UNCLASSIFIED

AD NUMBER
ADB027059
LIMITATION CHANGES
TO: **Approved for public release; distribution is unlimited.**
FROM: **Distribution authorized to U.S. Gov't. agencies only; Test and Evaluation; MAR 1978. Other requests shall be referred to Rome Air Development Center, Attn: OCSE, Griffiss AFB, NY 13441.**
AUTHORITY
RADC ltr, 26 Sep 1980

THIS PAGE IS UNCLASSIFIED

THIS REPORT HAS BEEN DELIMITED

AND CLEARED FOR PUBLIC RELEASE

UNDER DOD DIRECTIVE 5200.20 AND

NO RESTRICTIONS ARE IMPOSED UPON

ITS USE AND DISCLOSURE.

DISTRIBUTION STATEMENT A

APPROVED FOR PUBLIC RELEASE;

DISTRIBUTION UNLIMITED.

FOR FURTHER TRAN

C013989

AD B027059

RADC-TR-78-36, Volume I (of two)
Final Technical Report
Mar[redacted]78

AMOS PHASE III PROGRAM. Volume I.

AVCO Corporation

Sponsored by
Defense Advanced Research Projects Agency (DoD)
ARPA Order No. 2837

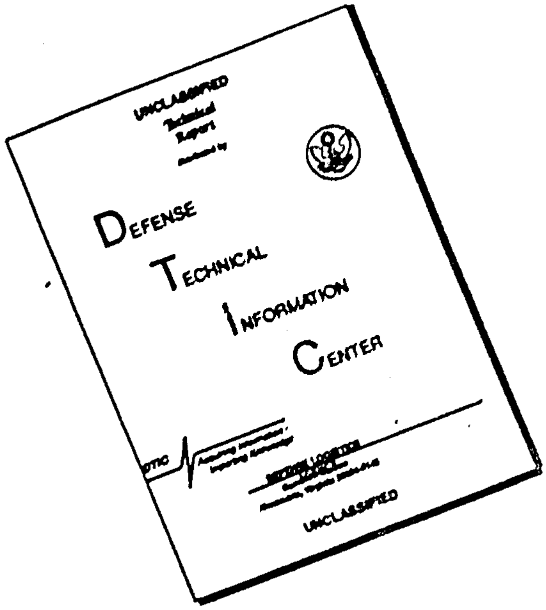
F4461-...-0044 | 2837 | 41

AD No.
DDC FILE COPY

Distribution limited to U.S. Government agencies only; test and evaluation; March 1978. Other requests for this document must be referred to RADC (OCSE), Griffiss AFB NY 13441.

ROME AIR DEVELOPMENT CENTER
Air Force Systems Command
Griffiss Air Force Base, New York 13441

DISCLAIMER NOTICE



THIS DOCUMENT IS BEST QUALITY AVAILABLE. THE COPY FURNISHED TO DTIC CONTAINED A SIGNIFICANT NUMBER OF PAGES WHICH DO NOT REPRODUCE LEGIBLY.

This report references the following classified documents:

AMOS Annual Report - 1 January 1976 - 31 December 1976 dated September 1977, SECRET, Avco Everett Research Laboratory, Inc., RADC-TR-77-330.

AMOS Annual Report - 1973 dated December 1973, SECRET, Avco Everett Research Laboratory, Inc., AERL 73-1311.

Advanced Multi-Color Tracker for AMOS (AMTA) dated May 1974, SECRET, Hughes Aircraft Company.

Have Lent III Quick Look Data Report dated 23 April 1976, SECRET, Avco Everett Research Laboratory, Inc., AERL M-1731.

RADC-TR-78-36, Volume I (of two) has been reviewed and is approved for publication.

APPROVED: Homer L. Harkleroad Jr.

HOMER L. HARKLEROAD, Captain, USAF
Project Engineer

AMOS PHASE III PROGRAM

Contractor: AVCO Everett Research Laboratory, Inc.
Contract Number: F04701-75-C-0047
Effective Date of Contract: 1 November 1974
Contract Expiration Date: 31 March 1978
Short Title of Work: AMOS Phase III
Program Code Number: 7E20
Period of Work Covered: Nov 74 - Dec 77

Principal Investigator: J. Hartogensis
Phone: 808 877-6594

Project Engineer: Captain H. Harkleroad
Phone: 315 330-3144
Autovon 587-3144

This research was supported by the Defense Advanced Research Projects Agency of the Department of Defense and was monitored by Captain Homer Harkleroad (OCSE), Griffiss AFB NY 13441 under Contract F04701-75-C-0047.

