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A SCIENTIFIC OPERATIONS PLAN FOR THE NASA SPACE TELESCOPE

DONALD K. WEST
S. RICHARD COSTA

**REVISED
NOVEMBER 1975**

GSFC —— **GODDARD SPACE FLIGHT CENTER** ——
GREENBELT, MARYLAND

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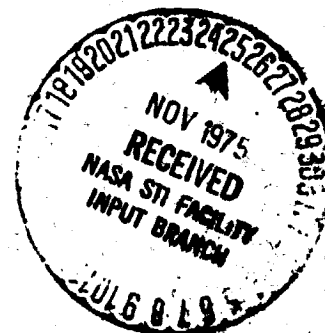
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Donald K. West*
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ABSTRACT

Mission and data operations studies at Goddard Space Flight Center have
identified some Space Telescope (ST) scientific operations requirements
which are logical extensions to our past experience and capability on
space telescopes such as OAO. These expanded requirements arise in
several areas. Image processing of large two dimensional arrays con-
taining millions of information elements require larger computers and
more complex software systems. An independent Science Institute has
been proposed for the ST. If this Science Institute is adopted it would
support a large number of principal and guest investigator observations
on several scientific instruments, dictating the need for extensive hard-
ware and software systems to accomplish long-range Observatory
scheduling and daily science planning. The additional constraint of
having to build and operate the ST for at least 15 years at very low cost
greatly increases the difficulty of formulating an effective scientific
operations plan. Goddard's approach to solving this problem is centered
about the use of existing and planned facilities which can be made avail-
able to the ST. Hardware and software facilities are presently being
developed for the IUE astronomical telescope. The IUE Observatory
will serve a large body of guest astronomers and features continuous
real-time operation as well as production processing of two dimensional
astronomical image data. The Image Processing Facility under develop-
ment at Goddard has the capacity of processing image data at several
hundred times the rate projected for ST. Other institutional facilities
which can be made available to the ST are the Telemetry Operations
Processing System which provides near real-time user support with
pre-processing quick-look capacity to handle large volumes of data.
It is concluded that the scientific operations requirements of the ST can
be met at low cost through the use of existing facilities at Goddard.

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INTRODUCTION

The purpose of this paper is to describe an ST ground system which is compatible
with the operational requirements of the ST. The goal of this approach to the
ground system is to minimize the cost of post launch operations without seriously
compromising the quality and total throughput of ST science, or jeopardizing the
safety of the ST in orbit. The resulting system is able to accomplish this goal
through optimum use of existing and planned resources and institutional facili-
ties. Cost is also reduced and efficiency in operation increased by drawing on
existing experience in interfacing guest astronomers with spacecraft as well as
mission control experience obtained in the operation of present astronomical
spacecraft.

The ground system addressed here is limited to the mission and data operations
elements of the total ST Program which includes the ST in orbit; the STDN (in-
cluding TDRSS); Mission Operations function; Scientific Operations functions;
new Scientific Instrument development; Principal Investigator and Guest Inves-
tigator support. The primary function of Mission Operations is to insure the
health and safety of the ST in orbit. Scientific Operations is mainly concerned
with the planning and implementation of science programs in both a long-range
and daily time frame.

THE ST SCIENCE INSTITUTE

An independent Science Institute has been proposed for the ST. If this Science
Institute is adopted it would be an international institution serving both U.S. and
foreign astronomers. The Institute would be operated by non-Government astron-
omers and would be headed by a Director who has overall responsibility for the
implementation of scientific programs selected for the ST in accordance with
the guidelines provided by the ST Board of Directors. The Director would be
assisted in the overall management and policy establishment by an Assistant
Director for Science and an Assistant Director for Operations.

The Science Institute would be responsible for proposal selection, telescope-
time schedules, science planning and the implementation of guest investigator
programs.

Guest Investigators as well as Principal Investigators would normally come to
the Institute to perform their astronomical observations although some fraction

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of routine observing programs could be conducted by mail. Normally the details of an observer's program would be checked out in advance of his period of activity at the Institute. During an observing run, the investigator would participate in the verification of the observing plan, real-time target acquisition, the analysis of quick-look data, changes to his observing plan, and the specification of data reduction procedures. Data processing would be performed to the user's specification to the point where scientific judgment and analysis is required. At this point, the data would be presented to the user in the form and format suitable for scientific analysis. A copy of the data would be kept at the Institute until after the period of properietary use by the guest investigator. After this time, (typically six months to one year) the data can be archived in the National Space Science Data Center.

