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LARGE SPACE TELESCOPE PHASE A FINAL REPORT

Volume I — Executive Summary

By Program Development

December 15, 1972

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George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama

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16. ABSTRACT

This document is a report of the Phase A study of the Large Space Telescope (LST). The study defines an LST concept based on the broad mission guidelines provided by the Office of Space Science (OSS), the scientific requirements developed by OSS with the scientific community, and an understanding of long range NASA planning current at the time the study was performed.

The LST is an unmanned astronomical observatory facility, consisting of an optical telescope assembly (OTA), scientific instrument package (SIP), and a support systems module (SSM). The report consists of five volumes: Volume I is an executive summary, Volume II is a summary of the entire report, and Volumes III, IV, and V contain the analyses and conceptual designs of the OTA, SIP, and SSM, respectively. The report describes the constraints and trade off analyses that were performed to arrive at a reference design for each system and for the overall LST configuration.

The LST will be launched into low earth orbit by the Space Shuttle and operated for 10 to 15 years. The Shuttle will also be used to maintain the LST and to update the scientific instrument complement. Several maintenance modes have been investigated, including on-orbit pressurization of the SSM to provide a shirtsleeve environment for maintenance, and earth return of the LST.

The LST will provide the scientific community with several fundamentally unique capabilities which will permit the acquisition of new and important observational data. Its location in space permits observations over the entire spectrum from about 100 nm to the far infrared.

A low cost design approach was followed in the Phase A study. This resulted in the use of standard spacecraft hardware, the provision for maintenance at the black box level, growth potential in systems designs, and the sharing of Shuttle maintenance flights with other payloads.

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LIST OF ACRONYMS

A/D	analog to digital
ACN	Ascension Island (tracking station)
ACS	attitude control system
AFO	Announcement for Flight Opportunity
AGC	automatic gain control
AGO	Santiago, Chili (tracking station)
ALU	arithmetic logic unit
AM	airlock module
AOS	acquisition of signal
APP	antenna position programmer
ASCS	attitude sensing and control system
ASR	automatic send/receive
ASTAM	automated system test and monitor
ATM	Apollo Telescope Mount
ATS	Applications Technology Satellite
AVE	Mojave, California (tracking station)
BDA	Bermuda (tracking station)
BECO	Teledyne-Brown Engineering Company
BER	bit error rate
BITE	built-in test equipment
BOL	beginning of life
BOM	basic operating module
BUR	Johannesburg, South Africa (tracking station)
C& DH	communications and data handling

LIST OF ACRONYMS (Continued)

C&DHS	communications and data handling system
C&W	caution and warning
CAM	computer address matrix
CCD	charge couple device
CCS	contamination control system
CDR	critical design review
CG, C.G.	center of gravity
CMG	control moment gyro
CMOS	complementary metal oxide semiconductor
CPU	central processor unit
CRO	Carnarvon (tracking station)
CSS	coarse sun sensor
CTU	command and telemetry unit
CYI	Canary Islands (tracking station)
D/A	digital to analog
DAU	data acquisition unit
DDT&E	design, development, test, and engineering
DEA	drive electronics assembly
DG	double gimbal
DGCMG	double gimbal CMG
DOD	depth of discharge
DPA	digital processor assembly
DSIF	Deep Space Instrumentation Facility
DTPL	domain tip propogation logic

LIST OF ACRONYMS (Continued)

DTU	data transmission unit
ECA	electrical control assembly
EC/LSS	environmental control/life support system
EDS	electrical distribution subsystem
EDU	electrical distribution unit
EIRP	effective isotropic radiated power
EM, em	electromagnet; engineering model
EMC	electromagnetic control
EMI	electromagnetic interference
EOL	end of life
EOM	end of mission
EPS	electrical power subsystem
ERTS	Earth Resources Technology Satellite
ESE	electrical support equipment
ETC	Engineering Training Center, Greenbelt, Maryland
EVA	extravehicular activity
EVLSS	extravehicular life support system
FGS	fine guidance system
FHST	fixed-head star tracker
FM	frequency modulated
FMEA	failure mode effects analysis
FOV	field of view
FRUSA	flexible, rollup solar array
FST	fixed star tracker

LIST OF ACRONYMS (Continued)

GAC	Grumman Aerospace Corporation
GDN	ground data network
GDSX	Goldstone (tracking station)
GESE	ground electrical support equipment
ghu	gyro hang-up
GMT	Greenwich mean time
GRARR	Goddard range and range rate
GSE	ground support equipment
GSFC	Goddard Space Flight Center
GST	gimbaled star tracker
GWM	Guam (tracking station)
HAW	Hawaii (tracking station)
HEAO	High Energy Astronomy Observatory
HEPA	high efficiency particulate air
HPI	high performance insulation
HSK	Honeysuckle Creek, Australia (tracking station)
I/O	input/output
I. D.	inside diameter
IESE	in-space electrical support equipment
IOCC	integrated operations control console
IOP	in the orbit plane
ISA	interstage adapter; interface systems adapter
IVA	intravehicular activity
LCP	left circular polarized
LOHARR	Lockheed heat rate program
LOS	line of sight

LIST OF ACRONYMS (Continued)

LSI	large scale integration
LST	Large Space Telescope
MAC	maximum allowable concentration
MAD	Madrid, Spain (tracking station)
MCC	mission control center
MCF	Mating/Checkout Facility
MIB	minimum impulse bit
MIL	Merritt Island, Florida (tracking station)
MMS	micrometeoroid shell
MNOS	metal nitride oxide silicon
MOJAVE	tracking station at Barstow
MOS/LSI	metal oxide semiconductor/large-scale integrated
MSFC	Marshall Space Flight Center
MSFN	Manned Space Flight Network
MSS	magnetometer sensing system
MT	magnetic torquer
MTBF	mean time between failures
MTE	magnetic torquer electronics
MTF	modulation transfer function
MTS	magnetic torquing system
MTU	magnetic tape unit
NASCOM	National Aeronautics and Space Administration Communications Network
NASO	National Astronomical Space Observatory
NDRO	nondestructive readout
NEA	noise equivalent angle

LIST OF ACRONYMS (Continued)

NFL	St. John's, Newfoundland (tracking station)
OAAR	other activities as required
OAO	Orbiting Astronomical Observatory
OAS	Orbit Adjust Stage
OMS	orbit maneuvering system
OOC	observatory operation center
ORRX	Orroral Valley (tracking station)
OSR	optical solar reflector
OTA	optical telescope assembly
OWS	Orbital Workshop
PCM	phase change material; pulse code modulator
PCS	peripheral communication system
PCU	power converter unit
PDR	preliminary design review
PEP	perpendicular to the ecliptic plane
PGA	pressure garment assembly
PM	pulse modulated
POP	perpendicular to the orbit plane
PRR	preliminary requirements review
PSD	power spectral density
PSK	phase shift keyed
PSU	power switch unit
QUI	Quito, Equador (tracking station)
R&D	research and development
RAM	research applications module (studies); reference alignment mode

LIST OF ACRONYMS (Continued)

RBV	return beam vidicon
RCD	remote command decoder
RCP	right circular polarized
RCS	reaction control system
REC	recurring costs
RF	radio frequency
RFI	radio frequency interference
RGA	reference gyro assembly
ROM	read-only-memory
ROS, ROSMAN	tracking station at Rosman, North Carolina
RSDP	remote site data processer
RTV	room temperature vulcanizing
RW	reaction wheel
SAA	South Atlantic anomaly
SBU	sensor buffer unit
SCAMA	switching, conferencing, and monitoring arrangement
SEC	secondary electron conduction
SFP	solicitation for proposal
SG	single gimbal
SGCMG	single gimbal CMG
SI	science instrument
SIP	scientific instrument package
SIT	silicon intensified target
SMS	secondary mirror sensor
SPD	solar power distributor

LIST OF ACRONYMS (Continued)

SPEH	special purpose equipment handler
SPF	single-point failure
SPG	single-point ground
SSM	support systems module
SSP	Space Station prototype
STADAN	Space Tracking and Data Acquisition Network
STDN	Spaceflight Tracking and Data Network
2-SPEED	two scissored pair ensemble explicit distribution
TA	transfer assembly
TACS	thrust attitude control system
TAN	Tananarive, Malagasy Republic (tracking station)
TBC	The Boeing Company
TCS	thermal control system
TDRS	tracking and data relay satellite (network)
TEX	Corpus Christi, Texas (tracking station)
TMR	triple modular redundancy
TOOMBA	tracking station at Cooby Creek
TRW	TRW Systems, Incorporated
TTY	teletypewriter
TWT	traveling wave tube
ULA	Fairbanks, Alaska (tracking station)
UPD	update buffer
USB	unified S-band
USBE	unified S-band equipment
VAB	Vertical Assembly Building
VGP	vehicle ground point

LIST OF ACRONYMS (Concluded)

VPM	variable permanent magnet
W-R	Wolf-Rayet
WASS	wide angle sun sensor
WFE	wavefront error
WNK	Winkfield, United Kingdon (tracking station)
XPDR	transponder

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CHAPTER I. INTRODUCTION

This study defines a Large Space Telescope (LST) concept based on the broad mission guidelines provided by the Office of Space Science (OSS), the scientific requirements as developed by OSS with the scientific community, and an understanding of long range NASA planning current at the time the study was performed. Continuing LST definition activities will reflect the most recent guidelines available.

A. Mission Description

The Large Space Telescope is a 3 m aperture optical telescope having near-diffraction-limited performance. The LST will be placed into earth orbit in 1980 by the Space Shuttle. At the time the present study was performed, a precursor LST was envisaged that would be operated for 5 years, followed by an advanced LST to be operated for 10 years. This concept has now been revised to a single LST to be operated for 15 years with periodic maintenance and refurbishment. A guideline in effect during the Phase A study which has subsequently been eliminated is the requirement that the LST be compatible with a Titan III launch. The Titan III was previously considered as an alternate launch vehicle, but at this time only the Space Shuttle is being considered.

An-orbit maintenance will be performed as required to replace failed or degraded components and to update scientific instruments. The LST may be returned to earth for a complete refurbishment and instrument replacement after sevaral years. This may be necessary if it is desired to replace the scientific instruments with instruments that cannot be accommodated in the existing supporting structures.

The LST will provide the scientific community with several fundamentally unique capabilities which allow the acquisition of new and important observational data. Its location in space allows observations over the entire spectrum from wavelengths of about 100 nm to the far infrared. In addition, the earth constraint of faint object detection is removed and the constraint of sky background is relaxed significantly. Thus, the LST offers all of the observational advantages of a large aperture instrument operating at true diffraction-limited performance over a very large bandwidth.

It is to be expected that the observation targets of most interest, the type of data to be obtained, and the subsequent analysis process to be applied will vary a great deal over the lifetime of the LST. In part, the direction these variations will take will be dependent on the results of initial LST observations.

B. Study Objectives and Approach

The objectives of the Phase A study were to determine mission feasibility, to study alternative spacecraft configurations and system designs, to investigate alternate on-orbit maintenance modes and the associated costs, to establish reliability and lifetime goals, and to study a spacecraft concept (design reference) to sufficient depth to establish hardware feasibility. The primary objective was to define a reference design configuration that could achieve the pointing accuracy and stability desired for the LST. A strong effort was made to utilize hardware and systems designs that were common to the High Energy Astronomy Observatory (HEAO) and other spacecraft in order to minimize new development requirements and costs.

The MSFC report "Large Space Telescope (LST) Preliminary Study," dated February 25, 1972, was used as the beginning point of reference for the Phase A study. During the Phase A study activity, participant responsibility was allocated as follows:

1. Itek Corporation, under contract to MSFC, was responsible for analysis and design of the optical telescope assembly (OTA). This responsibility included review, analysis, and utilization of the results from the light shield study performed by the University of Arizona. It also included assurance of satisfactory interfaces between the OTA and other major elements of the LST.

2. Kollsman Instrument Corporation, under contract to GSFC, was responsible for analysis and design of the scientific instrument package (SIP). This responsibility included assurance of satisfactory interfaces between the SIP and other major elements of the LST.

3. Marshall Space Flight Center (MSFC) was responsible for the analysis and design of the support systems module (SSM) and for integration of the overall LST.

The study approach employed during Phase A was to technically investigate, in some depth, a variety of promising LST configurations, systems, and substystems. Technical analyses and trade studies were conducted to select the more promising concepts. Analyses and trade studies were continued on these concepts until the reference design LST configuration was defined.