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER RADC-TR-78-36, Vol I (of two)	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) AMOS PHASE III PROGRAM		5. TYPE OF REPORT & PERIOD COVERED Final Technical Report 1 Nov 74 - 31 Dec 77
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) AVCO Everett Research Laboratory		8. CONTRACT OR GRANT NUMBER(s) F04701-75-C-0047
9. PERFORMING ORGANIZATION NAME AND ADDRESS AVCO Corporation AVCO Everett Research Laboratory, Inc. Everett MA 02149		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 62301E 28370101
11. CONTROLLING OFFICE NAME AND ADDRESS Defense Advanced Research Projects Agency 1400 Wilson Blvd Arlington VA 22209		12. REPORT DATE March 1978
		13. NUMBER OF PAGES 191
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office) Rome Air Development Center (OCSE) Griffiss AFB NY 13441		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE N/A

16. DISTRIBUTION STATEMENT (of this Report)

Distribution limited to U.S. Government agencies only; test and evaluation; March 1978. Other requests for this document must be referred to RADC (OCSE), Griffiss AFB NY 13441.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

Same

18. SUPPLEMENTARY NOTES

RADC Project Engineer: Captain Homer L. Harkleroad (OCSE)

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Telescopes	Photometry
Space Object Identification	Radiometry
Satellites	Laser Ranging

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The ARPA Maui Optical Station (AMOS) is engaged in research, development, and demonstration of advanced optical measurement techniques and in providing state-of-the-art measurement support to various government agencies.

The Defense Advanced Research Projects Agency, through executive agents in the Air Force Systems Command, contracted with the AVCO Everett Research Laboratory, Inc. to conduct Phase III operations at AMOS. The activities

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) during this period, which began 1 November 1974 and concluded 31 December 1977, were directed toward support of routine measurements with an overlay of research and development. Key accomplishments include bringing the 1.2-m telescope complex to a stable and controlled configuration for transition to the Air Force, completion of major system developments such as the 1.6-m telescope and laser beam director, supporting DARPA initiatives in advanced electro-optics systems technology, providing data collection and analysis for a variety of user experiments or investigations, and preparing for near-future integration and evaluation of large scale systems currently in development.

Volume I of this report provides a summary of the major efforts of the AMOS Phase III Program. It includes discussion of the goals and accomplishments in system development, the measurement program, data systems, special programs support and in routine program control activities. It represents the summation of a period in which AMOS achieved significant increases in capability, as well as maturity, as a multi-user superior quality asset for research and development in advanced optical technology and state-of-the-art optical measurement support.

Volume II of this report describes the results of some of the measurement programs as well as a detailed mission summary for 1977.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

Figure		Page
21	1.6-m Telescope Fully Assembled	58
22	Hartmann Images After Telescope Realignment	62
23	Double Star Photographs	64
24	Saturn	65
25	1.6-m Polar Balance Weight System	67
26	Laser Beam Director Schematic	70
27	Beam Forming System	72
28	Beam Forming System (Coude Optics in Foreground, Boresight TV Beneath Table)	73
29	Gimbal and Tracking Flat	76
30	Pointing and Tracking System Block Diagram	77
31	Ruby Laser (View Looking Toward 5X Expander and Beam Diverter)	79
32	Laser Control Console	83
33	Principal EROS Functions	87
34	CDC - 3500 Computer	93
35	CDC SC-17 Computer	94
36	System Configuration for Video Autotrack (1)	105
37	System Configuration for Video Autotrack (2)	106
38	Fire Alarm System	113
39	Fire Control System	114
40	Intercom System Main Frame	116
41	Intercom Stations	118
42	Timing System Block Diagram	121
43	All-Sky/CLOS System in Housing Stop AMOS Observatory	122

LIST OF TABLES

1.0 INTRODUCTION

This report presents a summary of Avco Everett Research Laboratory, Inc. (AERL) efforts under the Defense Advanced Research Projects Agency (DARPA) Maui Optical Station (AMOS) Phase III contract, F04701-75-C-0047. The duration of this contract extended from 1 November 1974 to 31 December 1977. The initial two months were devoted to an orderly transition of site activities from the previous contractor to AERL. For the remaining 36 months AERL was the sole contractor at AMOS, responsible for conducting operations and measurement programs along with an overlay of research and development activity.