REQUIREMENTS

Mission and data operations conceptual studies for the ST have been completed at Goddard. Basic requirements for the ST ground system were analyzed and evaluated relative to existing OAO experience and resources. The results of these studies showed that all of the mission operations requirements could be met through the direct or slightly modified use of hardware and software resources developed for OAO. Scientific operational requirements, however, call for the development of new resources in three areas.

The first of these new requirements involved the development and operation of a scheduling and science planning system for the ST Science Institute. The Institute would select, schedule, and render data processing support to Guest Investigators who come to the Institute to carry out their observations. Principal Investigator teams would also reside at the Institute where they would participate in conducting observations and reducing data as well as supervising the operation and calibration of their Scientific Instruments (SI's). Guest observer and PI support at the Institute will require sophisticated hardware and software systems to accomplish long-range observatory scheduling and science planning. This resource does not exist on OAO.

The second new requirement concerns the real-time operation of the SI's and spacecraft pointing control system to accomplish closed-loop-to-ground target acquisition and positioning in the SI apertures. Extended real-time contact periods and routine ground target acquisition systems needed to meet this new requirement is not available on OAO.

The third and most demanding new requirement is in science data management. The ST will transmit several images per orbit which will require preprocessing and image processing of millions of data points per day. The preprocessing of

raw telemetry data will strip out the science data and output it in a format suitable for data reduction tasks, such as image processing. Preprocessing of 10^9 bits/ day is an ST requirement which is outside the scope of OAO system compability. Image processing of 20 to 50 frames per day requires a computer with a highly sophisticated software system. This requirement identifies the need for a significant new resource.

A summary of these critical ST scientific operational new resource requirements is shown in Table I.

COST CONSTRAINTS AND GUIDELINES

Ultimately, an ST Science Institute may require autonomous dedicated operational facilities to maximize the scientific flexibility and data throughput in the planning of observations and the final science data processing and analysis. Initially, however, program cost constraints do not allow for the development of new hardware and software systems dedicated to the ST.

Table I

Scientific Operations Resource Requirements

Requirement	ST	OAO	Resource
1. Science Institute			
● Principal Investigators	4-6	2	Mod.
● Guest Investigators	50/Yr	2/Yr	New
2. Instrument Operation			
● Commands/Day	20 K	1K	Mod.
● Slews/Day	10	20	Exists
● Target Acquisition	Ground	Onboard	New
3. Data Management			
● Data Bits/Day	10^9	10^6	New
● Data Processing	I. P.	Conventional	New

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The Goddard study has produced a scientific operations plan which will meet the ST requirements within the limits of current cost ceilings. The plan is centered on existing and planned data facilities at Goddard which can be used by ST in shared modes of operation. The hardware and software facilities identified for ST have broad data handling and data processing capability extending far beyond the ST requirements for data rate, volume, and processing functions.

In order to develop a completely viable ST ground system which will effectively interface the Science Institute with the shared facilities, it is necessary to define the following self consistent set of operational guidelines:

1. The Mission Operations Center (MOC) will be located at Goddard Space Flight Center.

2. The ST Science Institute would be located at Goddard or its operational staff must co-located at Goddard.

3. The Science Institute would be responsible for all Observatory scheduling, observational implementation, science data management final processing, and archival.

4. The Science Institute staff would have the capability to operate all SI's and their support systems in real time with quick-look data in real time or near real time at the MOC.

5. A shared set of computers and software could be used for all mission operations and science planning.

6. All real time commands will be controlled by the MOC dedicated control computer.

7. Control and science planning software will be derived from existing software.

8. Raw data will be acquired, stored, and pre-processed by TELOPS.

9. Routine image processing hardware and system software is to be provided by GSFC Image Processing Facility (IPF).

10. The Science Institute would be responsible for providing scientific applications programs and calibration data sets for image processing to IPF.

11. Custom data processing would be done at the Science Institute.

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12.   Final reduced science data could be archived and distributed by the
      National Space Science Data Center.

IDENTIFICATION OF NEW RESOURCES

Following the above cost constraints and ground system design guidelines, a
study of existing and planned resources within the GSFC was performed. The
results of this study revealed that most of the new requirements for ST could
be met through the use of observational and data processing software and hard-
ware resources currently in development.