This resulting reference design configuration provides an overall integrated mechanical, thermal, and structural design concept. Analyses indicate that this reference design concept minimizes launch and environment loads to the primary optics, minimizes thermal distortions of the telescope, and isolates spacecraft disturbances from the primary mirror and telescope structural assembly. This design also provides for on-orbit maintenance for subsystem replacement and instrument update.

The selection of the Phase A LST reference design configuration as discussed in this document is meant to serve as a starting point for Phase B activities and should in no way constrain the option to investigate other concepts, systems, and subsystems.

C. Scientific Uses of the LST

The wide spectral band capability (110 nm to the far infrared) of the LST provided by its telescope design and instrumentation, the absence of atmospheric interference, and the greatly reduced sky background brightness provided by its position in space will allow the acquisition of new and important observational data. It is anticipated that the LST can aid in the advance of astronomical knowledge in many areas, including the following, which are of current high scientific interest:

1. Variation of Hubble constant with distance.
2. Stellar masses.
3. Quasars, Seyfert galaxies, and peculiar galaxes.
4. Characteristics of stellar chromospheres and coronae.
5. Details of intergalatic medium.
6. Globular clusters and nearby galaxies.
7. Distribution and features of matter in interstellar space.

8. Star formation.

9. Planetary nebulae and Wolf-Rayet type stars.

10. Optical observations of X-ray sources, pulsars, and neutron stars.

11. Detailed studies of planets.

12. Studies of asteroids, comets, and other small bodies.

13. Helium-rich stars.

14. Variable stars.

15. Infrared studies of stars and galaxies.

The concept of scientific instrumentation modularity for ease of removal and replacement has permeated the Phase A design. Maintenance on an instrument "black box" level provides for singularity of design and relatively simple interfaces, the most critical being the optical tolerances and thermal control designs. The ability to establish universal mechanical interfaces leaves the surrounding design of the instrument to expand or take on any required shape which would house an instrument with improved investigative powers for the LST.

In no sense does the LST compete with, or supplant, earth based astronomy. Instead, it is a tool to amplify on-going ground observational programs and to fill in data gaps in certain areas of research. Because of its potential for faint object detection and the expanded spectral window, the total available viewing time can be productively consumed many times over solely by gathering data in the spectral and brightness ranges which are inaccessible from the earth.

For this latter reason the LST observing program will be largely determined by the status of ground observational programs and research during its operating lifetime. In general, the observations will be confined to specific objects using instruments selected to provide data for answering questions or resolving problems that arise in the course of ground activities. Little work of a general survey nature will be done, with the possible exception of surveys for certain classes of faint objects. Even here, however, much work of this type can be accomplished as a secondary result of viewing specific target areas.

CHAPTER II. MISSION ANALYSIS

A. Orbit Selection

One of the first tasks in planning an earth orbital mission is the selection of the orbit which maximizes mission performance, provides the desired lifetime, and has a minimum impact on systems designs. Program constraints include the use of the Shuttle as the primary launch vehicle with the Titan IIIE/OAS as an alternate, Kennedy Space Center launch site, orbital accessibility by the Shuttle for maintenance or return, and a minimum lifetime of 5 years. Mission performance parameters that are a function of the orbital elements are:

1. Payload capability.
2. Orbit decay rate.
3. Ground station contact time.
4. Target visibility.
5. Target viewing time.

Orbital environments that affect systems designs are:

1. Trapped particle radiation.
2. Magnetic fields.
3. External disturbances.
4. Micrometeoroid flux.
5. Contamination.
6. Stray light.

A parametric orbit selection analysis was performed for the LST design study. Included in the analysis was the determination of minimum orbital altitude requirements for nominal mission conditions, lifetime and decay histories for the reference orbit, assessment of the effects of spacecraft configuration and mass changes on orbital lifetime, Space Shuttle performance capabilities, tracking network coverage, and mission timelines.

Consideration of all of the above performance and environmental parameters led to the selection of a circular orbit with an inclination of 28.5 degrees and an initial altitude of 611 km (330 n.mi.). A circular orbit was selected because there is no significant benefit derived from any elliptical orbit that can be achieved, given the capabilities of the Shuttle or Titan launch vehicle. An orbital inclination of 28.5 degrees, achieved with a due-east launch from KSC, was selected for the following reasons:

1. Lower inclinations require yaw steering and a significant loss in payload capability.

2. Higher inclination quickly reduces the prime earth shadow viewing time.

3. Most of the other Shuttle delivery missions that can be combined with LST maintenance visits are located in 28.5 degree orbits.

The sensitivity of other performance parameters to inclinations between 28.5 and 40 degrees is negligible.

The most significant parameters involved in the selection of an orbital altitude are (1) Titan payload capability, (2) orbital decay rate, and (3) trapped particle radiation environment. Payload capability and radiation environment make a low orbit desirable, whereas the decay rate makes a high orbit preferable. A good compromise occurs at an orbital altitude of 611 km. This selection was originally based on a 1978 launch date. The lower atmospheric density associated with the planned 1980 launch would permit an altitude reduction to approximately 556 km (300 n.mi.) if either a 181.5 kg (400 lb) increase in Titan payload capability or a 30 percent reduction in radiation environment is required. LST performance degradation due to residual atmospheric elements may become a significant factor in final orbit selection when this effect is better understood. Possible significance of increased ground station contact time with increased altitude must await a more complete evaluation of orbital operations and the design of the data and communication system to determine current network utilization at 611 km.

B. Launch Vehicle Analysis

1. Space Shuttle. The Space Shuttle will be the primary launch vehicle and will also be used for emergency and/or end-of-life LST retrieval. An LST delivery flight profile is shown in Figure II-1. Figure II-2 gives the

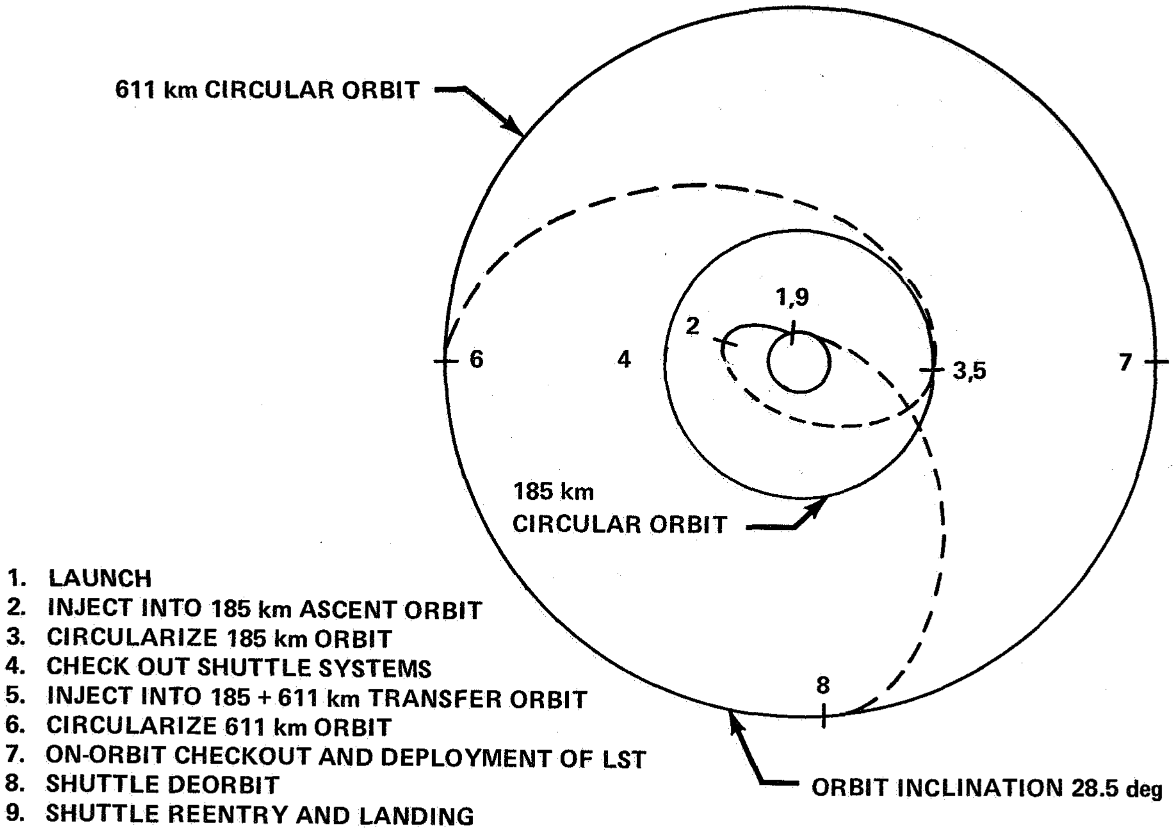


Figure II-1. LST deployment profile.

Shuttle performance capability to low-earth orbit with and without the addition of orbital maneuvering system (OMS) kits to the cargo bay. These data are for a 040C-2 Orbiter/parallel burn solid rocket motor launch assuming an OMS ΔV reserve of 15.2 m/sec (50 ft/sec). The Shuttle has the capability to deliver approximately 23 587 kg (52 000 lb) to the 611 km (330 n.mi.) design reference orbit with one OMS tank set added to the cargo bay.

A single OMS tank set requires 1.52 m (5 ft) of the 18.29 m (60 ft) long cargo bay. The docking module which will be carried in the cargo bay on the LST delivery and maintenance flights requires 2.13 m (7 ft) of the cargo bay length and has a mass of 900 to 1400 kg (2000 to 3000 lb). The Shuttle offers ample performance capability and payload cargo bay volume.

2. Alternate Expendable Launch Vehicles. An alternative expendable launch vehicle comparison study was performed to select a backup LST launch vehicle. The following launch vehicles were considered:

1. Titan IIIC.
2. Titan IIIC IA.
3. Titan IIIE/Centaur.
4. Titan IIID/Agena.
5. Titan IIIE/OAS.
6. Titan IIID/Burner II.
7. Titan IIIE/Integral.

The Titan IIID is designated Titan IIIE when flown out of the Eastern Test Range with the OAS, the Integral, or the Centaur stages. Of these, the Titan IIIC-IA and the Titan IIIE-OAS were condisered to be feasible candidates. All others were eliminated, either because of excessive costs or because of technical complexity. Since the planned HEAO launch vehicle at the time of this study was the Titan IIIE-OAS, it was slelected as the backup LST launch vehicle.