This final report for AMOS Phase III reviews goals and accomplishments in the major areas of program activity. The report is provided in two volumes, this unclassified one and a second which is classified secret. The second volume presents discussion of measurement and test activities whose objectives and/or results are classified. It also includes an appendix which lists all missions supported by AMOS in 1977.*

This volume is organized in six sections. Within each section each major topic begins with a summary of objectives and accomplishments in the subject area. Detailed discussion of the activities then follows.

After this Introduction, which includes an overview of background and objectives, Section 2.0 details the system development efforts. Subsections treat each major system, i.e., 1.2-m telescope, 1.6-m telescope, laser beam director, computer, etc.

Section 3.0 describes the Measurement Program while 4.0 adds discussion of Data Systems and the processing of the data product resulting from measurements.

Section 5.0 summarizes activities in Special Programs Support. This important area includes on-going large system support, special tests and evaluation and visiting experiments.

Finally, Section 6.0 covers Program Support and Controls, the more routine operating and administrative functions.

---

*Mission support listings for previous years appear in prior Annual Reports.[1, 2]

1.1 BACKGROUND/HISTORY

The chronology of AMOS is readily separable into distinct phases, which correspond to contractual periods, each having particular goals. AMOS was conceived by DARPA in the early sixties and was intended to be a ballistic missile mid-course optical measurement site. The design and construction (Phase I) contractor was the University of Michigan who functioned under the direct technical review of DARPA.

In mid-1969 the site achieved operational capability. At that time DARPA asked the Air Force Space and Missile Systems Organization (SAMSO) Deputy for Reentry Systems to assume responsibility for AMOS as executive agent for DARPA. Phase II contracts were let to Lockheed Missile and Space Company (LMSC) for site operation and maintenance and to Avco Everett Research Laboratory, Inc. (AERL) for scientific direction. This phase was designated as research and development operations. Overall capabilities were assessed during this period and resulting developments were aimed toward the goal of providing a more space oriented role for AMOS. As this role developed, in early 1974, the program responsibility was transferred from the SAMSO Deputy for Reentry Systems to the Deputy for Technology.

Beginning in January 1975 AERL became the sole contractor for AMOS, under Phase III of the program, with responsibility for efforts oriented more toward routine operations with an R&D overlay.

In late 1974 Air Force System Command and Aerospace Defense Command had evaluated AMOS capabilities and determined that a portion of the site, the 1.2-m telescope system, would be a valuable adjunct to the SPACETRACK network. Thus, plans were made by DARPA to develop this system to a routine operational capability for transition to the Air Force. At the same time, DARPA had begun certain development efforts which were destined for installation and evaluation at AMOS utilizing the 1.6-m telescope and laser beam director systems. The AERL Phase III contract, therefore, covered operation of the entire site for the first 18 months and the site minus the 1.2-m telescope systems for the second 18 months. It was anticipated that the Air Force would contract separately for the 1.2-m work starting in July 1976.

The large systems under development by DARPA intended for AMOS were being directed by the Air Force Systems Command, Rome Air Development Center (RADC). RADC also had experience with transitioning system capabilities to operational Air Force use. Therefore, in early 1976, AMOS program responsibilities were transferred from SAMSO to RADC.

In June of 1976 it was determined that the transition program had not been defined sufficiently to warrant separate Air Force contracting for the 1.2-m telescope system efforts. Instead, an Air Force sponsored definition phase effort, which lasted 13 months, was amended to the AMOS Phase III program.

In August of 1977 the MOTIF (Maui Optical Tracking and Identification Facility) Transition Contract was effected and, for the last 5 months of the Phase III contract, the site was operated under joint contractual tenancy.

