curve. The total exposure time would be $2^9 - 1 = 511$ times the minimum exposure time (i.e. the faintest exposure). Suppose that minimum were 1 sec, we would then require $8^{m}.5 + 8$ (3 min readout time) $= 32^{m}.5$.

The discussion in the Phase A Report pointed out the unfeasibility of having some device on board the spacecraft which would enable us to obtain absolute calibrations of the overall sensitivity of the system versus wavelength. For the most part, we will have to rely upon observing standard stars which have been measured by other experiments. In principle, the standard star calibrations would suffice to define the sensitivity function used for reducing astronomical data, but it would be desirable to have ground calibration runs to independently establish the nature of the factors (6)a to (6)c listed earlier, as well as the illumination lamp's relative intensity over various portions of the tube face.

Some thought should be directed toward what criteria should be applied to the selection of stars which would be suitable as standards. The sooner we apply these criteria, select the stars, and then publicize the list, the better will be our chances of having these stars observed by rocket-borne instrumentation whose absolute sensitivities have been calibrated. In a context broader than just the application to SAS-D calibration problems, now is a good time for some group of astronomers to decide upon which stars are best as standards for UV observations in general. Cross checking of separate observations of absolute fluxes would be more effective if we all agreed to look at the same stars!

An obvious requirement for a calibration star is that it should, as best as we can determine, be nonvariable and perferably, an ordinary sort of star. It should also be rather bright in the ultraviolet, so that small, well-calibrated instrumentation need not have problems gathering enough photons to measure. It would be helpful, but not really necessary, to have the stars at a high ecliptic latitude so that they could be observed any time of the year. For the SAS-D with the 40° baffle, stars within 50° of either ecliptic pole could always be observed when the Sun and the Earth are nearly in line. An open question is whether or not we could be further selective and favor northern stars since a majority of calibration flights may be carried out in the northern hemisphere. We solicit from the Astronomy Working Group any modifications or additional suggestions on criteria to consider in drawing up a list.

The calibration of wavelength versus position on the image which has been read out may be established in some detail if a lamp which has many emission lines all over the spectrum illuminates the spectrograph through the entrance slit. An observation of the calibration spectrum would yield information on the combined effect of the image distortion by the detector and the dispersion by the spectrograph elements. This calibration procedure would eliminate the need for fiducial marks on the detector face, which would interfere with the data at certain wavelengths. Fiducial marks, of course, only calibrate the tube's image distortion characteristics. To be sure, one could use observations of known interstellar lines to calibrate the wavelength scale, but interpolation between these lines may be uncertain if they are widely separated in wavelength.

The calibration lamp would be the only means one could determine the nature of the instrumental spread profile while the instrument is in orbit. Again, narrow interstellar lines might be of some use, but a much clearer picture of the spread function and its wavelength dependence could be obtained from the calibration emission line source. We should remember, however, that the profile for emission lines may be different from that for absorption features in a continuum, owing to the beam bending phenomena in TV dectectors. One drawback of the calibration source is that its beam does not precisely duplicate the properties of the light bundle delivered by the telescope from a celestial source. With the configuration which has been suggested in the Phase A Report, the f number would be much higher than that accomodated by the spectrographs. Hence there may be some error in representing the effects (7)b, (7)c and (8)a outlined earlier. Some insight from ground calibrations would help us ascertain how to correct for this effect. The broadening of the instrumental profile which may be ascribed to the finite size of the entrance aperture (item (7)a) pertains to the worst possible performance of the telescope guidance system; if the stability of the telescope were markedly better than ±1.5 arc sec, the slit width convolution would overstate the actual smearing in wavelength. A strong overexposure by the calibration lamp would help us measure the weak echelle scattering wings (item 7c in the list), but this effect could also be measured, or verified, by observing the residual intensity in the center of the interstellar Lyman-α absorption line in the spectrum of any bright star.

As a separate problem, we should consider what calibrations are needed for the acquisition camera, outside of its use as a monitor for stray light. It appears to us that knowlege of the exact nature of the photometric properties is of little importance. Such properties as the relative spectral sensitivity, absolute sensitivity and image scale will be well enough defined by the basic system design. The only critical parameter to determine in orbit will be precisely how the recorded image elements map onto the sky. This relationship should be known so that a computer can devise the proper commands to point the telescope toward a star recorded anywhere in the acquisition field.

A practical scheme would be to rely on the ground calibration for the initially assumed function to be used in the early days of observing. If, for some reason, this function is not very accurate after the instrument is launched, we would operate at reduced efficiency. We would find it necessary to converge on a star with two or more spacecraft movements, with intervening looks by the acquisition camera, much in the manner of an inexperienced golfer. Nonetheless, if we programmed the computation system to keep track of the errors made in the course of routine acquisition trials (during regular observing), after some experience it would be possible to update the mapping function. Provided the characteristics of the acquisition camera are stable, we might soon expect to execute a "hole-in-one" every time. It would be desirable to avoid a waste of orbital time in a more formal calibration of the acquisition field.

V. SEQUENCE OF CALIBRATIONS

To summarize our suggested procedures from an operational standpoint, we might classify the calibrations according to where they fit in the overall schedule.

(1) Ground calibration:

(a) diffuse illumination lamp intensity over the detector face.

(b) mirror reflectivity, blaze efficiency and detector tube response as a function of wavelength.

(c) Initial version of acquisition field mapping function.