These facilities will be in operation several years prior to ST launch and can be
made available to ST during the post launch period if their effective use by ST is
assured. The effective use of these shared facilities has been strongly depend-
ent upon the proximity of the user. Three important resources have been
identified.

The International Ultraviolet Explorer (IUE) is an international observatory which
will host at least 50 guest observers per year. Astronomers will come to
Goddard to carry out their observations in a continuous real time operating en-
vironment similar to ground based observatories. Software and hardware for
long-range guest observer scheduling and real time target acquisition systems
are currently being developed for a 1977 launch. These IUE scientific opera-
tions systems are ideally matched with the ST requirements for guest observer
support and real time closed-loop-to-ground target acquisition.

The ST requirements for the temporary storage and pre-processing of space-
craft data and 1×10^9 bits per day of science data merging, stripping, process-
ing, formatting, and quick-look output can be completely satisfied by using the
Telemetry Operations Processing System (TELOPS). This system which is
currently being built at Goddard is sized for data volume and pre-processing re-
quirements several orders of magnitude greater than those of the ST.

The most difficult ST requirement in terms of development and operational costs
is for the daily processing of 1×10^9 bits of image data. The Image Processing
Facility (IPF) under development at Goddard is a large scale, fast computer
system which can process up to 2×10^{11} bits per day. In addition, IPF is able
to accommodate the scientists' need for direct control of calibration data sets,
scientific algorithms and applications programs which are to be developed and
maintained by the user. The IUE Image Processing System now under develop-
ment is designed to perform geometric and radiometric corrections; flux and
wavelength calibrations; and periodic and random noise removal. This system
which is based on the JPL VICAR image processing system has been modified

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and expanded to handle 768 x 768 TV camera images of Echelle spectrum and will be operational early in 1977.

Table II gives a summary of the major resources which will fully meet the ST requirements and which will be available to ST during the pre-launch development and post launch operational phases.

Figure 1 shows the major elements of the proposed ST ground system. Those elements which will provide institutional support services to ST are shaded. Unshaded blocks contain ST dedicated facilities. The mission planning computer, STDN and NSSDC presently provide institutional support services to OAO. These facilities have been well demonstrated, and need not be discussed here. The capabilities of the new resources which will help to meet the new requirements of ST are now briefly described.