This Phase III Final Report, therefore, covers 18 months of solely DARPA oriented efforts, 13 months of joint DARPA responsibility and Air Force MOTIF Definition Phase effort, and the final 5 months of reduced DARPA-only activity.

1.2 OBJECTIVES

AMOS represents a unique state-of-the-art optical facility which has continuously evolved to meet changing DARPA goals. During Phase III the goals for AMOS can be classified as more "end use" oriented - that is, activities were directed toward achieving specific capabilities for applications which are currently envisioned as being the ultimate uses of individual AMOS systems.

While further DARPA research activities are planned for some of the AMOS systems, no major on-going efforts have been identified for the 1.2-m telescope system. This capability, therefore, became candidate for transition to a user agency. This transition is in compliance with DARPA's objective of developing a technology to maturity for use by other DoD organizations. The Phase III activities for the 1.2-m system were therefore directed toward providing a stable and controlled configuration capable of providing routine measurement support to the Space Object Identification (SOI) community. Certain system upgrades and completion of sensor development efforts were necessary before the transition could begin. These tasks, reported individually in Section 2.0 below, were performed during the first 18 months of Phase III.

The 1.6-m telescope is to be the test bed for the Compensated Imaging System (CIS) which is under separate development by DARPA. The Phase III efforts for this system were therefore directed toward developing, evaluating, and characterizing all aspects of 1.6-m telescope operation for this future use. Attendant activities, such as Atmospheric Characterization as well as in-house and visiting experiments which used the system, have contributed to fully qualifying and preparing AMOS for the CIS. These activities are discussed in detail in Sections 2.0 and 5.0 below.

The laser beam director system completed initial development early in Phase III. The DARPA programs which were anticipated to use the system did not immediately materialize, however. The system remained dormant, therefore, until the final few months of Phase III. At that time reactivation of the system, completion of ranging system development, and full calibration and characterization of system potential were undertaken for an on-going DARPA application. The initial development work is described in Section 2.0 while the more recent efforts are included in Section 5.0 below.

Throughout Phase III, which is generally characterized as a period of routine operations with an R&D overlay, numerous measurement requirements existed. AMOS capabilities in state-of-the-art optical measurement support were readily related to measurement objectives by a variety of government users. The summary of the measurement activities in Section 3.0 and visiting experiment users in Section 5.0 reflects the varied objectives, as well as accomplishments, in routine operations support.

1.3 PROGRAM RESPONSIBILITIES

Specific responsibilities are tasked to AERL under AMOS Phase III. Site or system operation and maintenance, configuration control, instrument calibration, quality assurance, safety, and administrative support represent the basic tasks in the conduct of the facility. Development activities, that is the implementation of modifications to existing systems or the integration, installation and checkout of new systems, comprise a major portion of the effort. The support of target measurements and system performance testing, and the resulting reduction and analysis of data, equally share importance with the development activities.

Beyond these contractually oriented specific responsibilities there exists a less precisely defined layer of interrelated responsibilities which AERL contributes to or shares with other organizations. These include liaison with proposed users of site capabilities or data products, interfacing with associate contractors developing subsystems to be tested at AMOS, participating in range planning, and pursuing joint objectives with various government agencies and Federal Contract Research Centers (FCRC's).

Each of AERL's AMOS responsibilities, it should be clear, emanate from direction by or in response to DARPA through its executive agent RADC. Control of program functions, authorization for activities to be undertaken and approval of end products remains at those levels. A well coordinated relationship has existed between the three organizations, AERL, RADC, and DARPA. As a result AMOS has become an important national asset for research, development, and application of advanced electro-optical systems technology.

2.0 SYSTEM DEVELOPMENT PROGRAM

System Development is the name given to those activities which are directed toward adding to or improving existing AMOS capabilities, principally by hardware modifications.

No major new hardware systems were initiated during Phase III. However, a number of large system efforts which had been begun in Phase II had not been completed at the end of that Phase. AERL, therefore, was assigned those efforts. The 1.6-m telescope restoration, the 1.2-m telescope upgrades, the Laser Beam Director and the Teal Amber facility construction were transferred from the previous contractor to AERL.