(d) wavelengths and instrumental profiles for the full beam entering the telescope versus that from the calibration source.

(2) Extensive initial calibration shortly after launch, with only very occasional quick checks later:

(a) Relationship of acquisition camera fogging to diffuse contamination from Earth, Moon, or Sun, and definition of operational limits.

(b) observations of standard stars for absolute intensities.

(3) Calibrations done on a routine basis in orbit:

(a) readout bias measurement (this should probably be checked rather frequently).

(b) wavelength position and spread function determination using emission line source.

(c) intensity calibration of pixels using a sequence of exposures from the flood lamp.

(d) observations of standard stars for absolute intensities.

(e) verifications that the background between lines is valid.

(4) Calibrations which are inherently performed during regular observing

(a) Background measurement.

(b) Contamination illumination monitoring by acquisition camera.

(c) Acquisition field mapping (improved version).

One of the objectives of the calibration subcommittee was to ascertain what fraction of the orbital time must be taken up with calibration exercises. The necessary frequency of routine calibrations, however, appears to be a difficult parameter to define at this point. Indeed, members of the subcommittee have ventured guesses ranging from once every 8 hour shift to once a week. Clearly, actual orbital experience should settle the question of how much time must be allocated to calibrations, but for advanced planning it would be helpful if those responsible for engineering the equipment could estimate or measure the time constants for the stability of various components. We also need to better define the sensitivity of the equipment to environmental changes (i.e., voltage fluctuations, absolute temperature, temperature differences, radiation, scattered light, etc.) so that we can ascertain how fine the grid of calibrations must be against these variables, if measurable in orbit.

APPENDIX C
COMPUTING SPEED REQUIREMENT FOR IMAGE PROCESSING COMPUTER

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Computing speed requirements have been developed under the following assumptions:

a. Time required for backup of the spacecraft command and control computer can be ignored.

b. Time required to recalibrate the experiment can be ignored. (Calibration exposures will be scheduled as regular exposures.)

c. Time to develop software during spacecraft operations can be ignored.

d. Each of the operations outlined under paragraph 6.5 Image Processing, is necessary for every HRE and LRS image.

e. The images arrive in the system at the rate outlined in paragraph 6.5.2, Inputs to Image Processing.

For convenience the timing estimates from Table 6.5-1 are repeated here. In addition timing estimates for an XDS Sigma 5 have been included for comparison.

Table C-1
Timing Estimates

Step	Type	Sigma 5 (Minutes)	Sigma 9 Model 3 (Minutes)
Noise removal	CPU	15.0	8.6
Distortion removal	CPU	23.0	12.0
Resolution enhancement	CPU	23.0	12.0
Rough wavelength determination	I/O	2.0	2.0
Photometric calibration	I/O	4.5	4.5
Precise wavelength calibration	I/O	2.0	2.0
Final output preparation	I/O	2.0	2.0
Graphics support average	I/O	2.0	2.0
		73.5	45.1

The observatory will be used 16 hours per day and, under average conditions, images arrive at a rate of one image per 55 minutes. This produces 17.5 images a day, half of which would be LRS images.

Using the time estimates given in Table C-1 and a ratio of 5 to 1 for HRE-to-LRS computing times (since LRS is 1/8 of the data of HRE, a 5-to-1 rule-of-thumb ratio of computing times is adequate), Table C-2 shows the hours needed to do the data reduction tasks.

Table C-2
Data Reduction Time

		Sigma 5	Sigma 9, Model 3
9 HRE Images		11.0 hrs	6.7 hrs
9 LRS Images		2.2 hrs	1.3 hrs
	Total	13.2 hrs	8.0

The figures in Table C-2 represent current estimates of the IUE Astronomy Group. The actual distribution of images could change drastically from the estimates for the following reasons:

a. The normal behavior of the astronomer may vary; he may take many short exposures or a few long ones. Either type requires the same processing power per image but the affect on the arrival rate varies. Also, the astronomers may or may not take 50 percent HRE and 50 percent LRS as anticipated.

b. The amount of in-flight calibration needed for the instrument may vary. It may be necessary to recalibrate some functions every few images. This could have a drastic affect on required computer time.

c. There may be effects that require corrections not yet considered.

d. Some data may need to be reprocessed because of errors of judgment on the part of the data reduction operator.

e. The amount of time that the image processing computer will spend backing up the command and control computer is uncertain.

f. The estimates for correcting for known effects could be inaccurate. Tasks associated with the extraction of the spectrum from a "cleaned" image are particularly uncertain in this respect, since this is a comparitively new field.

The choice of XDS computer is restricted by processor speed to the Sigma 8 or 9. The choice is further narrowed to a Sigma 9, Model 3, by the fact that it is the least expensive. The Sigma 7 is also rejected on the basis of higher cost.

In the absence of firm information to the contrary, the machine has been configured on the following assumptions:

a. The machine is monoprogramming and processing only one image at a time. This may waste operator think time, but I/O wait time is usually not wasted since VICAR allows applications programs to be performing other calculations during I/O waits.

b. Sufficient core is available so that all modules required to be co-resident with the largest applications program can be loaded at one time.

Worst-case core requirements will be during periodic noise removal, since this is the largest application program.

Graphics support may be needed with periodic noise removal, and it will certainly be needed with precise wavelength calibration. It should be emphasized, however, that since the proposed high-resolution displays are self refreshing, they could continue to display an image even though support programs are not in core. The support programs could thus be overlaid in emergencies.