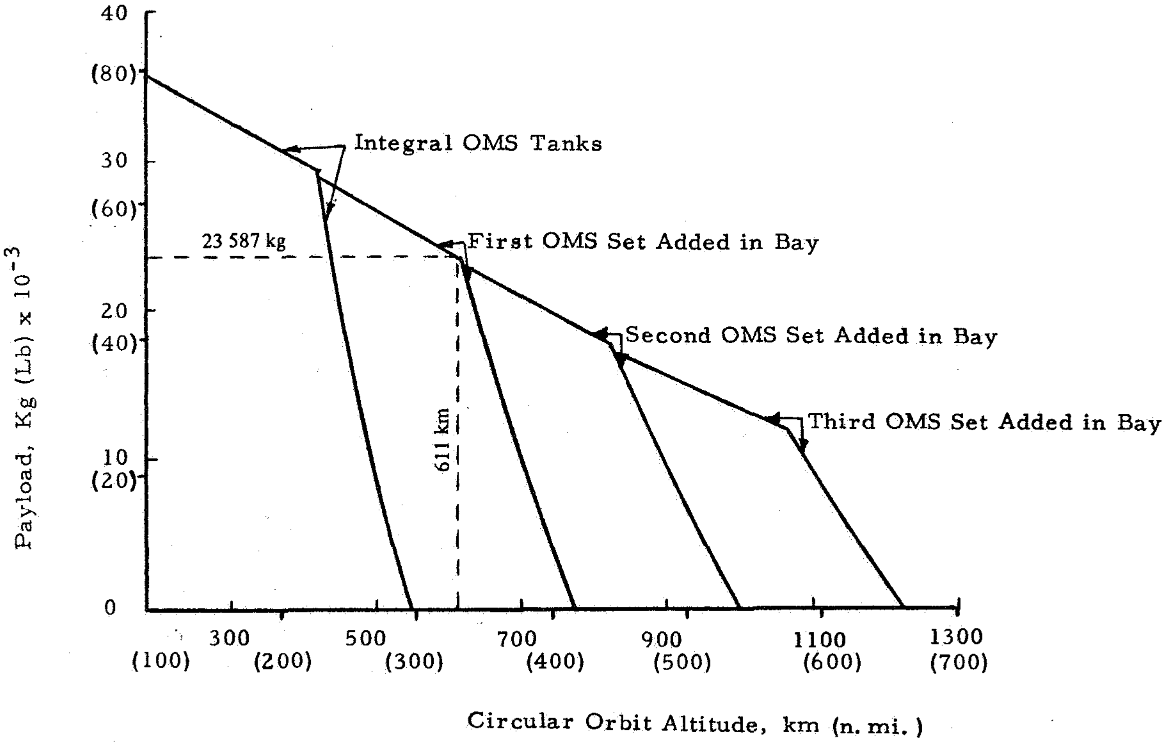


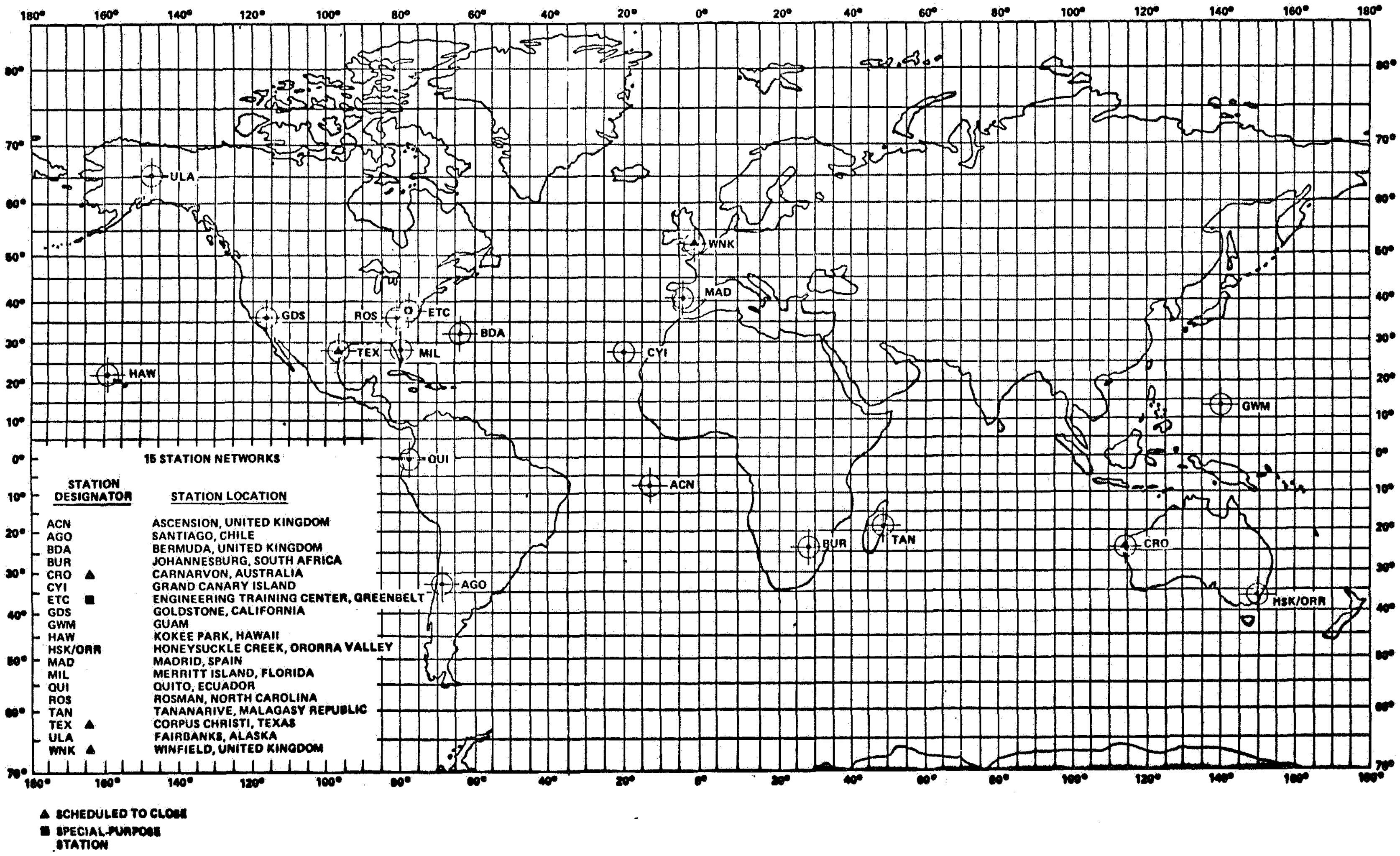
Figure II-2. Shuttle performance.

C. Tracking Coverage

The primary guidelines that were used in this overall study were those that would satisfy the basic requirement that good scientific data be transmitted from the spacecraft to the ground. The ground network that will be in existence during the LST mission flight time is probably one of the more important constraints. The network used as the design reference is generally called the Spaceflight Tracking and Data Network (STDN) and is composed of the stations of Manned Space Flight Network (MSFN) and the old Space Tracking and Data Acquisition Network (STADAN) system. However, only stations with unified S-band (USB) capability were selected for this mission. The locations comprising the STDN are indicated in Figure II-3. The stations that are scheduled (or are being contemplated) for retirement are shown by the triangles on the map. Six stations were selected to provide support in the tracking of the spacecraft, commanding the spacecraft, and for retrieving data from the spacecraft in near-real and real time. Stored data may also be transmitted to these stations for forwarding to the control center.

Two criteria were used in selecting the stations. The first was that the station had to be visible to the spacecraft during its pass around the earth. The second ground station selection parameter was the type of equipment available at the station. To maintain the intensive communications and control links between earth and LST experiments, the STDN provides 6 ground tracking stations equipped with 9.144 m (30 ft) diameter antennas. The selected ground sites were originally Canary Islands (CYI), Ascension Island (ACN), Carnarvon (CRO), Guam (GWM), Hawaii (HAW), and Goldstone (GDSX). Current NASA studies have dictated a requirement that the tracking facilities at Carnarvon (CRO) be phased out of the STDN in 1974. Since the LST is scheduled to operate initially in 1980, subsequent analysis has assumed a possible participation of Orroral Valley (ORRX) instead of CRO.

The STDN configuration was evaluated to satisfy the requirement of one contact per orbit with a 5 min minimal contact and to provide the minimum contact time necessary for the transmission of data. An evaluation of ground coverage statistics for the reference design network is illustrated in Table II-1. Contact conditions are shown for a computer simulation of 70 orbital revolutions, which is adequate to assure reasonably stable statistics. In this table, the conditions computed are externally constrained by a minimum 5-min contact time and elimination of the ground station having the shorter contact time in the event of station multicoverage. This configuration would provide an average contact time of 26 min per revolution. An average contact time of 11 min per revolution is established for each STDN station whenever a contact is made. The average number of station contacts suitable for transmission is 2.2 per orbit, giving an average transmission time of 22 min per orbit, or 5.6 hours per 24 hour day.



15 STATION NETWORKS

STATION DESIGNATOR		STATION LOCATION
ACN		ASCENSION, UNITED KINGDOM
AGO		SANTIAGO, CHILE
BDA		BERMUDA, UNITED KINGDOM
BUR		JOHANNESBURG, SOUTH AFRICA
CRO	▲	CARNARVON, AUSTRALIA
CYI		GRAND CANARY ISLAND
ETC	■	ENGINEERING TRAINING CENTER, GREENBELT
GDS		GOLDSTONE, CALIFORNIA
GWM		GUAM
HAW		KOKEE PARK, HAWAII
HSK/ORR		HONEYSUCKLE CREEK, ORORRA VALLEY
MAD		MADRID, SPAIN
MIL		MERRITT ISLAND, FLORIDA
QUI		QUITO, ECUADOR
ROS		ROSMAN, NORTH CAROLINA
TAN		TANANARIVE, MALAGASY REPUBLIC
TEX	▲	CORPUS CHRISTI, TEXAS
ULA		FAIRBANKS, ALASKA
WNK	▲	WINFIELD, UNITED KINGDOM

▲ SCHEDULED TO CLOSE
■ SPECIAL-PURPOSE STATION

Figure II-3. STDN station map.

TABLE II-1. STDN COVERAGE SUMMARY FOR LST [ORBITAL COUNT = 70 REVOLUTIONS, ALTITUDE = 611 km (330 n.mi.), INCLINATION = 28.5 deg]

Contact Conditions	STDN Configuration 611 km Altitude
Total Contact Time in 70 Revolutions (min)	1796.97
Number of Contacts in 70 Revolutions	165
Percent of Contact Time in 70 Revolutions	24.65
Average Contact Time per Revolution in 70 Revolutions (min)	25.67
Average Contact Time per Station per Revolution with Contact (min)	11.09
Minimum Time of Combined Contacts During any Revolution (min)	13.28
Minimum Station Contact Time Achieved (min)	5.03
Maximum Time of Combined Contacts During any Revolution (min)	47.07
Maximum Station Contact Time Achieved (min)	13.43
Average Number of Contacts per Day	32
Minimum Number of Contacts per Revolution	1
Number of Revolutions Without Contact	0
Maximum Gap Duration Achieved in 70 Revolutions (min)	89.73
Average Gap Duration in 70 Revolutions (min)	33.39
Percent of Coverage Gap Less Than 1 Hour Long	92.07

Notes: Minimum 5 min contact time.
Elimination of overlapped station with shorter contact time.
Bias time for acquisition of signal and loss of signal not deducted from contact time.

A Tracking Data Relay Satellite (TDRS) concept using two tracking and data-relay satellites placed in geostationary orbit to track the LST spacecraft over long arcs in the circular orbit was also analyzed. The primary aim of this hypothetical concept is to increase orbital and geographical coverage and to improve tracking accuracy. With its unique capability for the continuous reception of data in real time, the TDRS objectively commands, tracks, and relays data from the LST to fewer ground stations. Although it would provide complete tracking coverage for the LST, the TDRS may pose a problem of accessibility since the scientific data generated on the LST orbital mission would not require continuous real-time data dumping or real-time ground control of experiment and subsystem operations.

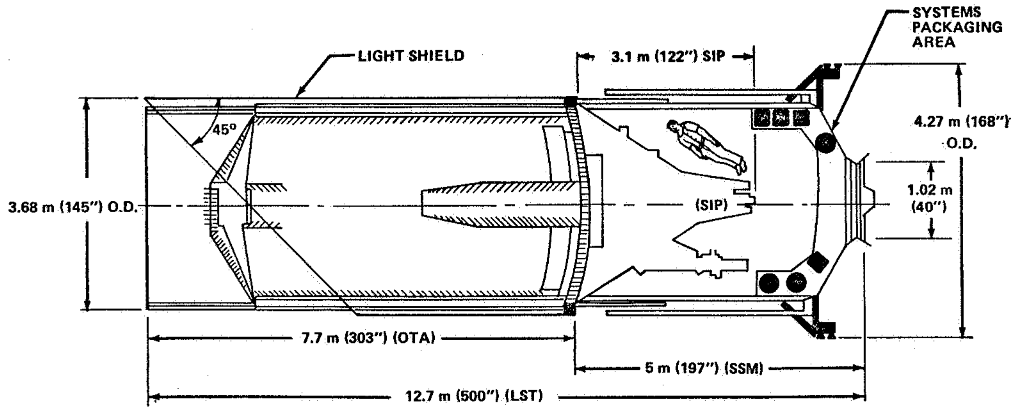
The mission analysis using the TDRS shows that each communications satellite is capable of tracking the LST constantly for about 1 hour during each revolution. Thus, a 611 km orbit gives an average TDRS network coverage of about 95 percent compared to 26 percent coverage for the STDN Configuration.

The coverage statistics generated in the mission analysis indicate that the STDN Configuration which includes Orroral Valley instead of to-be-phased-out Carnarvon may be adequate for the LST coverage requirements. The TDRS concept, when developed and deployed, should be designed to track a spacecraft such as the LST.

CHAPTER III. LST CONFIGURATION AND SYSTEMS DESIGN

The basic elements of the LST are shown in Figure III-1. These elements and their major subassemblies are defined as follows:

1. Optical Telescope Assembly (OTA).
   - a. Primary and Secondary Mirrors.
   - b. Metering Truss.
   - c. Primary (Main) Ring.
   - d. Meteoroid Shield on Telescope.
   - e. Light Shield.
   - f. Fine Guidance Sensors and Equipment.
   - g. Telescope Peculiar Sensors.
   - h. Primary Structure Supporting the Scientific Instruments.