Table II

Identification of New Resources

Resource	ST Requirements
IUE	
● Observatory Scheduling System	● Guest Observer Visit Support
● Real-Time Operating System	● Target Acquisition (Closed-Loop with Ground)
Telemetry Operations Processing System (TELOPS)	
● Pre-Processing/Storage	● 10^9 Bits/Day
Image Processing Facility (IPF)	
● Computer System	● Image Processing (10^9 Bits/Day)
● Software (VICAR/IUE)	● Applications Program
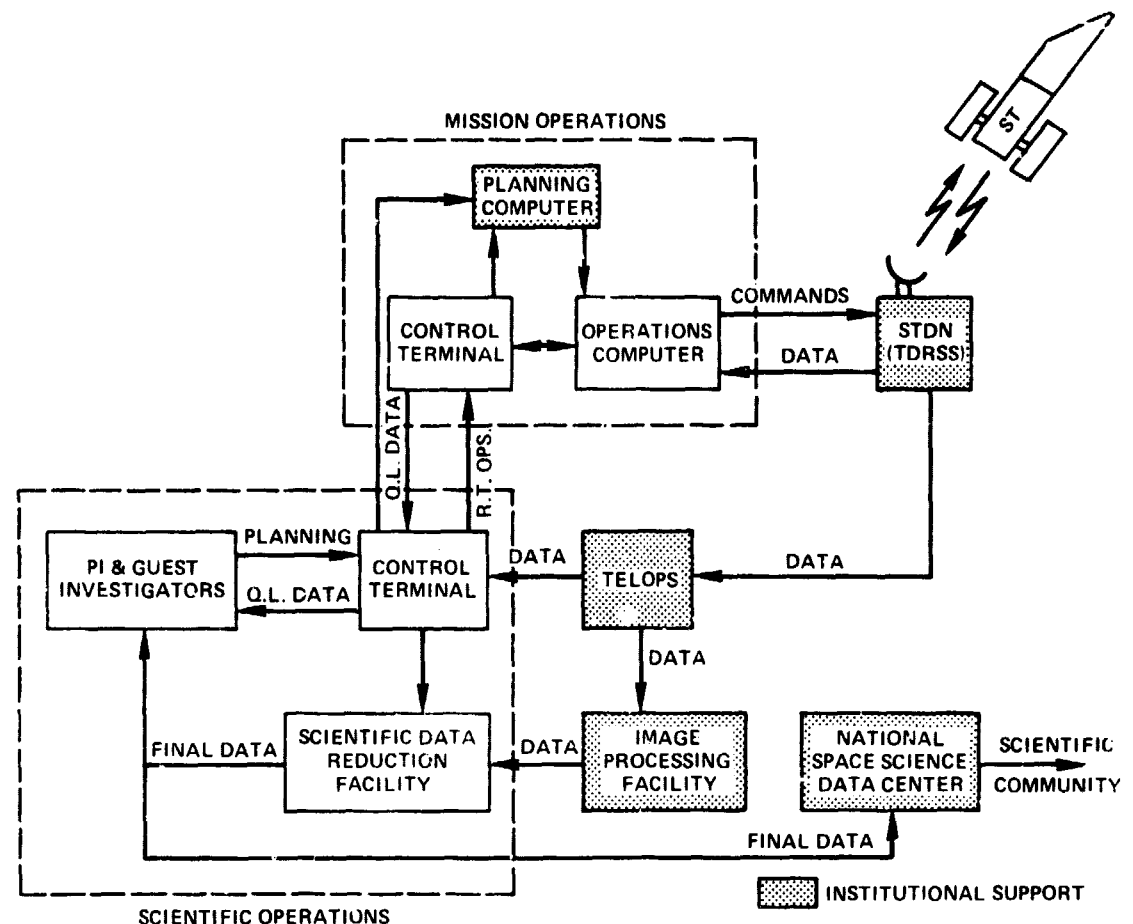
Figure I. ST Operations Support Facilities

TELEMETRY OPERATIONS PROCESSING SYSTEMS (TELOPS)

TELOPS serves as an on-line digital interface between the network and the ST
ground system. It provides spacecraft and user support in near real-time with
a storage and processing capacity to handle large volumes of data. The system
components are shown in Figure II. The features of the system include: data
capture, data staging, data editing, rapid access on-line storage, off-line data
archival, 24 hour-seven day/week operation, and a fa''-safe protect system.
System capacity characteristics are: on-line data input from network on 22
lines simultaneously, 20 lines up to 108 K bit rate each, combined peak rate of
up to 2.6 M bits, processing capacity of 450 M data points per day, and on-line
storage of 169 billion bytes.

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Figure II.   TELOPS System Components

The Input Processor System receives and logs near-real-time TM, delayed TM, and non-telemetry data over communication lines. It processes selected TM by high priority procedures including quick-look requirements, stages TM data for storage in the Mass Storage System, and monitors system and message status to support the Integrated Information System.

The Intermediate Processor System features are: Processes satellite TM data into users acceptable format and content, operates on large aggregates of data, performs lengthy and complex calculations requiring a large scale computer, performs multipass functions, and performs all functions resulting in alteration of data (subsequent to recording on MSS; hence, original data is preserved).

The Output Processor System capabilities are: decommutation of TM data (separate or joint responsibility with inter-processing), decom of a group of edited TM data for any subset of users, transmit decommutated output to users' remote terminals via communications lines; two modes of operation: (1) conversational request mode, (2) automatic mode, and procedures which insure that only authorized users can enter the system and reference appropriate data.

The Mass Storage System features are: capacity of 2×10^{12} bits, direct access storage devices, system control computers and peripherals, off-line access to archival system, data backup storage, and access on one file at a time.

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The Integrated Information System (IIS) has the following features: provides information for control of TELOPS, performance evaluation of TELOPS, and quality control of TM data; establishes preliminary process control priorities and schedules from forecasts of new and long-term process requirements; performs process control and monitoring within each TELOPS subsystem through local IIS subsystem console; provides status information concerning processing of TM messages to the TELOPS subsystems; performs data collection functions for use in reporting, for responding to queries, and for support of the subsystem operation; gathers, retains, and disseminates data related to subsystem operation or TM data by creation and maintenance of data bases.