Worst-case core requirements for image processing are as follows:

Operating system	15 K words
System executive	9 K words
Graphic Support	20 K words
Task controller (VMAST/VTRAN equivalent)	5 K words
Largest application program	77 K words
I/O buffers	2 K words
Total	128 K words

The image processing computer is also intended as a backup for the spacecraft command and control computer. Core requirements for the latter are given in the IUE C&C Feasibility Study. In outline the core requirements are as follows:

	Resident Functions	Core Required (Words)
1.	Operating system spacecraft control functions	15 K
2.	System executive	5 K
3.	Data acquisition	10 K
4.	Command management	11 K
5.*	[Real-time processor	15 K
6.	CRT display processor	8 K
7.	Spectrograph experiment processor	5 K
8.	History/report]	2 K
	Total	55 K

Experimenter Planning Interval Software Support Functions

9.*	[Graphics support	40 K
	Maneuver computations	40 K
	Session continuity]	10 K
10.	Executive and common areas	20 K
	Total	60 K
11.	Background processing area	12 K
	Grand total	127 K

The image processing computer is intended to back up all significant functions of the spacecraft command and control computer. The requirement of 127 K words will conveniently be accommodated in the IP computer which will have 128 K words of core storage.

*Items within brackets are swapped.

APPENDIX D

PREDICTED SIGNAL MARGINS FOR SPACECRAFT LINKS REQUIRING STDN STATION SUPPORT

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PREDICTED SIGNAL MARGINS FOR SPACECRAFT LINKS REQUIRING STDN STATION SUPPORT

This appendix contains tables which present an estimate of the signal margins for each spacecraft link requiring STDN station support. Tables D-1 through D-4 slow link margins expected during the transfer orbit. These link margins are based on the equipment at Orroral. The link margins for the same equipment at other stations are similar to the values shown in these tables. Tables D-5 through D-10 show the link margins expected at the U.S. ground station during the mission orbit. Tables D-11 and D-12 show the GRARR margins for Rosman and Santiago during the mission phase.

Table D-1
IUE Uplink (Prime), Transfer Phase, 148.980-MHz, SATAN Command System, 5-kw Transmitter (Orroral)

Parameters	Units	Values		Estimated Tolerances DB	
		Max Rng 50138 KM 8.5 El	Min Rng 186 KM 90.0 El	Fav	Adv
Command					
Effective Radiated Power	DBM	87.0	87.0	1.0	-1.0
Free Space Dispersion Loss	DB	-169.9	-121.8	0.0	0.0
Atmospheric Loss	DB	0.0	0.0	0.0	0.0
Polarization Loss	DB	-3.0	-3.0	2.5	0.0
Spacecraft Antenna Gain	DBI	0.0	0.0	1.0	-1.0
Spacecraft Passive Loss	DB	0.0	0.0	0.1	-0.1
Maximum Total Received Power	DBM	-85.9	-37.3	2.9	-1.4
Spacecraft Antenna Null Depth	DB	-11.0	-11.0	0.0	0.0
Minimum Total Received Power	DBM	-96.9	-48.3	2.9	-1.4
Command Receiver Threshold	DBM	-106.0	-106.0	1.0	-1.0
Available Margin	DB	9.1	57.7	3.0	-1.7
Required Performance Margin	DB	3.0	3.0	0.0	0.0
Net Margin	DB	6.1	54.7	3.0	-1.7

Table D-2
IUE Uplink (Prime), Transfer Phase, 148.980-MHz SCAMP
Command System, 2.5-kw Transmitter (Orroral)

Parameters	Units	Values		Estimated Tolerances DB	
		Max Rng 50138 KM 8.5 El	Min Rng 186 KM 90.0 El	Fav	Adv
Command					
Effective Radiated Power	DBM	80.0	80.0	1.0	-1.0
Free Space Dispersion Loss	DB	-169.9	-121.3	0.0	0.0
Atmospheric Loss	DB	0.0	0.0	0.0	0.0
Polarization Loss	DB	-3.0	-3.0	2.5	0.0
Spacecraft Antenna Gain	DBI	0.0	0.0	1.0	-1.0
Spacecraft Passive Loss	DB	0.0	0.0	0.1	-0.1
Maximum Total Received Power	DBM	-92.9	-44.3	2.9	-1.4
Spacecraft Antenna Null Depth	DB	-11.0	-11.0	0.0	0.0
Minimum Total Received Power	DBM	-103.9	-55.3	2.9	-1.4
Command Receiver Threshold	DBM	-106.0	-106.0	1.0	-1.0
Available Margin	DB	2.1	50.7	3.0	-1.7
Required Performance Margin	DB	3.0	3.0	0.0	0.0
Net Margin	DB	-0.9	47.7	3.0	-1.7

Table D-3
IUE Downlink (Prime), Transfer Phase, 136.860-MHz
6-watt Transmitter, SATAN Receive System (Orroral)