OTA: OPTICAL TELESCOPE ASSY.
SIP: SCIENTIFIC INSTRUMENT PKG.
SSM: SUPPORT SYSTEMS MODULE

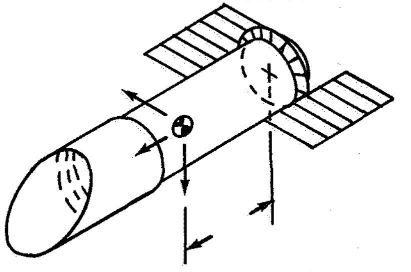
Figure III-1. Basic system elements.

2. Scientific Instrument Package (SIP).
    a. All Science Instruments.
    b. Secondary Structure Supporting Instruments.
    c. Support Equipment for Instruments.
3. Support Systems Module (SSM).
    a. All Primary Load-Carrying Structure Aft of the Primary Ring.
    b. Attitude Control Equipment.
    c. Electrical Power and Distribution Equipment.
    d. Communications and Data Handling Equipment.
    e. Thermal Control Equipment.
    f. Contamination Control Equipment.

The divisions between the basic elements are somewhat arbitrary and must be investigated further in the next phase of the study. The most difficult division is between the OTA and the SIP, since these two elements are more closely coupled than any of the other combinations. The SIP region is a hybrid one, containing telescope-peculiar instruments such as the figure sensor, the focus sensor, and the fine guidance assembly as well as scientific instruments. Hence the term "scientific instrument package" is somewhat misleading. A mass characteristics summary is given in Figure III-2.

A. Optical Telescope Assembly

The reference concept that resulted from this study is a Ritchey-Chretien telescope, 3 m in aperture, with a primary focal ratio of f/2.2 and a system focal ratio of f/12 (Fig. III-3). The primary mirror is a Cer-Vit monolith supported at three points with Invar leaf spring flexures attached to a titanium supporting bulkhead. A metering truss, manufactured from graphite-epoxy, supports the four-point spider and mirror support ring, to which is attached the secondary mirror, its alignment system, and the fine guidance actuation and drive.

Configuration	Center of Gravity (TA)	Centroidal Intertia[a] kg-m^2 (slug-ft^2)		
	mm (in.)	I_x	I_y	I_z
	4944 (195)	19 318 (14 257)	123 703 (91 293)	126 839 (93 607)

a. Includes a 20 percent contingency.

Major Component	Mass (kg)	Weight (lb)
Optical Telescope Assembly	4579	10 098
Scientific Instrument Package	1001	2 209
Support Systems Module	2583	5 682
Total	8163	17 989
Contingency (20 percent)	1633	3 598
Total with Contingency	9796	21 587

Figure III-2. LST mass characteristics.

1. Structural Design. The three structural systems that make up the OTA — namely, (1) the optical metering truss, (2) the SIP primary structure, and (3) the telescope protective system — have been effectively designed to be structurally independent and thermally isolated from each other. The optical metering truss supports only the optics, whereas the SIP primary structure supports the associated optical instrumentation. Thermal isolation of the metering truss and SIP is accomplished by both insulating the structure and using an athermalizing truss design. A three-bay, eight-point mount truss with graphite-epoxy members appears to be a most suitable design for the metering truss. The SIP truss structure is also governed by the same general requirements as the metering truss, but to a lesser degree. Consequently, a graphite-epoxy composite truss design is also recommended. This truss has the added feature of satisfying the accessibility and maintainability requirements for the SIP. Structural isolation is accomplished by providing independent load paths. The pressure bulkhead and primary ring form the main structural support base for both the metering truss and the SIP primary structure.

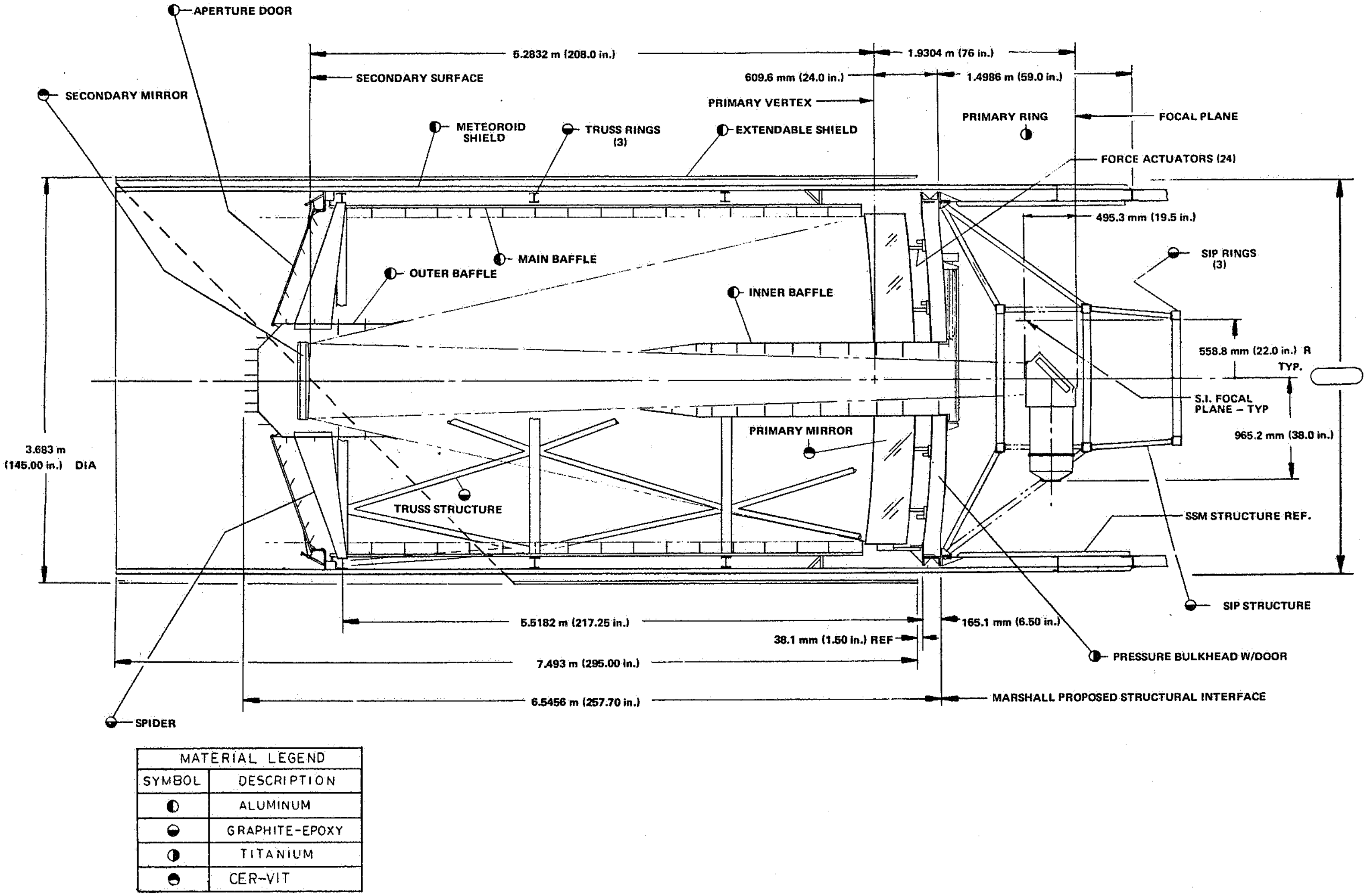


Figure III-3. Optical telescope assembly.

The primary mirror, which serves as the optical reference, is the most critical component and has the greatest overall impact on the optical performance of the system. A series of force actuators is provided to augment the capability of the primary mirror in minimizing surface degradations caused by various unpredictable forces. Although uncertainties exist about the nature of the degrading forces, estimates can still be made as to the required corrective actuator forces.

2. Optical System Design. The LST will have the highest resolution of any telescope ever constructed. The space environment eliminates the atmospheric limitations to the system performance and makes it possible to build as large and as nearly perfect a telescope as desired. The theoretical factor governing the resolution is the aperture diameter, which has been set at 3 m. All other factors will be minimized or made insignificant to permit the entire system to take full advantage of that aperture.

The optical quality for a nearly perfect optical system is essentially diffraction-limited if the wavefront is perfect to $1/4\,\lambda$ peak to valley (J.W. Strutt, Lord Raleigh). The current goal is a value of $0.05\,\lambda$ rms, which is roughly equivalent to the $1/4\,\lambda$ peak to valley. For the LST, this has been taken a step farther by adding the unusually stringent requirement that all possible sources of image degradation be included, thereby developing a total imaging system that will give the best possible performance with a 3 m aperture.

The LST will achieve this near perfect performance. It has a basic Ritchey-Chretien optical design to give very good performance over a 5 arc min radius data field and adequate performance over a 24 arc min diameter guide star tracking field. The telescope will have a relatively fast f/2.2 primary to keep the structure short. The secondary will have a magnification of 5.5 to give a relative aperture of f/12 at the primary image plane.

3. Thermal Design. A reference design concept for thermal control of the OTA has been developed and consists of active and passive elements. Heaters will be used to maintain the primary and secondary mirrors at or near their manufacturing and figuring temperature. The reference design includes passive thermal control of two kinds, superinsulation and external thermal control finishes. The supporting structure between the primary and secondary mirrors consists of a three-bay, graphite-epoxy, composite truss from the main support ring forward. Thermal isolation of this truss is accomplished by sandwiching it between two superinsulation blankets that are themselves supported by the intenal light baffle and by the external meteoroid shell. The spider supporting the secondary mirror and its 5-degree-of-freedom mount is not insulated since the use of a thermal blanket in this area is detrimental

to system optical performance. The thermal control finish on the exterior meteoroid shell will provide a cold external environment for the LST walls in order to maintain thermal control of the active elements within the system at all times, regardless of solar orientation.

4. Stabilization and Control. The design reference stabilization and control system provides within the telescope a fine tracking capability that has wider bandwidths than the vehicle itself. The secondary mirror of the telescope is moved by actuators to compensate for instability excursions that are too small to invoke a response from the spacecraft attitude control system (Chapter III, Section C.5). There are two advantages in moving the secondary mirror for fine tracking: (1) The entire image plane, including the offset guide field, is moved as a unit, preventing significant defocus or differential distortion, and (2) the image position can be maintained in all f/12 planes in a closed control loop via the offset guidance.

5. Light Shield. A light shield will be extended for orbital viewing in order to exclude direct sunlight from the telescope and to reduce the intensity of scattered light from all sources at the image plane. It was determined that a light shield truncated at 45 degrees would be highly desirable for viewing in the solar hemisphere since the relatively large heat input from the sun would overheat the primary mirror after relatively short observation periods and direct sunlight would interfere with faint source viewing.

The reference design is truncated at 45 degrees and extends 6.52 m (257 in.) forward of its stowed position. The light shield is made of aluminum alloy. Deployment is by means of motor driven tubular members. These members are wrapped on storage drums; when they are extended, they form slotted tubes. There is no rotation of the light shield with respect to the OTA.

B. Scientific Instrument Package

The scientific instrument package is an energy selection, analyzing and processing system that has been tailored to match a 3 m diameter, f/12 Ritchey-Chretien type telescope. Energy reaching the focal plane is selectively imaged on a variety of detectors or spectrographs. The selection and design of the individual instruments is the result of preliminary trade-off studies of several system configuration concepts.

1. Configuration. The general SIP configuration is shown in Figure III-4. The basic structure consists of three rings which are connected by trusses to provide bending and torsional stability. The stability of the structure is independent of the rigidity of the instruments. The three-ring

assembly is attached to the OTA/SSM primary ring at eight points. The open truss work permits access to all areas of the package. The instruments have been systematically arranged to allow for the removal of an individual instrument without disturbing any other. Self-aligning devices and insertion guiderails are provided for replacing instruments in order to minimize the need of astronaut dexterity and specialized maintenance skills. Moreover, all of the image sensors can be replaced and accurately repositioned without removing the associated optical elements or affecting any other subassembly of any instrument. The accessibility of the modules permits periodic maintenance, repair, and replacement in orbit, which also allows the overall performance to be upgraded with improved instruments.

2. Instrument Complement. Current scientific objectives and technological capabilities lead to the tentative inclusion of the following instrumentation subsystems into the scientific instrument package:

1. High (spatial) resolution camera (f/96).
2. Two high resolution spectrographs.
3. Three faint object spectrographs.
4. Fourier interferometer.
5. Wide field camera (f/12).