In addition, a number of minor modifications to current AMOS systems and some significant additions of new experimental subsystem hardware did occur during the course of Phase III. Typical of the modifications were upgrading of the Advanced Multi-Color Tracker for AMOS (AMTA) sensor and the addition of mount safety controls to both telescopes. Typical of new equipment are the Contrast Mode Photometer for the 1.2-m telescope system and the All-Sky Camera for obtaining clear-line-of-sight statistics as part of Atmospheric Characterization efforts.

These System Development efforts are described below. Major systems are treated individually in Sections 2.1 through 2.4, while subsystems or miscellaneous developments are collected in Section 2.5.

2.1 1.2-m TELESCOPE SYSTEM

The 1.2-m telescope system consists of two 1.2-m diameter, Cassegrain telescopes mounted on a single, high performance tracking mount. Associated subsystems include sensors, controls, and ancillary equipment such as the dome structure, windscreen, etc. This system is currently being transitioned to ADCOM under Contract F30602-77-C-0184, to be used for routine satellite tracking operations in support of the Air Force SPACETRACK network. When transition is completed the system will be known as the Maui Optical Tracking and Identification Facility, or MOTIF.

During the AMOS Phase III Program several additions and improvements were made to the 1.2-m telescope system to enhance its capabilities for routine SOI operations. This section describes these improvements. It also provides a complete report of current hardware status.

2.1.1 Summary

2.1.1.1 Objectives

The objectives of the various upgrade programs all had a central theme; i.e., to provide a high quality optical system which would be reliable, easy to maintain, and able to incorporate a variety of sensor systems. In meeting these objectives some of the programs involved correcting observed deficiencies in the existing equipment while others involved adding new capabilities.

At the onset of the Phase III program the two 1.2-m optical systems exhibited certain deficiencies. The f/20 telescope, referred to as the b = 29,* showed severe astigmatism along with a substantial boresight shift attributable to primary mirror tilt as the telescope was moved. Both problems were related to the primary mirror support system. The f/8 telescope, referred to as the b = 30, included a secondary mirror and drive which demonstrated poor optical/mechanical performance. For future experiments the single instrument mounting surface of the b = 30 telescope would be a constraint and the f/8 configuration would not satisfy many of the sensor requirements. In addition to the optical problems relating to each telescope, a problem existed between the two, referred to as strabismus, which prevented simultaneous data collection due to a line-of-sight offset.

Problems also existed with various ancillary systems. The dome drive exhibited very poor reliability and was difficult to maintain. It also caused excessive vibration which degraded telescope performance. The servo control system for the telescope mount, as well as being obsolete, was not optimized for the current configuration of the telescopes. In addition, the mount control system did not preclude runaway motion which could potentially damage the telescope or sensor equipment. Balancing of the mount was time-consuming and hazardous since it was accomplished by bolting lead weights in various places.

Sensor capability, in January 1975, consisted of the AMTA mounted on the b = 29 telescope along with a boresight television camera. The b = 30 telescope did not have a resident sensor but was utilized more for short term, special experiments. It was clear that a photometric capability was required and that the operational capabilities of both the AMTA and the television systems could be improved.

2.1.1.2 Accomplishments

A new primary mirror cell and support system were installed on the b = 29 telescope to correct the tilt and astigmatism problems. An air bag and mercury belt arrangement (identical to the system used on the b = 30 telescope) for axial and radial support, respectively, were included.

The entire secondary mirror and drive were replaced on the b = 30 telescope. This not only corrected the poor optical/mechanical performance

---

* Throughout this report the 1.2-m telescopes are identified by their back-working distance, the distance from the front surface of the primary mirror to the focal plane, on the telescope axis. This distance is referred to as "b".

but also allowed conversion from f/8 to f/16 to provide better optical match to sensor systems. (This telescope is now referred to as the b = 37.) To correct the strabismus problem AERL designed, fabricated, the installed a beamsteering system on the b = 37 telescope. This device, under computer control, tilts the secondary mirror such that the b = 29 and b = 37 lines-of-sight remain parallel at all telescope attitudes. Finally, to enhance the versatility of the overall system, a folded Cassegrain instrument mounting surface was installed on the East side of the b = 37 telescope. This allows simultaneous mounting of sensor systems which can alternately be utilized by remotely controlling a folding mirror mounted at 45° to the telescope axis within the telescope.