Parameter	Units	Values		Estimated Tolerances DB	
		Max Rng 50318 KM 8.5 El	Min Rng 186 KM 90.0 El	Fav	Adv
Total Transmitter Power	DBM	37.8	37.8	1.0	-1.0
Spacecraft Passive Losses	DB	0.0	0.0	0.0	0.0
Spacecraft Antenna Gain	DBI	0.0	0.0	1.0	-1.0
Free Space Dispersion Loss	DB	-169.2	-120.6	0.0	0.0
Atmospheric Loss	DB	0.0	0.0	0.0	0.0
STDN Antenna Gain (Effective)	DBI	20.5	20.5	0.5	-0.5
Polarization Loss	DB	-0.5	-0.5	0.5	-0.5
Maximum Total Received Power	DBM	-111.4	-62.8	1.6	-1.6
Spacecraft Antenna Null Depth	DB	-10.0	-10.0	0.0	0.0
Minimum Total Received Power	DBM	-121.4	-72.8	1.5	-1.6
System Noise Density	DBM/Hz	-170.1	-170.2	-1.4	4.6
IF Noise BW (30.000 kHz)	DB-Hz	44.8	44.8	0.0	0.0
IF SNR (Min)	DB	3.9	52.6	2.1	-4.9
Carrier Channel					
Carrier/Total Power	DB	-6.9	-6.9	0.7	-0.7
Received Carrier Power (Min)	DBM	-128.3	-79.7	1.7	-1.7
Carrier Loop Noise Bandwidth (60 Hz)	DB-Hz	17.8	17.8	0.0	0.0
Noise Power	DBM	-152.3	-152.4	1.4	-4.6
Carrier/Noise	DB	24.0	72.7	2.2	-4.9
Required Carrier/Noise	DB	15.0	15.0	0.0	0.0
Available Carrier Margin	DB	9.0	57.7	2.2	-4.9
Required Performance Margin	DB	3.0	3.0	0.0	0.0
Net Margin	DB	6.0	54.7	2.2	-4.9
Data Channel (PCM/PM)					
Data/Total Power (MI = 1.10 RAD)	DB	-1.0	-1.0	0.1	-0.1
Received Data Power (Min)	DBM	-122.4	-73.8	1.6	-1.6
Video Noise BW (15.000 kHz)	DB-Hz	41.8	41.8	0.0	0.0
Video Noise Power	DB	-128.3	-128.4	1.4	-4.6
Video SNR	DB	5.9	54.6	2.1	-4.9
Data Rate (1.250 kbps)	DB-BPS	31.0	31.0	0.0	0.0
Available Signal/Noise Density	DB-Hz	47.7	96.4	2.1	-4.9
Required Energy/Bit	DB	11.6	11.6	0.0	0.0
Required Signal/Noise Density	DB-Hz	42.6	42.6	0.0	0.0
Available Signal Margin	DB	5.1	53.8	2.1	-4.9
Required Performance Margin	DB	3.0	3.0	0.0	0.0
Net Margin	DB	2.1	50.8	2.1	-4.9

Table D-4
IUE GRARR Downlink, Transfer Phase, 136.890-MHz, 6-watt Transmitter, GRARR VHF System (Orroral)

Parameter	Units	Values		Estimated Tolerances DB	
		Max Rng 50318 KM 8.5 El	Min Rng 186 KM 90.0 El	Fav	Adv
Total Transmitter Power	DBM	37.8	37.8	1.0	-1.0
Spacecraft Passive Losses	DB	0.0	0.0	0.0	0.0
Spacecraft Antenna Gain	DBI	0.0	0.0	1.0	-1.0
Free Space Dispersion Loss	DB	-169.2	-120.6	0.0	0.0
Atmospheric Loss	DB	0.0	0.0	0.0	0.0
STDN Antenna Gain (Effective)	DBI	20.0	20.0	0.5	-0.5
Polarization Loss	DB	-0.5	-0.5	0.5	-0.5
Maximum Total Received Power	DBM	-111.9	-63.3	1.6	-1.6
Spacecraft Antenna Null Depth	DB	-10.0	-10.0	0.0	0.0
Minimum Total Received Power	DBM	-121.0	-73.3	1.6	-1.6
System Noise Density	DBM/Hz	-169.2	-169.4	-1.3	4.4
IF Noise BW (100.000 kHz)	DB-Hz	50.0	50.0	0.0	0.0
IF SNR (Min)	DB	-2.7	46.1	2.0	-4.7
Carrier Channel					
Carrier/Total Power	DB	-1.4	-1.4	0.1	-0.1
Received Carrier Power (Min)	DBM	-123.3	-74.7	1.6	-1.6
Carrier Loop Noise Bandwidth (60 Hz)	DB-Hz	17.8	17.8	0.0	0.0
Noise Power	DBM	-151.4	-151.6	1.3	-4.4
Carrier/Noise	DB	28.1	76.9	2.1	-4.7
Required Carrier/Noise	DB	15.0	15.0	0.0	0.0
Available Carrier Margin	DB	13.1	61.9	2.1	-4.7
Required Performance Margin	DB	3.0	3.0	0.0	0.0
Net Margin	DB	10.1	58.9	2.1	-4.7
Tone Ranging-Acq (PM)					
Ranging/Total Power (MI = 0.800 RAD)	DB	-5.7	-5.7	0.6	-0.6
Transponder Degradation	DB	0.0	0.0	0.0	0.0
Received Ranging Power (Min)	DBM	-127.6	-79.0	1.7	-1.7
Available Ranging/Noise Density	DB-Hz	41.6	90.4	2.1	-4.7
Required Signal/Noise Density	DB-Hz	32.0	32.0	0.0	0.0
Available Signal Margin	DB	9.6	58.4	2.1	-4.7
Required Performance Margin	DB	3.0	3.0	0.0	0.0
Net Margin	DB	6.6	55.4	2.1	-4.7