IMAGE PROCESSING FACILITY

The general function of IPF is to provide standard image processing support operations to users. Image processing operations include: pre-processing, annotation and guiding, radiometric calibration, geometric corrections, editing, data merging, reformatting, product generation, near real-time transmission, enhancement and differencing. Figure III shows a block diagram of the facility.
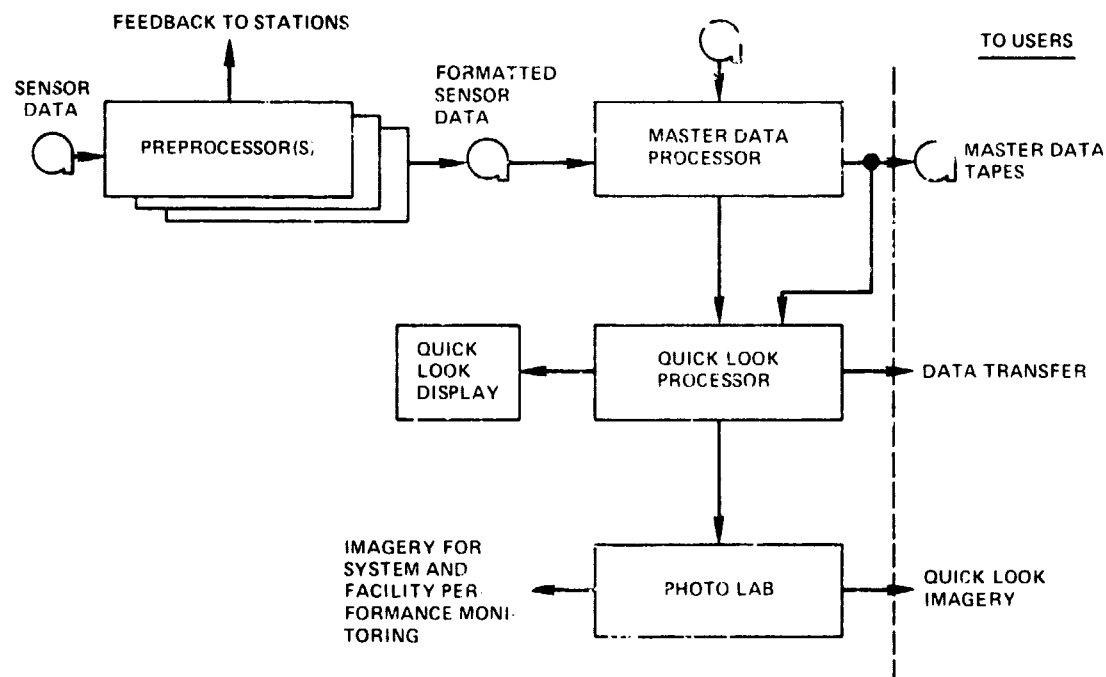

Figure III. Image Processing Facility Block Diagram

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The characteristics of the Master Data Processor are: digital radiometric and geometric corrections; geometric corrections are performed on the basis of image correction data and reference control points (relative or absolute); primary purpose of geometric corrections is temporal registration of data; resampling algorithms using nearest neighbor and six x/x approximation (at least cubic); processing volume of 10^{11} bits/16 hours; and input-output in form of high density tapes or general computer compatable tapes.

The Quick-Look Processor has the following characteristics: generation of quick-look imagery in tape and film form for quality control and system performance monitoring; general purpose computer hardware with high density tape interfaces; off-line film recording capability, format conversion and editing capability; and input/output in form of high density tapes and computer compatable tapes.

Image generation equipment includes: a 9-1/2" high resolution (laser) film recorder producing black/white and photographic color composites; a 105 mm color crt recorder with optical enlargement to 9-1/2" and a 70 mm black/white crt recorder with optical enlargement to 9-1/2".

Output products of the IPF are in the form of: computer compatable 9-track 800/1600 bpi; high density tapes with 1.4×10^{10} bits/reel min; 9-1/2" black/white transparency or print, and 9-1/2" color composit transparency or print; 70 mm black/white transparency; monthly catalogs on microfiche or paper, and a monthly image product catalog in microfilm, b/w, or color.