The dome azimuth and windscreen drive systems were completely redesigned. Reliability of the dome drive was improved by eliminating the positive (sprocket/chain) coupling between the motor gearbox and the rotating inertia of the dome and by providing a more rugged design utilizing individually driven wheeled support trucks. Maintainability was enhanced by mounting all components interior to the dome. Vibration was reduced by eliminating the aforementioned sprocket-to-chain drive.

A new mount servo system was installed which provided a separate control channel for each of the three axes. (The original servo had only two channels.) The new system is totally contained in a single 19" standard rack chasis, whereas the original system required a complete rack. Both electronic limits and mechanical shock-absorbing stops were added to prevent potentially damaging mount orientations. The mount control system was also improved by the installation of a standard balance weight scheme.

Sensors were both upgraded and provided with additional capabilities. Minor improvements were made to AMTA including the provision of an automatic calibration scheme and an improved operator display. Its capability was enhanced by the incorporation of a Long Term Integration (LTI) system which allows infrared measurements to be made on very faint targets. A state-of-the-art photometric capability was added with the installation the AERL designed Contrast Mode Photometer (CMP) on the b = 29 telescope and improved television system sensitivity was realized with the addition of various new camera systems, including the Quantex QX-10 with a digital averaging option.

2.1.2 Telescope Systems

2.1.2.1 b = 37 1.2-m Telescope

Background

During 1974, it became apparent that certain modifications to this telescope were desirable. In order to increase measurement capability and versatility a second instrument mounting surface was indicated. Because of previously demonstrated poor optical/mechnical performance of the existing secondary mirror and its drive, a reworking or replacement of that subsystem was also determined to be necessary. Analysis of planned sensor system requirements (e. g., FOV) showed that an f/16 system would be preferred over the existing f/8. This latter conclusion, plus the desire to minimize telescope downtime, resulted in the adoption of the "replacement" approach rather than that of merely reworking existing components.

b = 37 Folded Cassegrain System

A second focal plane capability was provided by the installation of a 45° mirror (referred to as the #3 mirror) between the primary and secondary of the Cassegrain system to divert the beam through a hole in the East side of the declination housing. Instruments can be mounted on a new Blanchard ground surface using bolt circles identical to those on the b = 29 and 1.6-m telescopes.

Transition between the two modes of operation is accomplished by activating a switch located in the mount control console which causes the #3 mirror to rotate to the desired position. The time required to effect the transition is a few seconds. A primary mirror baffle supports the #3 mirror assembly. All hardware was provided under a subcontract to Boller & Chivens. Table 1 gives the important system specifications.

b = 30 to b = 37 (f/16 Conversion)

Early in 1975, design and fabrication of the following basic hardware was approved for the conversion of the existing b = 30 (f/8) telescope to a b = 37 (f/16) system:

1. A lightened secondary mirror and support system similar to that on the b = 29 telescope.

2. A focus drive and readout system similar to the one installed on the 1.6-m telescope.

3. New fins and supporting ring for the above including an extension ring for the existing tube.

Most of the hardware was supplied under a subcontract to Boller & Chivens. Design and fabrication of certain existing hardware modifications (e. g., extension of the INVAR metering rods to accommodate the larger intermirror separation for the f/16 system) was accomplished by AERL.

Following extensive testing of the performance of the existing b = 30 system to establish a baseline, and following optimization of the primary mirror support system, the new hardware was installed. Figure 1 shows the new mirror, support system and extension ring installed in the telescope.

After installation of the hardware was completed (September 1975), initial alignment of the system was accomplished, primarily, by the use of a knife edge. Results indicated that the b = 37 primary is quite good. It was determined, however, that the back working distance (BWD) for best

TABLE 1

IMPORTANT SYSTEM SPECIFICATIONS FOR b = 37
FOLDED CASSEGRAIN SYSTEM

Mirror Material	Cervit
Wavefront Performance	$\lambda/10$ P-V; $\lambda/30$ rms (λ = 632.8 nm)
Reflectance (Al plus SiO overcoat)	0.85 for $0.4 \leq \lambda \leq 0.75$ μm
Cell & Support	1. Maintain wavefront performance for all attitudes (zenith to horizon) 2. Maintain folded optical axis, relative to Side Blanchard, to $\pm$ 5 x 10^{-4} inches for all mount attitudes.
Baffling	10 arcmin for f/16 cine. Reduce scattered sunlight by 10^4 when pointing within 20° of sun.
Side Blanchard Surface	Designed to support a 500 lb instrument package with its CG at the folded focal plane.