Table D-5
IUE Uplink (Prime), Mission Phase, 148.980-MHz, SATAN Command System, 10-kw Transmitter (U.S. Ground Station)

Parameter	Units	Values		Estimated Tolerances DB	
		Max Rng 46300 KM 56.5 El	Min Rng 28500 KM 38.0 El	Fav	Adv
Command					
Effective Radiated Power	DBM	90.0	90.0	1.0	-1.0
Free Space Dispersion Loss	DB	-169.2	-165.0	0.0	0.0
Atmospheric Loss	DB	0.0	0.0	0.0	0.0
Polarization Loss	DB	-3.0	-3.0	2.5	0.0
Spacecraft Antenna Gain	DBI	0.0	0.0	1.0	-1.0
Spacecraft Passive Loss	DB	0.0	0.0	0.1	-0.1
Maximum Total Received Power	DBM	-82.2	-78.0	2.9	-1.4
Spacecraft Antenna Null Depth	DB	-11.0	-11.0	0.0	0.0
Minimum Total Received Power	DBM	-93.2	-89.0	2.9	-1.4
Command Receiver Threshold	DBM	-106.0	-106.0	1.0	-1.0
Available Margin	DB	12.8	17.0	3.0	-1.7
Required Performance Margin	DB	3.0	3.0	0.0	0.0
Net Margin	DB	9.8	14.0	3.0	-1.7

Table D-6
IUE Uplink (Backup), Mission Phase, 148.980-MHz, SCAMP Command System, 5-kw* Transmitter (U.S. Ground Station)

Parameters	Units	Values		Estimated Tolerances DB	
		(Max Rng 46300 KM 56.5 El)	(Min Rng 28500 KM 38.0 El)	Fav	Adv
Command					
Effective Radiated Power	DBM	83.0	83.0	1.0	-1.0
Free Space Dispersion Loss	DB	-169.2	-165.0	0.0	0.0
Atmospheric Loss	DB	0.0	0.0	0.0	0.0
Polarization Loss	DB	-3.0	-3.0	2.5	0.0
Spacecraft Antenna Gain	DBI	0.0	0.0	1.0	-1.0
Spacecraft Passive Loss	DB	0.0	0.0	0.1	-0.1
Maximum Total Received Power	DBM	-89.2	-85.0	2.9	-1.4
Spacecraft Antenna Null Depth	DB	-11.0	-11.0	0.0	0.0
Minimum Total Received Power	DBM	-100.2	-96.0	2.9	-1.4
Command Receiver Threshold	DBM	-106.0	-106.0	1.0	-1.0
Available Margin	DB	5.8	10.0	3.0	-1.7
Required Performance Margin	DB	3.0	3.0	0.0	0.0
Net Margin	DB	2.8	7.0	3.0	-1.7

*10-kw power output can be used if required.

Table D-7
IUE Downlink (Prime), Mission Phase, 2249.800-MHz, 6-watt Transmitter, 12-meter Parabolic Antenna System With Planned Modifications
(U.S. Ground Station)

Parameter	Units	Values		Estimated Tolerances DB	
		Max Rng 46300 KM 56.5 El	Min Rng 37700 KM 0.0 El	Fav	Adv
Total Transmitter Power	DBM	37.8	37.8	1.0	-1.0
Spacecraft Passive Losses	DB	-1.0	-1.0	0.1	-0.1
Spacecraft Antenna Gain	DBI	0.0	0.0	1.0	-1.0
Free Space Dispersion Loss	DB	-192.8	-191.0	0.0	0.0
Atmospheric Loss	DB	0.0	0.0	0.0	0.0
STDN Antenna Gain (Effective)	DBI	46.5	46.5	0.5	-0.5
Polarization Loss	DB	-0.5	-0.5	0.5	-0.5
Maximum Total Received Power	DBM	-110.0	-108.2	1.6	-1.6
Spacecraft Antenna Null Depth	DB	-3.0	-3.0	0.0	0.0
Minimum Total Received Power	DBM	-113.0	-111.2	1.6	-1.6
System Noise Density	DBM/Hz	-179.6	-179.1	0.0	0.2
IF Noise BW (300.000 kHz)	DB-Hz	54.8	54.8	0.0	0.0
IF SNR (Min)	DB	11.3	13.1	1.6	-1.6
Carrier Channel					
Carrier/Total Power	DB	-6.9	-6.9	0.7	-0.7
Received Carrier Power (Min)	DBM	-119.9	-118.1	1.7	-1.7
Carrier Loop Noise Bandwidth (20 Hz)	DB-Hz	13.0	13.0	0.0	0.0
Noise Power	DBM	-166.6	-166.1	0.0	-0.2
Carrier/Noise	DB	46.7	48.0	1.7	-1.7
Required Carrier/Noise	DB	15.0	15.0	0.0	0.0
Available Carrier Margin	DB	31.7	33.0	1.7	-1.7
Required Performance Margin	DB	3.0	3.0	0.0	0.0
Net Margin	DB	28.7	30.0	1.7	-1.7
Data Channel (PCM/PM)					
Data/Total Power (MI = 1.10 RAD)	DB	-1.0	-1.0	0.1	-0.1
Received Data Power (Min)	DBM	-114.0	-112.2	1.6	-1.6
Video Noise BW (750.000 kHz)	DB-Hz	58.8	58.8	0.0	0.0
Video Noise Power	DB	-120.8	-120.3	0.0	-0.2
Video SNR	DB	6.8	8.1	1.6	-1.6
Data Rate (40.000 kbps)	DB-BPS	46.0	46.0	0.0	0.0
Available Signal/Noise Density	DB-Hz	65.6	66.9	1.6	-1.6
Required Energy/Bit	DB	12.5	12.5	0.0	0.0
Required Signal/Noise Density	DB-Hz	58.5	58.5	0.0	0.0
Available Signal Margin	DB	7.1	8.4	1.6	-1.6
Required Performance Margin	DB	3.0	3.0	0.0	0.0
Net Margin	DB	4.1	5.4	1.6	-1.6