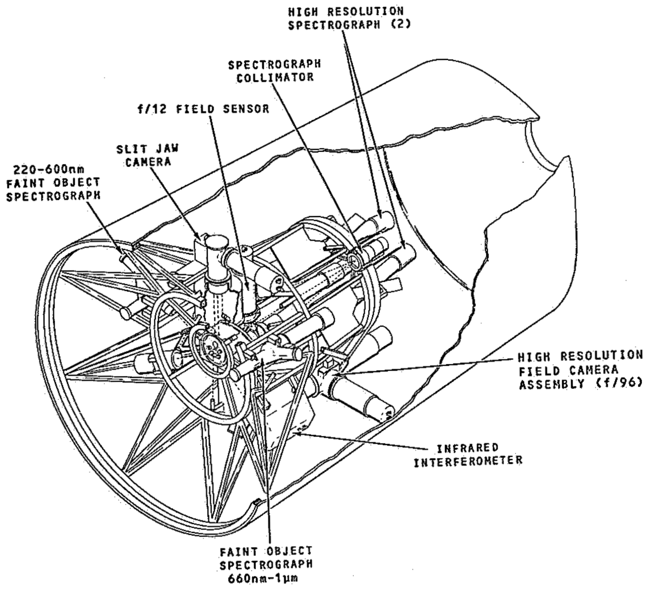


Figure III-4. SIP configuration.

The instruments described here are not to be construed as the final choice of instrumentation for the LST. Rather, as chosen, they represent a configuration which:

1. Provides a means of broad range observational capability.

2. Allows the study of packaging problems.

3. Exposes hidden problems.

4. Permits the establishment of tolerance ranges.

5. Provides a reference to explore the interaction of spacecraft pointing, optical performance, and detector capability on the overall scientific instrumentation system.

A functional block diagram of the SIP is shown in Figure III-5. The focus and figure sensors are shown in this diagram because they are physically located in the SIP area. Their functions, however, are associated with the optical telescope assembly, rather than the SIP.

a. High (Spatial) Resolution Camera Assembly (f/96). The f/96 camera contains three sensors from which the experimenter can choose for response in a particular spectral range of interest or, by successive observations, explore the total available spectral range. The spectral bands or ranges are as follows:

1. Range I — 115 to 300 nm

2. Range II — 160 to 600 nm

3. Range III — 500 to 1100 nm

Each of the three sensors is provided with a filter select mechanism which permits the inclusion of up to four spectral filters.

b. High Resolution Spectrographs. The two high resolution spectrographs are nearly identical instruments; one covers the spectral range 110 to 180 nm, and the other covers the spectral range 180 to 350 nm. The major differences in the instruments are the grating ruling frequencies and the photocathodes of the detectors.

The two spectrographs are the largest instruments of the group and are located in the aft section of the SIP. Instrument selection in the aft section is accomplished by first offsetting the LST so that light from

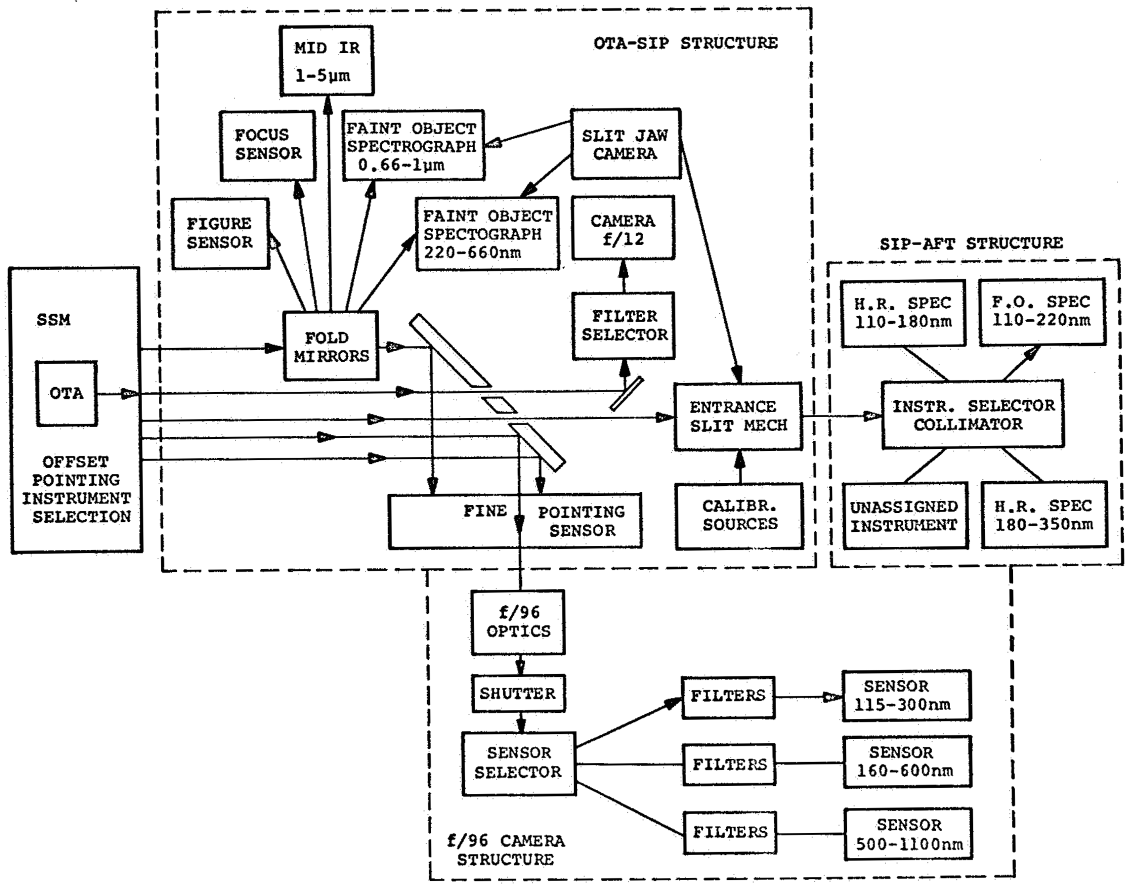


Figure III-5. Scientific instrument package functional block diagram.

the object of interest passes through the slit. Then the off-axis collimator is rotated to the position which directs the light to the selected instrument grating.

c. Faint Object Spectrographs. The faint object spectrographs cover the spectral range from 110 to 1000 nm with three instruments. The first is a single dispersion instrument which covers the range 110 to 220 nm, using two interchangeable gratings to break the spectrum into two intervals, 110 to 160 nm and 160 to 220 nm. This instrument is located in the aft section of the SIP.

The other two units are smaller than the first and are located in the forward section of the SIP. Each is accessed by small pickoff mirrors located about 0.3 mr off axis. The telescope is offset to select one of these mirrors. The second instrument covers the spectral range from 220 to 660 nm. It contains a dichroic beam-splitter which reflects the light in the

220 to 350 nm range and transmits the light in the 350 to 660 nm range. The third instrument is a single grating version of the first instrument with a grating selected to cover the range from 660 to 1000 nm.

d. Mid-IR Interferometer Assembly. The lack of noncryogenic vidicon tubes capable of efficient operation in the middle infrared range (1 μm to 5 μm) and the lack of efficient dispersive systems for that range leads to the choice of a modified Michelson interferometer. The interferometer is used to generate the interferogram of the source. A Fourier transform program, performed by ground computer, converts that interferogram into the power spectrum of the source.

e. f/12 (Wide Field) Camera. The f/12 camera is a single instrument designed for the purpose of the initial survey of the vicinity of the experiment target. This application dictates the largest possible field of view, permitting observation of known constellations or star groups.

The f/12 camera is at the Cassegrain focus of the telescope and receives its light after only three reflections. It is accessed by offsetting the telescope.

3. Ancillary Subsystems

a. Slit Jaw Camera. Each of the three spectrographs is equipped neither to acquire a target's image nor to hold an image in its slit. With the aid of the field select mirror assembly, image acquisition and maintenance is performed by the slit jaw camera. The camera views the target field, which has already been imaged in the immediate vicinity of the spectrographic slit, and displays that view at a remote (ground) station. The experimenter analyzes the display and, if necessary, originates the appropriate orientation commands to position the target's image into the slit, admitting light to the spectrograph.

b. Field Select Mirror Assembly. Located near the telescope focal plane, the field select mirror assembly is an array of fixed mirrors that apportions the field of view among the various instruments.

C. Support Systems Module Systems

The SSM interfaces structurally and electrically with the OTA and provides the OTA and the SIP with electrical power, communications and data handling, environmental control, coarse attitude sensing and control, launch vehicle structural and electrical interfaces, and a docking structure for on-orbit servicing or retrieval by the space Shuttle.

1. Structure. The SSM is primarily a cylindrical structure with a total length of 5000 mm (197 in.) and an I.D. of 3300 mm (130 in.) (Fig. III-6). The aft end is a shallow cone ending in a standard androgynous docking assembly.

The LST support systems contained in the SSM are structures, thermal control, electrical, communications and data handling, and attitude control. The components of these systems have been arranged to provide ease of astronaut maintenance while permitting adequate thermal control of these systems and the SIP.

The dynamic envelope of the shroud used with the Titan (alternate) launch vehicle limits the diameter of the LST. For a 12 700 mm (500 in.) long LST, the diameter cannot exceed 3680 mm (145 in.). An aft cone is required to stiffen the SSM and to support the shroud. If the requirement for compatibility of the LST and Titan launch were removed, the LST could be longer, have a larger diameter, and be more massive.

2. Thermal Control

a. System Description. The function of the SSM thermal control system is to maintain the equipment located in the SSM within prescribed temperature limits through all mission phases. System design must also allow for dissipation of heat from the SIP through the walls of the SSM. Temperature control is achieved by establishing a heat balance between the absorbed radiation (solar, albedo, and earth), internal heat dissipation, and emitted energy. High efficiency multilayer insulation, thermal covers, and coatings minimize the effect of large variations in incident radiation caused by changes in orbital parameters or LST orientation.

Components, such as the batteries, that experience large variations in internal heat dissipation during an orbit are placed in compartments separated from the other electronic equipment. Their heat balance is closely controlled with separate louvers, radiating surfaces, and heaters.

The amount of heat emitted from the SSM is controlled by the treatment of the surface on the pressure shell. Variations in heat absorption and dissipation that may result from orbital excursions are attenuated by these

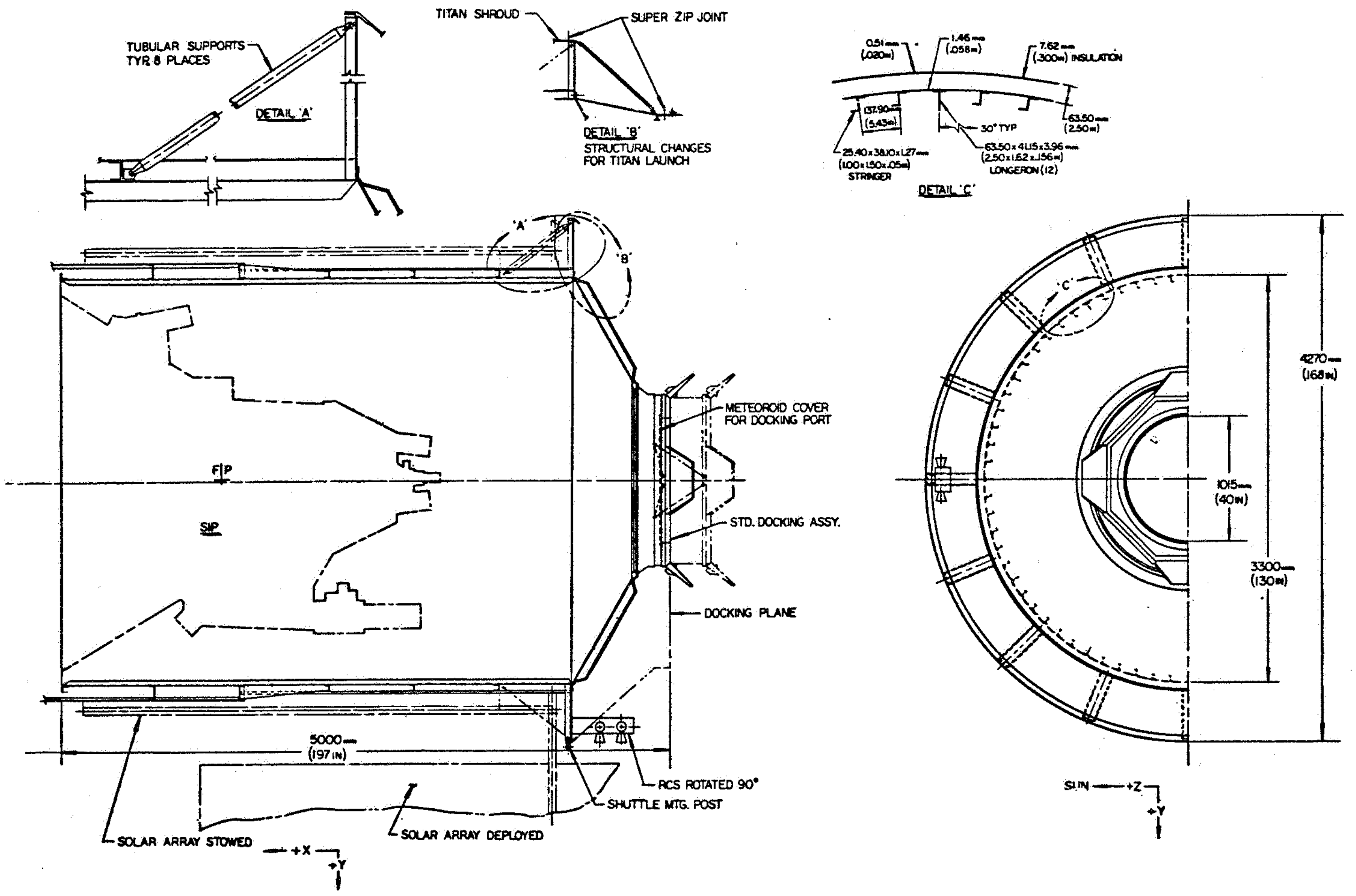


Figure III-6. SSM reference design longitudinal cross section.