GROUND SYSTEM DATA FLOW

The major functional elements which will make up the ST ground system are shown in Figure IV. Those elements which provide institutional support services to ST are shaded. Mission Operations and ST Science Operations areas will contain all of those elements dedicated to ST.

An observation request will originate with the principal and guest investigators in the form of target coordinates, time and duration of observations, measurement accuracy, and instrument configuration. These requests will routinely be checked well in advance of the observer's visit. Pre-observation planning and daily planning are carried out by the Institute Operations staff. The planning computer receives observing plans from the Institute via terminals, punched card, or tape input. Mission control inputs current spacecraft constraints to the computer which translates the observing plan into 24 hours of ST commands. This command message will be approved by the MOC for transmission to the ST via STDN (TDRSS). Real time operation, such as target acquisition, is
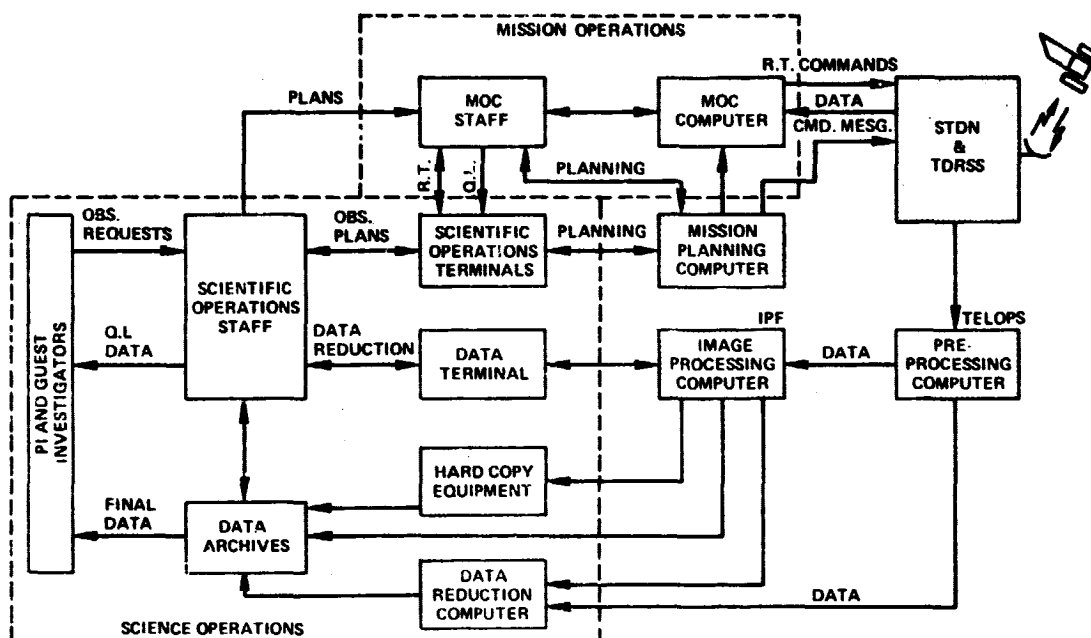
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Figure IV. ST Ground System

accomplished by direct commanding of the ST by the MOC computer in response to requests from terminals. Real time science data and housekeeping telemetry is received by the MOC computer and relayed to terminals and displays.

The ST will transmit science and engineering data which will be relayed by STDN (TDRSS) to TELOPS at GSFC. Engineering data will be available for spacecraft monitoring and analysis in the MOC. Science data in quick-look form will be available to the users by the operations computer or TELOPS. TELOPS receives, stores and pre-processes large quantities of science data for image processing by the Image Processing Facility (IPF) which then will output the reduced data. Final data products will be produced to the point where scientific analysis is required. Reduced data will be given to the user for his analysis and to the NSSDC for timely distribution to the general scientific community.

SCIENTIFIC INTERFACES

The question of how guest astronomers interface with the ST is a central one. Staff astronomers, night assistants, and technicians will assist visiting guest investigators to make their observing programs compatible with the ST. The interfaces between astronomers and the ST in orbit will be the planning computer.

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In order to minimize cost, a central set of software will be developed for science planning, program preparation, observing scheduling, and data retrieval. IUE software can be made available for long-range planning includes exposure time estimation, constraint violation checks, determination of pointing accuracies, guidestar selection, and target availability. This software can also be used for scheduling telescope time in a program integrated mode over a long-term period, or in a PI block time mode over shorter periods of time or combinations of the two modes.