Table D-8
IUE Downlink (Backup S-band), Mission Phase, 2249.800-MHz, 6-watt Transmitter ERTS 9-meter Parabolic Antenna System (U.S. Ground Station)

Parameter	Units	Values		Estimated Tolerances DB	
		Max Rng 46300 KM 56.5 El	Min Rng 38430 KM 10.0 El	Fav	Adv
Total Transmitter Power	DBM	37.8	37.8	1.0	-1.0
Spacecraft Passive Losses	DB	-1.0	-1.0	0.1	-0.1
Spacecraft Antenna Gain	DBI	0.0	0.0	1.0	-1.0
Free Space Dispersion Loss	DB	-192.8	-191.2	0.0	0.0
Atmospheric Loss	DB	0.0	-0.2	0.0	0.0
STDN Antenna Gain (Effective)	DBI	43.0	43.0	0.5	-0.5
Polarization Loss	DB	-0.5	-0.5	0.5	-0.5
Maximum Total Received Power	DBM	-113.5	-112.1	1.6	-1.6
Spacecraft Antenna Null Depth	DB	-3.0	-3.0	0.0	0.0
Minimum Total Received Power	DBM	-116.5	-115.1	1.6	-1.6
System Noise Density	DBM/Hz	-178.7	-176.4	0.0	0.2
IF Noise BW (300.000 kHz)	DB-Hz	54.8	54.8	0.0	0.0
IF SNR (Min)	DB	7.4	5.5	1.6	-1.6
Carrier Channel					
Carrier/Total Power	DB	-6.9	-6.9	0.7	-0.7
Received Carrier Power (Min)	DBM	-123.4	-122.0	1.7	-1.7
Carrier Loop Noise Bandwidth (20 Hz)	DB-Hz	13.0	13.0	0.0	0.0
Noise Power	DBM	-165.7	-162.4	0.0	-0.2
Carrier/Noise	DB	42.3	40.4	1.7	-1.7
Required Carrier/Noise	DB	15.0	15.0	0.0	0.0
Available Carrier Margin	DB	27.3	25.4	1.7	-1.7
Required Performance Margin	DB	3.0	3.0	0.0	0.0
Net Margin	DB	24.3	22.4	1.7	-1.7
Data Channel (PCM/PM)					
Data/Total Power (MI = 1.10 RAD)	DB	-1.0	-1.0	0.1	-0.1
Received Data Power (Min)	DBM	-117.5	-116.1	1.6	-1.6
Video Noise BW (750.000 kHz)	DB-Hz	58.8	58.8	0.0	0.0
Video Noise Power	DB	-119.0	-116.6	0.0	-0.2
Video SNR	DB	2.4	0.5	1.6	-1.6
Data Rate (40.000 kbps)	DB-BPS	46.0	46.0	0.0	0.0
Available Signal/Noise Density	DB-Hz	61.2	59.3	1.6	-1.6
Required Energy/Bit	DB	12.5	12.5	0.0	0.0
Required Signal/Noise Density	DB-Hz	58.5	58.5	0.0	0.0
Available Signal Margin	DB	2.7	0.8	1.6	-1.6
Required Performance Margin	DB	3.0	3.0	0.0	0.0
Net Margin	DB	-0.3	-2.2	1.6	-1.6

Table D-9
IUE Downlink (Backup VHF), Mission Phase, 136.860-MHz,
6-watt Transmitter, SATAN Receive System
(U.S. Ground Station)