Figure 1   f/16 Secondary Mirror and Support System focus using the new secondary was not correct, therefore, the mirror was reworked to provide the required b = 37.

Extensive optical testing of the reworked system was accomplished to determine system performance. The first positive conclusion that could be reached concerned the surface quality of the primary mirror. This evaluation was made using knife edge (Foucault) tests. The surface errors that were detected were attributable to the primary since rotation of the secondary had no effect on the location or shape of any observed irregularity. The only significant primary surface defect was a turned down outer edge (outer 2 inches). Since the actual mirror diameter is 50 inches the mirror is quite good throughout a 48-inch (1.2-m) clear aperture. For optimum imaging performance, the outer edge of the primary should be masked.

The second conclusion concerned the BWD. Hartmann data taken at BWD's of 34, 37 and 40 inches gave results of 0.90, 0.81 and 1.20 arcsec respectively for 80% of the energy.

With respect to final system performance, then, the BWD of 37 inches was chosen. The 0.81 arcsec Hartmann value for a star diameter at b = 37 should be taken as an upper boundary. The double star 7 Tau having a separation of 0.5 arcsec is the closest double to have been resolved visually thus far. On the other hand, many stars having separations under an arcsec have been resolved.

Table 2 lists the final telescope performance parameters.

2.1.2.2 <u>b = 29 Primary Mirror Cell and Support System</u>

The primary mirror in the b = 29 telescope was axially supported by an 18-pt. whiffletree arrangement of elastomer pads. Radial support was provided by three sets of tensioned steel bands, anchored at points 120° apart on the rim of the primary mirror cell. The bands, however, did not symmetrically straddle the center of mass of the mirror, and when tensioned so as to prevent lateral motion, the resultant moment tended to tip the mirror off the back supports. This caused severe astigmatism and sudden, unpredictable shifts in boresight and mirror stress producing zone-aberrated images.

Based upon the excellent results that were obtained by replacing a similar support system for the b = 37 primary with an airbag (axial) and a mercury belt (radial), Boller & Chivens was contracted to provide the same capability for the b = 29. A new primary cell also was specified.

The new b = 29 cell (Figure 2) is a steel weldment designed to support the weight of the primary mirror (about 1200 lbs) and a 500 lb sensor package with the latter's center of gravity at the Cassegrain focus. Structural integrity is such that the mirror is not distorted (i.e., optical performance is maintained) for all attitude operation (zenith to -5° elevation) of the telescope. The mirror cell is designed such that the mirror support system floats the mirror 100% radially, and 98% axially. Collimation is maintained by three equally spaced axial back pads that pick up 2% of the mirror's weight.

TABLE 2

1.2-m, b = 37 TELESCOPE CHARACTERISTICS

Aperture	1.22-m (48 inches)
Focal Ratio	f/16.2
Focal Length	19.8-m (780 inches)
Type (2 Choices Switch Selectable)	Cassegrain
a) Conventional Working Distance	48 cm (19 inches)
b) Folded Working Distance	25 cm (10 inches)
Optical Quality	4 x Diffraction Limit
Primary Support	Air Bag - Axial
	Mercury Belt - Radial
Secondary	Remote Focus Drive
	Beamsteering
Thermal Control	Invar Rods
Instrumentation:	
a) LLLTV* - Type	ISIT
- Bandpass	0.38 - 0.70 μm
- FOV (~2 choices)	156 $\widehat{''}$ x 210 $\widehat{''}$
	78 $\widehat{''}$ x 108 $\widehat{''}$
- Location	Rear Blanchard
- Sensitivity	> +19 M_v