treated surfaces and by the meteoroid shield. The surfaces are designed to maintain the observatory thermal balance under long-term orbital, seasonal, and orientation conditions, as well as to provide flexibility to respond to changes in thermal requirements that may be identified during development.

b. Hardware Description

(1) Louvers. Each SSM louver assembly consists of four separate blades. The louver design is similar to that used on HEAO. Each louver assembly is placed on the battery baseplate external surface and views the pressure shell. Bimetallic actuators sense the local battery baseplate temperature and provide the torque to rotate the louver blades.

(2) Insulation. The installation techniques are similar to those of other spacecraft. The insulation material is 24-layer, aluminized mylar. All the blankets are made in sections to fit around the spacecraft between the pressure shell and the meteoroid shield. Venting occurs through the gaps and perforations in each layer. The perforations are staggered to avoid radiation heat loss. A thermal barrier is maintained between the SIP and the SSM compartments by a polished-aluminum sheet, with the polished surface facing the SIP (Fig. III-7).

(3) Paint. Zinc orthotitanate (ZN_2TiO_4), a high-emittance white paint, was chosen as a design reference for use on the SSM external surface. This paint is one of many being tested on the Skylab program. It was chosen because of its low α/ϵ ratio and low degradation alpha value of 0.005 per year. As a backup to the Zn_2TiO_4 paint, a mosaic of optical solar reflectors (OSR) and white paint could be used.

(4) Heaters. The heaters are standard, flexible strip heaters that can be bonded to a conducting surface with a low outgassing adhesive. The heaters are available in wattages from 1 to 10 at 28 volts. Heaters are enabled by command, after which turn-on is controlled automatically by a standard snap-acting thermoswitch. The number, size, and setting for the heaters are to be determined.

3. <u>Electrical.</u> The electrical system includes the following two subsystems:

1. Electrical power subsystem (EPS).
2. Electrical distribution subsystem (EDS).

The electrical system has intimate interfaces with all other active LST systems. Since very little of the reference hardware has been qualified for the life and reliability required for the LST mission, maintenance is essential to achieve mission objectives. A simplified block diagram of the reference electrical system is given in Figure III-8.

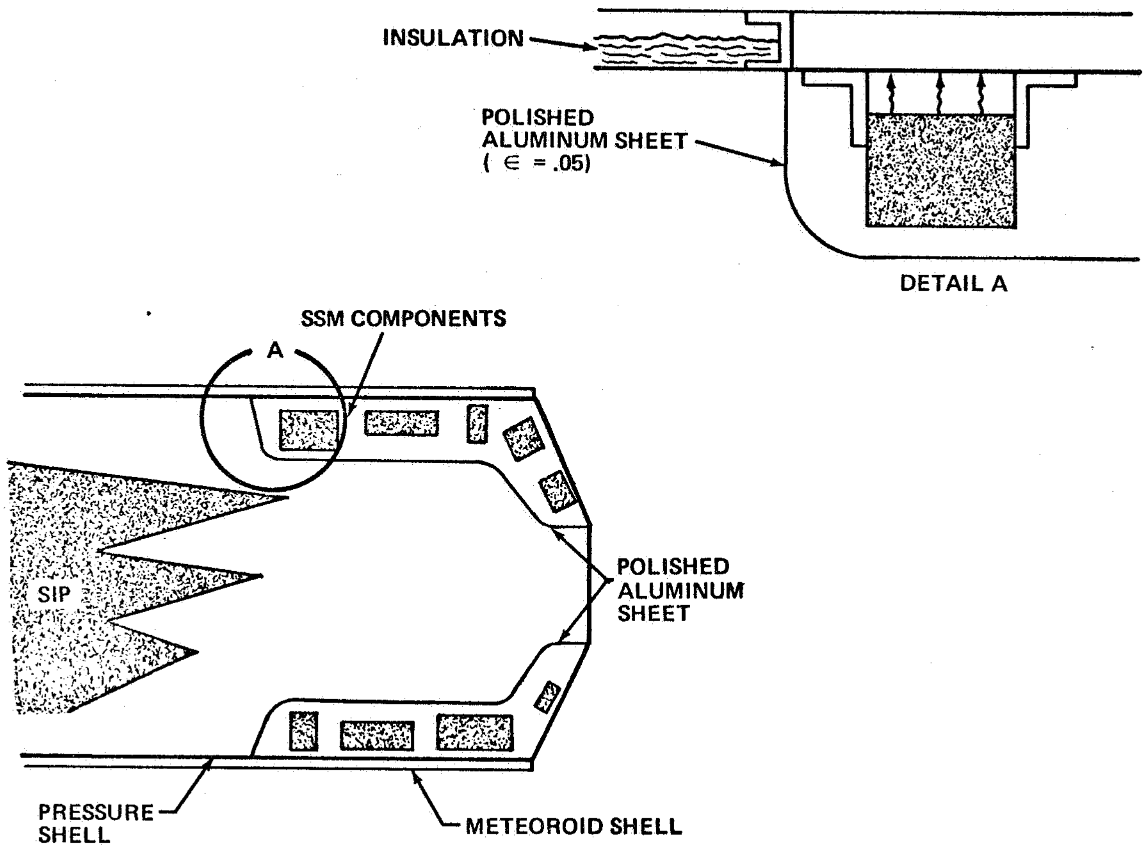


Figure III-7. SSM thermal control concept.

a. Electrical Power Subsystem. The EPS is a conventional solar array-battery system, with power conditioning and output series regulators. The design reference EPS is designed to supply an orbital average load of 1500 watts and a peak load of 2700 watts. The presently identified orbital average electrical load is 1283 watts; thus, the EPS has an average orbital power margin of 217 watts.

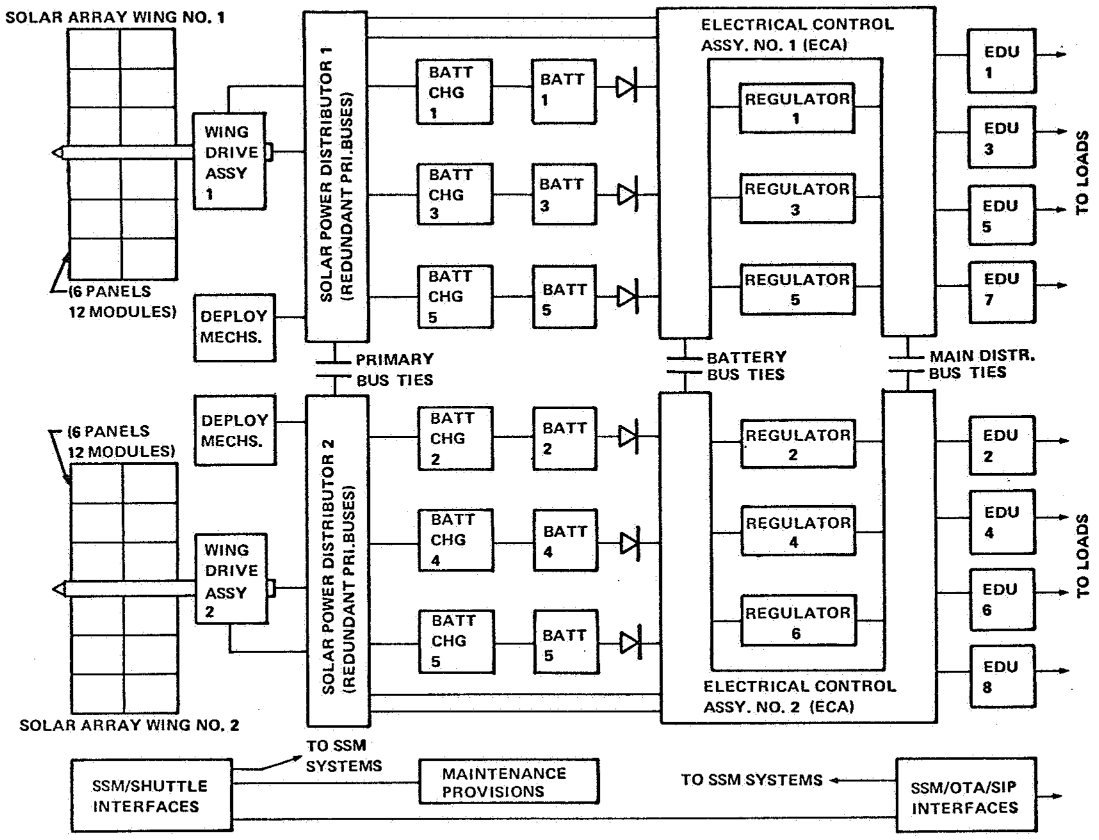


Figure III-8. Reference electrical system.

Six regulator assemblies provide ample peak capacity and overload protection of the primary power sources. Three assemblies can sustain the full LST load. Power regulated at 28 Vdc ±2 percent is delivered to the main buses for distribution to loads.

Energy is stored during the sunlight period of each orbit by six rechargeable, nickel-cadmium battery assemblies. Six charger assemblies receive and condition power from the solar buses and deliver the necessary recharge power. The energy capacity of the 6 batteries is 5400 W-h. For a minimum sunlight orbit orientation, the energy required from the batteries is 1024 W-h. Therefore, the battery depth of discharge for this condition is 19 percent. With proper temperature control, a battery lifetime of over 2 years is expected.

The solar array consists of two boom-mounted wings attached to the aft end of the SSM. Each wing is composed of 12 honeycomb substrate modules on which solar cells are mounted flat. The modules are connected to form six rigid, hinged panels that fold out when the boom is erected. The wings can be retracted as necessary. The wings are oriented about the boom axis by drive motors to position the solar cells perpendicular to the sun during all normal operations.

b. Electrical Distribution Subsystem. The EDS provides three levels of power distribution:

1. Power transmission network.
2. Main distribution network.
3. Secondary distribution network.

The power transmission network transmits and controls primary power between the sources, primary buses, and power assemblies. The main distribution network receives power from the power assemblies and controls main feeders. It distributes regulated power to decentralized secondary distribution units. The secondary distribution network consists of electrical distribution units (EDUs), cabling, and the test and control interfaces established to provide decentralized, highly adaptive, distribution service for the various subsystem loads.

4. Communications and Data Handling. The design reference communications and data handling system includes all the equipment required to manage the flow of data to and from the OTA, SIP, and SSM components. This includes the receipt, processing, and execution of real-time and stored commands; the formatting, storage, and transmission to ground of all diagnostic and status information from all LST systems; and the routing of scientific data and transmission to ground. The ground network being utilized for the LST mission is called the Spaceflight Tracking and Data Network. Only stations with unified S-band capability were selected for this mission.