Parameter	Units	Values		Estimated Tolerances DB	
		Max Rng 46300 KM 56.5 El	Min Rng 28500 KM 38.0 El	Fav	Adv
Total Transmitter Power	DBM	37.8	37.8	1.0	-1.0
Spacecraft Passive Losses	DB	0.0	0.0	0.0	0.0
Spacecraft Antenna Gain	DBI	0.0	0.0	1.0	-1.0
Free Space Dispersion Loss	DB	-168.5	-164.3	0.0	0.0
Atmospheric Loss	DB	0.0	0.0	0.0	0.0
STDN Antenna Gain (Effective)	DBI	20.5	20.5	0.5	-0.5
Polarization Loss	DB	-0.5	-0.5	0.5	-0.5
Maximum Total Received Power	DBM	-110.7	-106.5	1.6	-1.6
Spacecraft Antenna Null Depth	DB	-10.0	-10.0	0.0	0.0
Minimum Total Received Power	DBM	-120.7	-116.5	1.6	-1.6
System Noise Density	DBM/Hz	-170.2	-170.2	-1.6	4.6
IF Noise BW (30.000 kHz)	DB-Hz	44.8	44.8	0.0	0.0
IF SNR (Min)	DB	4.7	8.9	2.2	-4.9
Carrier Channel					
Carrier/Total Power	DB	-6.9	-6.9	0.7	-0.7
Received Carrier Power (Min)	DBM	-127.6	-123.4	1.7	-1.7
Carrier Loop Noise Bandwidth (20 Hz)	DB-Hz	13.0	13.0	0.0	0.0
Noise Power	DBM	-157.2	-157.2	1.6	-4.6
Carrier/Noise	DB	29.6	33.8	2.4	-4.9
Required Carrier/Noise	DB	15.0	15.0	0.0	0.0
Available Carrier Margin	DB	14.6	18.8	2.4	-4.9
Required Performance Margin	DB	3.0	3.0	0.0	0.0
Net Margin	DB	11.6	15.8	2.4	-4.9
Data Channel (PCM/PM0					
Data/Total Power (MI = 1.10 RAD)	DB	-1.0	-1.0	0.1	-0.1
Received Data Power (Min)	DBM	-121.7	-117.5	1.6	-1.6
Video Noise BW (15.000 kHz)	DB-Hz	41.8	41.8	0.0	0.0
Video Noise Power	DB	-128.4	-128.4	1.6	-4.6
Video SNR	DB	6.7	10.9	2.3	-4.9
Data Rate (1.250 kbps)	DB-BPS	31.0	31.0	0.0	0.0
Available Signal/Noise Density	DB-Hz	48.5	52.7	2.3	-4.9
Required Energy/Bit	DB	11.6	11.6	0.0	0.0
Required Signal/Noise Density	DB-Hz	42.6	42.6	0.0	0.0
Available Signal Margin	DB	5.9	10.1	2.3	-4.9
Required Performance Margin	DB	3.0	3.0	0.0	0.0
Net Margin	DB	2.9	7.1	2.3	-4.9

Table D-10
IUE Downlink (Backup VHF), Mission Phase, 136.860-MHz, 6-watt Transmitter, SATAN Receive System (U.S. Ground Station)

Parameter	Units	Values		Estimated Tolerances DB	
		Max Rng 46300 KM 56.5 El	Min Rng 35820 KM 7.9 El	Fav	Adv
Total Transmitter Power	DBM	37.8	37.8	1.0	-1.0
Spacecraft Passive Losses	DB	0.0	0.0	0.0	0.0
Spacecraft Antenna Gain	DBI	0.0	0.0	1.0	-1.0
Free Space Dispersion Loss	DB	-168.5	-166.3	0.0	0.0
Atmospheric Loss	DB	0.0	0.0	0.0	0.0
STDN Antenna Gain (Effective)	DBI	20.5	20.5	0.5	-0.5
Polarization Loss	DB	-0.5	-0.5	0.5	-0.5
Maximum Total Received Power	DBM	-110.7	-108.5	1.6	-1.6
Spacecraft Antenna Null Depth	DB	-10.0	-10.0	0.0	0.0
Minimum Total Received Power	DBM	-120.7	-118.5	1.6	-1.6
System Noise Density	DBM/Hz	-170.2	-169.6	-1.1	4.6
IF Noise BW (30.000 kHz)	DB-Hz	44.8	44.8	0.0	0.0
IF SNR (Min)	DB	4.7	6.3	1.9	-4.9
Carrier Channel					
Carrier/Total Power	DB	-6.9	-6.9	0.7	-0.7
Received Carrier Power (Min)	DBM	-127.6	-125.4	1.7	-1.7
Carrier Loop Noise Bandwidth (20 Hz)	DB-Hz	13.0	13.0	0.0	0.0
Noise Power	DBM	-157.2	-156.6	1.1	-4.6
Carrier/Noise	DB	29.6	31.2	2.0	-4.9
Required Carrier/Noise	DB	15.0	15.0	0.0	0.0
Available Carrier Margin	DB	14.6	16.2	2.0	-4.9
Required Performance Margin	DB	3.0	3.0	0.0	0.0
Net Margin	DB	11.6	13.2	2.0	-4.9
Data Channel (PCM/PM)					
Data/Total Power (MI = 1.10 RAD)	DB	-1.0	-1.0	0.1	-0.1
Received Data Power (Min)	DBM	-121.7	-119.5	1.6	-1.6
Video Noise BW (15.000 kHz)	DB-Hz	41.8	41.8	0.0	0.0
Video Noise Power	DB	-128.4	-127.8	1.1	-4.6
Video SNR	DB	6.7	8.3	1.9	-4.9
Data Rate (1.250 kbps)	DB-BPS	31.0	31.0	0.0	0.0
Available Signal/Noise Density	DB-Hz	48.5	50.1	1.9	-4.9
Required Energy/Bit	DB	11.6	11.6	0.0	0.0
Required Signal/Noise Density	DB-Hz	42.6	42.6	0.0	0.0
Available Signal Margin	DB	5.9	7.5	1.9	-4.9
Required Performance Margin	DB	3.0	3.0	0.0	0.0
Net Margin	DB	2.9	4.5	1.9	-4.9

Table D-11
IUE Downlink (Range and Range Rate), Mission Phase, 136.860-MHz, 6-watt Transmitter, VHF GRARR System (Rosman)