Standard computer terminals will be used to initiate programs on the planning computer. The output of these software runs will be displayed at interactive graphics display devices as well as standard printout and tapes. Similar interactive display/control computer terminals will interface astronomers with the operations (command-control) computer in the MOC. These terminals will be used for real time operation which includes commanding the SI's and their support systems, viewing target acquisition information, requesting small angle slews for target/slit adjustments, and for the display and evaluation of quick-look science data and SI engineering data.

The interface between astronomers and the data processing facilities will be standardized and pre-defined in terms of the number and type of data reduction processes available and in the types of output and formats available to the user for his analysis. The user will have the capability of reviewing scientific data in condensed (quick-look) form prior to image processing. As a result of this evaluation, he could specify which data he would like reduced first and what type(s) of processing are best suited for his particular analysis. This interface also allows for the timely update of scientific algorithms, applications programs and calibration data, all of which can be provided by the user. IPF will deliver well specified output products.

The Institute would have the responsibility for the management of all SI science data. Routine image processing tasks which require large computers and operating crews will be handled by IPF. All other processing of science data and the production of hard copy will be accomplished in the dedicated data reduction facility. The hardware required to do this job includes a small computer with standard peripherals, plotters, digital image hard copy devices, and photographic equipment. The output products of all data reduction and image processing will be assembled to form a data package which will be given to the user for his proprietary analysis and publication, and to the NSSDC for storage and future distribution. The data package which is given to the user includes: paper printout, magnetic tape, stripcharts, photographic prints and negatives, and a complete historical record of his observations and data reduction.

MISSION CONTROL

The primary responsibility of the Mission Control Center (MOC) will be to monitor orbital operation of the spacecraft to insure the health and welfare of the ST for the life of its mission. Other important MOC functions are to support the: mission planning and scheduling of SSM and OTA subsystem tests; checkout and calibration procedures; monitoring subsystem status and engineering data; spacecraft and command control; routine and emergency analysis of ST performance; specification and update of all spacecraft operational constraints, and the initiation of spacecraft emergency procedures.

All real-time command requests will pass through the command control "software supervisor" which resides in the operations computer. Real-time violations of safe operations rules will be blocked by the operations computer and a violation message sent back to the requester and to the real-time mission controller who can override the computer or advise the requester to change his plan. Preplanning target pointings, SI, OTA, and SSM operational commands will be screened by the planning computer for constraint violations. The computer will either abort the planning run and/or send flags to the user and to the mission planning controllers. Minor warnings or false flags may be passed by the mission planning controller but serious violations and aborts must be corrected and rerun until a valid contact message has been generated and passed by MOC control personnel.

Another important function of the MOC will be to monitor the ST's vital signs for possible problems arising in its subsystems. The operations computer will display engineering data at subsystem monitor consoles during real-time contacts, and in a playback mode for data stored on-board during non-real-time contact periods. The operations computer will also provide limited processing of engineering data, quick-look science data, and target acquisition data prior to display.

The MOC computer will have adequate peripheral hardware to handle all tape, card, and printer input and output requirements as well as a multi-disk capacity for the storage of programs, constraint data base, and the temporary storage of engineering and quick-look data. The MOC computer will also support interactive terminals, TV and other displays, control consoles, and stripchart recorders.

The MOC will operate 24 hours a day, 7 days a week with a staff comprised of spacecraft analysists, substem engineers, mission planners, mission controllers, shift operators, data technicians, and clerks. The staff will be formed into a number of teams to cover three shifts per day. Operations and maintenance of MOC hardware and software will be provided by GSFC institutional support contracts.

LST SIMULATOR

An ST simulator will be used prior to launch for personnel training and total ground system "shake down" trials. Post launch simulations will train new personnel and test out new equipment, software, and operational procedures. The simulator will be a software package which runs on an off-line non-ST-dedicated computer. All major ST subsystems, science instruments, and status data points in OTA, SI, and SSM will be simulated. Scientific data and real time target acquisition feedback and quick-look data will also be provided by the simulator.

FUTURE DEVELOPMENT

This scientific operations plan was developed in order to meet the immediate requirements of the ST within the pre-launch budgetary constraints. The plan described here not only accomplishes this goal but in addition, contains modular design concepts which provide considerable flexibility for future development.