The design reference communication configuration (Fig. III-9) consists of two unified S-band transponders, an Apollo Block II transponder called the engineering data transponder, and a modified ERTS transponder called the scientific data transponder. This combination of transponders provides a flexible communications system. The PM receive-transmit capability of the engineering transponder is required for tracking to match the ground station PRN ranging capability in the PM mode. This unit also provides the PM data downlink for command verification and spacecraft housekeeping data. The scientific transponder provides the high data rate (1 Mb/sec) downlink for transmission of the scientific data.

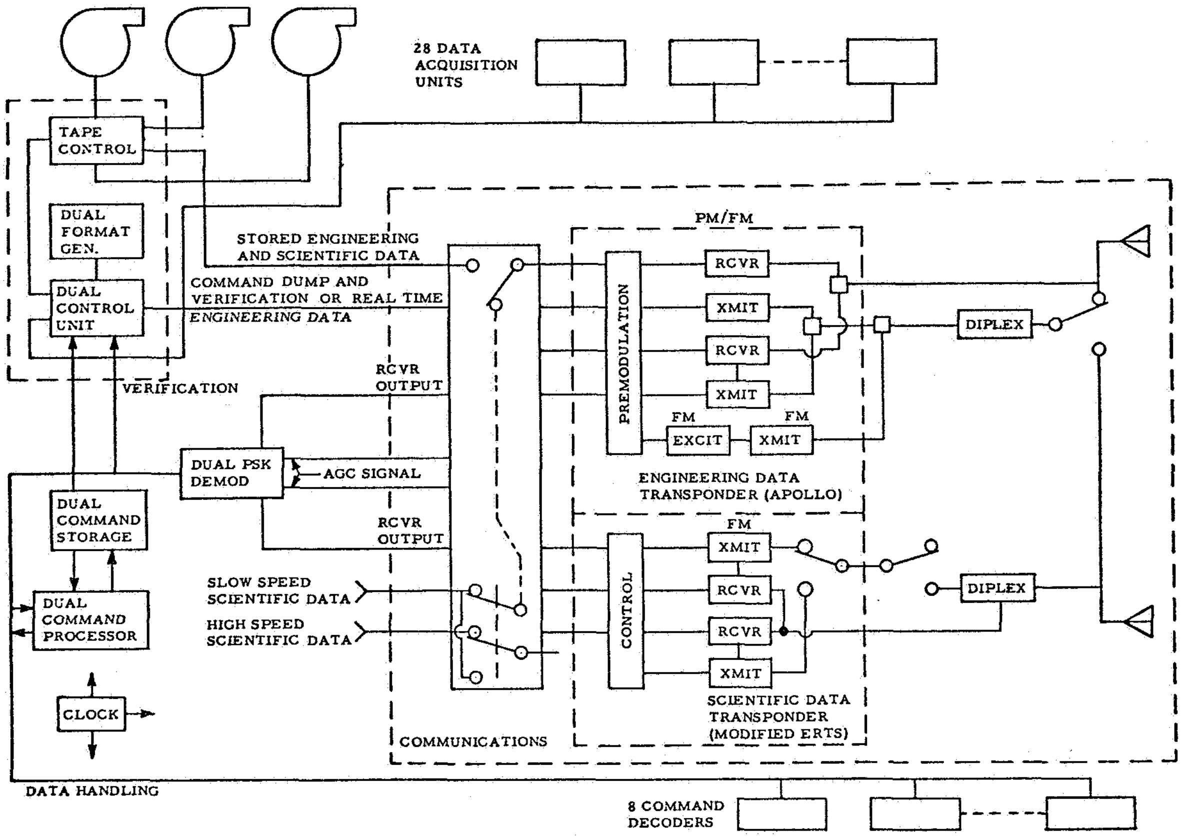


Figure III-9. LST communications and data handling system.

The command distribution system of the LST consists of a command processor, a command memory, and eight addressable command decoders. The system can process both real-time and delayed commands. Real-time commands are sent directly to the command decoders for processing. Delayed commands are stored in the command memory and are retrieved and executed when the command's time tag agrees with the spacecraft clock.

The communications and data handling system accepts both analog and digital engineering data from the OTA, SIP, and SSM components. These data can be taken directly from the data acquisition units (DAUs), formatted, and transmitted in real-time to the ground at a rate of 51.2 kbs. The data may also be stored on magnetic tape at a rate of 1.6 kbs until time for transmission to the ground stations at the 51.2 kbs rate.

Scientific data are acquired primarily by the use of SEC vidicons. The distinguishing characteristic of this tube is its ability to store images for several hours. This quality enables the SEC to integrate for hours on dim stars and store the data until ground contact is acquired. This tube storage capability eliminates the requirement for a mass memory for storing frames of scientific data. The information may be read directly from the tube and transmitted to the ground. A single frame of data on a 50 × 50 mm format with 60 cycle/mm resolution, sampled at twice the Nyquist rate, and coded with 8 bits/sample can be transmitted to the ground in 10 min at an approximate rate of 1 Mbs.

5. Attitude Control. A functional block diagram of the design reference attitude control system (ACS) is shown in Figure III-10. The three fixed star trackers (FSTs) are oriented in the Y-Z plane. Normally, two are active with the third in a redundant standby status. When operated in this manner, approximately 99 percent coverage of the celestial sphere is attained with the capability of providing 3-axis attitude error signals. The accuracy of the trackers has been selected to adequately align the telescope LOS so that preselected guide stars will appear within the coarse field-of-view (FOV) of the fine guidance system (FGS) sensors located within the OTA.

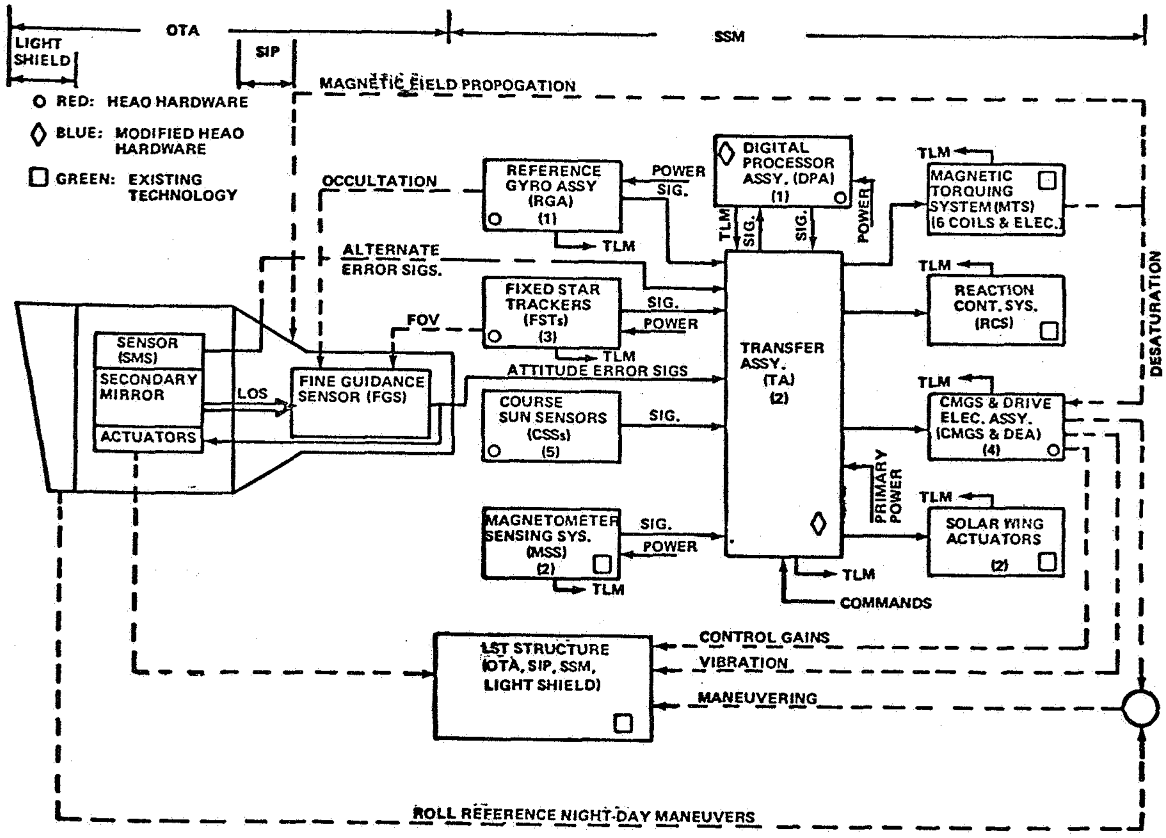


Figure III-10. ACS block diagram and RGA interfaces for LST.

Data source acquisition and tracking is normally accomplished in the following manner:

1. The LST is maneuvered by the SSM ACS actuators under control of the reference gyro assembly to the attitude required to acquire preselected reference stars in the FOV of the FSTs.

2. The coarse alignment mode is entered upon acquisition of the reference stars by the FSTs. Under control of the FSTs and RGA error signals, the spacecraft attitude is adjusted to a minimum 2-axis line of sight (LOS) accuracy of ±30 arc sec and ±0.1 degree about the roll axis.

3. Preselected guide stars are then acquired in the 1 arc min diameter coarse FOV of the FGS sensors. The presence of the guide stars in the FOV is assured by the accuracy of the coarse alignment mode.

4. The fine pointing mode is initiated upon acquisition of the guide stars by the FGS. Using 3-axis error signals from the FGS to command the SSM ACS actuators, the attitude of the LST spacecraft is adjusted in three axes to an accuracy of ±1 arc sec. This action places the guide stars within the 1 arc sec fine FOV of the FGS sensors.

5. The final absolute LOS alignment in 2 axes to ±0.1 arc sec with respect to the two guide stars is accomplished using FGS error signals to command the secondary mirror actuator system. The overall LST 3-axis attitude is maintained to within ±1 arc sec of the LOS to the guide stars by the ACS actuators using FGS error signals obtained from a combination of secondary mirror position information and the FGS roll sensor.

6. A stability about the LOS of 0.005 arc sec rms is maintained by adjusting the tip and tilt of the secondary mirror by secondary mirror actuator commands based upon FGS error signals.

Five coarse sun sensors (CSSs) are included. Coverage of 4π steradians is provided for sun acquisition and emergency sun acquisition. Two of the CSSs are located on the solar wings (one per wing) and provide monitoring of solar panel offset with respect to the sunline.

The reference gyro assembly (RGA) consists of six gyros in a skewed dodecahedron configuration with the necessary support electronics. In normal operation, four gyros are active and two are in a redundant standby mode.

A magnetometer sensing system (MSS) consisting of two 3-axis magnetometers (one redundant) is provided to sense the earth's magnetic field. Voltage outputs proportional to the field strength along each axis are used to calculate the required torquing currents for the magnetic torquer coils.

The transfer assembly (TA) serves as an interface assembly for all ACS components. It has a sensor buffer unit that places the required sensors on line for the control mode in use and routes signals between the sensors and digital processor assembly (DPA) via the computer input/output section of the TA.

The DPA receives data inputs from the various sensors via the TA, processes the data, and provides the following outputs via the TA:

1. Control moment gyro (CMG) gimbal commands.

2. Torque commands to the magnetic torquer system.

3. Gyro drift compensation obtained from onboard sensors or ground update commands.

4. Solar wing actuator commands.

Four single gimbal CMG assemblies, each complete with redundant drive electronics assemblies (DEAs), are mounted in a skewed configuration so that each CMG can provide a portion of the momentum requirements for each control axis. The CMGs provide the momentum storage capability required to maintain the LST in an accurate inertial hold attitude and supply the control torques required to maneuver the LST. The magnetic torquers supply control torques for CMG momentum desaturation.

A reaction control system (RCS) is included in the ACS primarily to serve as an emergency backup control system to the basic ACS. The RCS is in a standby "go" condition during certain critical LST maneuvers to be available if necessary. The RCS will also be required to provide control torques for the LST in the event of a complete or partial failure of the basic ACS. The RCS is a pressure regulated, gaseous nitrogen, propulsion system modularized into three basic elements — a propellant tank, a black box, and two major thruster modules.

6. <u>Contamination Control.</u> The optical surfaces of the scientific instruments must be protected from particulate and trace contaminants because deposits on these surfaces will degrade instrument performance. The requirements established for contamination control are: 10 000 class particulate

control in the SIP, 100 000 class particulate control in the SSM volume about the SIP, and 10 to 15 ppm of trace contaminants for low to high vapor pressure constituents.