Parameter	Units	Values: Max Rng 46170 KM 68.0 El	Values: Min Rng 28160 KM 43.0 El	Estimated Tolerances DB: Fav	Estimated Tolerances DB: Adv
Total Transmitter Power	DBM	37.8	37.8	1.0	-1.0
Spacecraft Passive Losses	DB	0.0	0.0	0.0	0.0
Spacecraft Antenna Gain	DBI	0.0	0.0	1.0	-1.0
Free Space Dispersion Loss	DB	-168.5	-164.2	0.0	0.0
Atmospheric Loss	DB	0.0	0.0	0.0	0.0
STDN Antenna Gain (Effective)	DBI	20.0	20.0	0.5	-0.5
Polarization Loss	DB	-0.5	-0.5	0.5	-0.5
Maximum Total Received Power	DBM	-111.2	-106.9	1.6	-1.6
Spacecraft Antenna Null Depth	DB	-10.0	-10.0	0.0	0.0
Minimum Total Received Power	DBM	-121.2	-116.9	1.6	-1.6
System Noise Density	DBM/Hz	-169.4	-169.4	-1.4	4.4
IF Noise BW (100.000 kHz)	DB-Hz	50.0	50.0	0.0	0.0
IF SNR (Min)	DB	-1.8	2.5	2.1	-4.7
Carrier Channel					
Carrier/Total Power	DB	-1.4	-1.4	0.1	-0.1
Received Carrier Power (Min)	DBM	-122.6	-118.3	1.6	-1.6
Carrier Loop Noise Bandwidth (20 Hz)	DB-Hz	13.0	13.0	0.0	0.0
Noise Power	DBM	-156.4	-156.4	1.4	-4.4
Carrier/Noise	DB	33.8	38.1	2.1	-4.7
Required Carrier/Noise	DB	15.0	15.0	0.0	0.0
Available Carrier Margin	DB	18.8	23.1	2.1	-4.7
Required Performance Margin	DB	3.0	3.0	0.0	0.0
Net Margin	DB	15.8	20.1	2.1	-4.7
Tone Ranging-Acq (PM)					
Ranging/Total Power (MI = 0.800 RAD)	DB	-5.7	-5.7	0.6	-0.6
Transponder Degradation	DB	0.0	0.0	0.0	0.0
Received Ranging Power (Min)	DBM	-126.9	-122.6	1.7	-1.7
Available Ranging/Noise Density	DB-Hz	42.5	46.8	2.2	-4.7
Required Signal/Noise Density	DB-Hz	32.0	32.0	0.0	0.0
Available Signal Margin	DB	10.5	14.8	2.2	-4.7
Required Performance Margin	DB	3.0	3.0	0.0	0.0
Net Margin	DB	7.5	11.8	2.2	-4.7

Table D-12
IUE Downlink (Range and Range Rate), Mission Phase, 136.860-MHz, 6-watt Transmitter, VHF GRARR System (Santiago)

Parameter	Units	Values		Estimated Tolerances DB	
		Max Rng 47910 KM 32.6 El	Min Rng 26485 KM 69.7 El	Fav	Adv
Total Transmitter Power	DBM	37.8	37.8	1.0	-1.0
Spacecraft Passive Losses	DB	0.0	0.0	0.0	0.0
Spacecraft Antenna Gain	DBI	0.0	0.0	1.0	-1.0
Free Space Dispersion Loss	DB	-168.8	-163.6	0.0	0.0
Atmospheric Loss	DB	0.0	0.0	0.0	0.0
STDN Antenna Gain (Effective)	DBI	20.0	20.0	0.5	-0.5
Polarization Loss	DB	-0.5	-0.5	0.5	-0.5
Maximum Total Received Power	DBM	-111.5	-106.3	1.6	-1.6
Spacecraft Antenna Null Depth	DB	-10.0	-10.0	0.0	0.0
Minimum Total Received Power	DBM	-121.5	-116.3	1.6	-1.6
System Noise Density	DBM/Hz	-169.4	-169.4	-1.4	4.4
IF Noise BW (100.000 kHz)	DB-Hz	50.0	50.0	0.0	0.0
IF BNR (Min)	DB	-2.1	3.1	2.1	-4.7
Carrier Channel					
Carrier/Total Power	DB	-1.4	-1.4	0.1	-0.1
Received Carrier Power (Min)	DBM	-122.9	-117.7	1.6	-1.6
Carrier Loop Noise Bandwidth (20 Hz)	DB-Hz	13.0	13.0	0.0	0.0
Noise Power	DBM	-156.4	-156.4	1.4	-4.4
Carrier/Noise	DB	33.5	38.7	2.1	-4.7
Required Carrier/Noise	DB	15.0	15.0	0.0	0.0
Available Carrier Margin	DB	18.5	23.7	2.1	-4.7
Required Performance Margin	DB	3.0	3.0	0.0	0.0
Net Margin	DB	15.5	20.7	2.1	-4.7
Tone Ranging-Acq (PM)					
Ranging/Total Power (MI = 0.800 RAD)	DB	-5.7	-5.7	0.6	-0.6
Transponder Degradation	DB	0.0	0.0	0.0	0.0
Received Ranging Power (Min)	DBM	-127.2	-122.0	1.7	-1.7
Available Ranging/Noise Density	DB-Hz	42.2	47.4	2.2	-4.7
Required Signal/Noise Density	DB-Hz	32.0	32.0	0.0	0.0
Available Signal Margin	DB	10.2	15.4	2.2	-4.7
Required Performance Margin	DB	3.0	3.0	0.0	0.0
Net Margin	DB	7.2	12.4	2.2	-4.7