Contamination control hardware located in the LST consists primarily of ducting and filters, as shown in Figure III-11. The ducting conveys "clean air" from the Shuttle to the forward end of the SSM and, through high efficiency particulate air (HEPA) filters, into the SIP. The flow of filtered air through the SIP will provide a class 10 000 environment within the SIP and a class 100 000 environment within the SSM outside the SIP.

Contamination control equipment located on the Shuttle consists of fans, trace contamination absorber beds, oxidizers, and filters. The trace contamination loop is located on the Shuttle but is physically separated from the remainder of the Shuttle habitable environment by a fabric curtain.

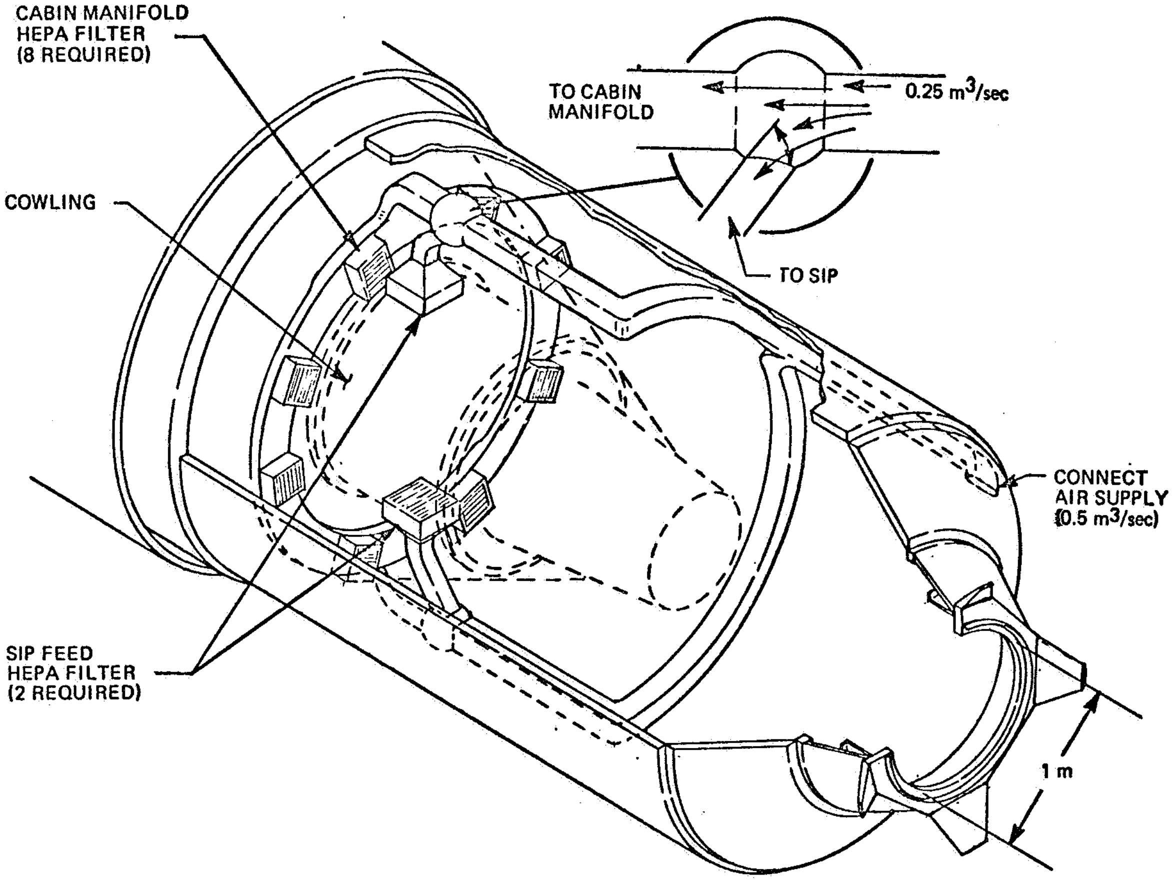


Figure III-11. Class 10 000/100 000 LST contamination control system layout.

Electrical power required for contamination control equipment is provided by the Shuttle.

7. Systems Reliability Summary. The SSM and OTA reliabilities are listed in Table III-1. "Failure" is defined as an event resulting in loss of the LST or requiring a maintenance action. The high reliability shown in Table III-1 arises from the following factors:

1. Incorporation of "reasonable" redundancy.

2. Use of existing equipment, or equipment common with the HEAO program. This in some instances, implies acceptance of higher redundancy than would be planned in a new design.

3. Exclusion of noncritical and certain other system elements (due to a lack of credible data) from the reliability analyses.

The most significant exclusions from the reliability analysis are the battery/charger units, which have been identified as a possible reliability problem. Data collected during the Phase A study have led to inconsistent battery reliability predictions.

No estimate for the SIP reliability can be given because those failure conditions justifying a maintenance action were not identified during the Phase A study.

TABLE III-1. SSM/OTA RELIABILITY

System	One Year Reliability
Attitude Control (SSM)	0.9880
Communication and Data Handling (SSM)	0.9981
Electrical (SSM)	0.9980[a]
Thermal Control (SSM/OTA)	0.9991
Main Optics and Structures (OTA/SSM)	0.9998
Data Handling and Control (OTA)	0.9988
Electrical (OTA)	0.9983
Pointing and Stabilization (OTA)	0.9860
Alignment Sensors and Logic	0.9898
Harmonic Drive Actuators and Control	0.9999
Light Shield	0.9958
Aperture Door	0.9952
SSM/OTA	0.9478

[a] Does not include battery/charger units, solar array drive mechanisms, and solar arrays.

CHAPTER IV. MAINTENANCE ANALYSIS

The mission goal of the LST is to provide 15 years of on-orbit observation time. To maintain an acceptably high level of operational performance, it is necessary to accomplish the following:

1. Provide a means for instrument update whenever warranted by changing scientific interest or advances in technology.

2. Assure system performance for long-time observatory operation.

3. Minimize total LST program cost.

The first two objectives may be accomplished either by using several expendable LSTs or by using a fewer number of maintainable LSTs. With the expendable approach, a new LST would be placed into orbit whenever the performance of an existing LST fell below an acceptable level, or whenever it was desired to operate with an improved or revised instrument package. With the maintainable approach, either degraded or nonoperational components would be replaced in orbit and the LST returned to a fully operational level or the LST would be returned to earth, refurbished, and returned to orbit. Scientific instrument updating would be performed in the same manner.

It has been estimated that two maintainable LSTs or eight expendable LSTs would be required to provide a 15 year mission lifetime. The maintainable LSTs consist of one precursor, which would operate for the first 5 years, and one advanced LST, which would operate during the final 10 years. The estimate of a requirement for 8 expendable LSTs is based on a component design lifetime of 2 years, which would require launch of a new LST every 2 years.

It has been estimated that the total program cost using the expendable LST approach would be 1.8 times the total cost using the maintainable LST approach. Because of this cost difference, the maintainable LST approach was selected as the design reference maintenance mode.

A preliminary maintainability analysis was conducted for the LST mission to determine and define a feasible maintenance concept. The four following maintenance modes were initially considered for the LST spacecraft:

1. On-orbit manned maintenance — pressurized.

2. On-orbit manned maintenance — unpressurized.

3. On-orbit manipulator maintenance.

4. Earth return maintenance.

These four maintenance modes were compared on the basis of a number of factors, such as the level of maintenance that could be performed, the number and complexity of the required operations, the time required, cost, growth potential and flexibility of design. The comparison, at this point in time, is qualitative. From a technical viewpoint it can be argued that all four modes are feasible — each with certain attractive and detrimental features.

Since the on-orbit maintenance mission does not utilize either the full mass or volume payload capability of the Orbiter, LST costs could be reduced if some other mission shared the flight with the LST maintenance mission. Employing this premise, the Space Shuttle Mission Model was surveyed to locate compatible payloads to share flights with the LST maintenance mission.

As a result of this preliminary analysis, the pressurized maintenance mode was selected and used as the basis of the Phase A feasibility analysis. This mode was selected because it was judged to offer the greatest potential for high mission success, mission flexibility, and maintainability. It provides for man's direct access to the equipment, and the elimination of complexities such as manipulators and the environments associated with repeated earth return. Although the preliminary cost comparisons were not absolutely conclusive, the pressurized concept did exhibit a slight cost advantage. The very cursory nature of this analysis emphasizes the need for a more comprehensive maintenance mode analysis during the Phase B definition.

CHAPTER V. CONCLUSIONS AND RECOMMENDATIONS

The results of the Phase A study indicate that a 3-m optical telescope can be operated in low earth orbit for 5 or more years. The telescope support requirements can be provided by onboard systems to provide near-diffraction-limited optical performance. The LST spacecraft may be launched by either the Shuttle (primary) or the Titan IIIE/OAS (alternate) vehicle.

The systems concepts utilized in the reference configuration appear to provide a feasible solution to the requirements. Some of the more critical areas for further study and analysis are the areas of fine error sensing, image motion compensation, pointing control, structural stability, imaging sensors and their cooling, large high-precision optics, optical system figure sensing and control, and maintenance.

It is believed that most of the basic technology and much of the systems hardware required by the LST will be available from other programs, thus reducing costs and improving reliability significantly. Other ways must be found to reduce costs and still achieve the scientific objectives of the mission. The use of man in such unmanned satellite programs as the LST, no matter what its configuration, can be more effective and can be accomplished with much less impact on the design of the hardware than was experienced on the Apollo or Skylab programs, due to differences in the nature of the missions and the experience gained on those programs.

A. Optical Telescope Assembly

An f/12 Ritchy-Chretian version of the Cassegrainian design is recommended over the Gregorian, since it is clearly superior for the LST application. A primary focal ratio of f/2.2 is recommended upon considerations of overall length, mass, and volume.

It was concluded that a three-bay, eight-point mount truss with graphite-epoxy members was a suitable design for the metering truss. A feasible alternate was found to be a graphite-epoxy shell structure, which may offer the advantages of a smaller overall diameter and greater stiffness. A three-point axial leaf design is recommended for the primary mirror mount. A light shield truncation angle of 45 degrees is recommended as being a good compromise between providing maximum sky coverage and minimizing design problems.

The thermal control concept recommended for the OTA is a combination of active thermal control for the optical elements and passive control for the supporting structure. Since the maximum rate of temperature change in the elements of the metering truss is less than 4.5 degrees per hour and appears linear, it is concluded that fewer than two refocusing operations per hour will be required.

B. Scientific Instruments

The feasibility of design and construction of scientific instruments that are capable of diffraction-limited imagery and high spectral resolution for a large range of celestial bodies has been established. The instruments can be repaired in orbit and the complement can be changed and upgraded in response to the requirements of the scientific community. Thus, the LST is capable of being usable for several decades and of obtaining scientific data not available on the ground.

It should be possible to align instruments replaced during on-orbit maintenance to within the specified tolerances. If these specified replacement tolerances are exceeded, the instruments will still function but performance will be degraded.

C. Support Systems Module

A conventional pressurized cylindrical structure of simple skin/stringer construction utilizing conventional materials, such as aluminum alloys in standard gages, was found quite adequate to meet the LST requirements. A passive thermal control system is feasible and compatible with a component arrangement to provide adequate clearance for astronaut maintenance.

A solar array reference design, based upon conventional solar panels, can satisfy all power requirements. However, it is a high mass approach with complex storage, deployment, and retraction and is not a good candidate for in-space maintenance. Therefore, it is recommended that an alternate roll-up array be studied and compared for a possibly more cost effective approach.

The feasibility of transmitting to ground over two frames per orbit of high resolution camera data was established. Data storage in the SEC vidicon tube permits the use of conventional state-of-the-art hardware to provide a flexible communications and data handling system that meets or exceeds the LST requirements.

It was found feasible to meet the LST pointing requirements utilizing the design reference attitude control system in conjunction with the OTA fine guidance system. Tip and tilt positioning of the secondary mirror in response to the fine guidance sensor star tracker outputs is required to maintain the 0.005 arc sec pointing stability.

D. General

The concept of unscheduled, on-orbit, manned maintenance utilizing the Shuttle orbiter for support appears to lead toward the most cost-effective approach. This allows reduction in equipment design lifetime from a goal of 2.5 years to a shorter time. Shuttle flight sharing with other payloads is a prime means of reducing maintenance costs.

There is a high degree of commonality between the reference design and hardware from other programs. For example, an approximate breakdown of the SSM components follows:

1. 42 percent identical to HEAO.
2. 17 percent from other programs.
3. 13 percent could probably be identical if shown to be cost-effective.
4. 23 percent new design requiring development but no new technology.