*Low Light Level Television

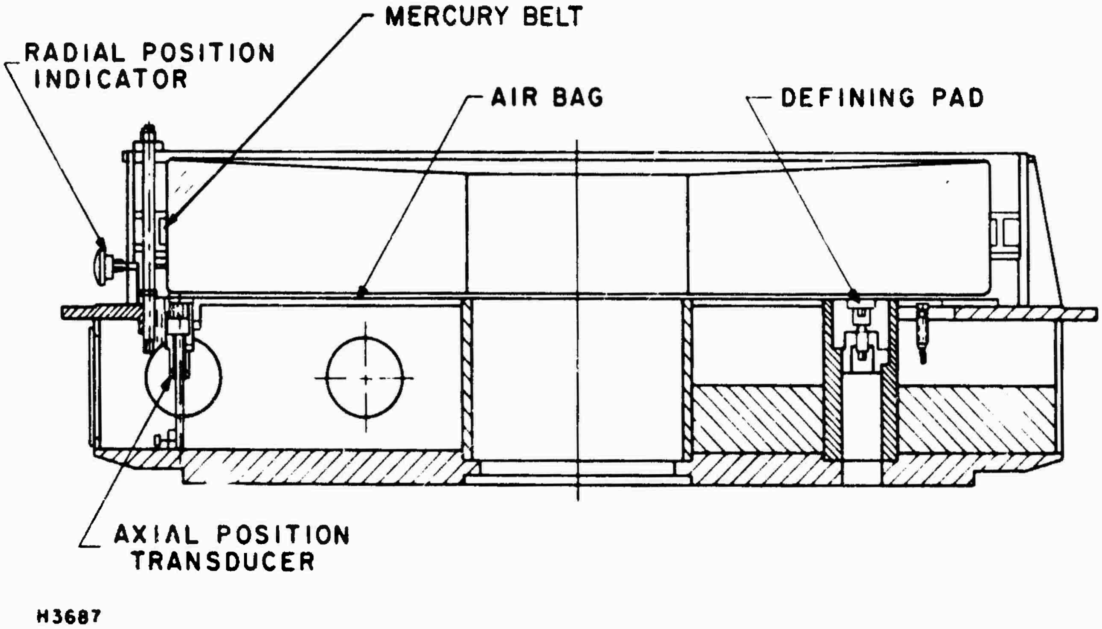


Figure 2 AMOS 1.2-m (b = 29) Primary Cell and Mirror Support System

Radially the mirror is supported and restrained by a flat tubular ring, filled with mercury, designed for the diameter and weight of the mirror, and located at the axial center of gravity. The mercury creates the buoyant force which radially supports and defines the mirror statically, and also provides the compensating forces during acceleration. Axially, the mirror is floated on controlled air pressure, contained within three flat air bags and defined by three defining pads. The airbag (flexible neoprene coated) is made in three sections for fabrication and installation convenience, but the sections are connected in parallel to apply the same unit pressure over the whole contact area. A calibrated pressure regulator controls the air pressure in the bag to compensate for changing gravitational force on the mirror as the telescope moves away from zenith.

Following installation of the new cell and mirror support system, performance tests were conducted. The axial support system (airbag) performance was monitored with three linear transducers having remote readouts that indicate mirror axial position changes as small as 5×10^{-4} inches while the radial support system (mercury belt) performance was monitored by two dial indicators having the same measurement precision. The transducers are located as shown in Figure 2. In order to meet the axial shift and tilt specifications, the readouts could show a maximum deviation of only one count for all indicators and a differential between indicators of no more than a single count. This is to hold for all telescope angles from -5^{o} elevation to zenith. The complete results of acceptance testing showed that Boller & Chivens had provided a system that met all performance specifications. Table 3 lists the final telescope performance parameters.

2.1.3 Sensor Systems

2.1.3.1 AMTA

The Advanced Multi-Color Tracker for AMOS (AMTA) system[3, 4] is a routinely operational LWIR sensor which has supported numerous AMOS missions and experiments since it was first installed in March of 1973. The AMTA upgrade has been an ongoing program either to correct system defficiencies or to improve system performance. The tasks outlined under the Phase III contract to be completed as part of the AMTA upgrade program were:

1. Provide an automatic blackbody calibration fixture.

2. Improve the AMTA Z-axis operator display.

3. Complete programs to computer process AMTA data for an onsite quick-look capability.

4. Provide for the recording of 10 detector dc outputs.

5. Replace the stainless steel gas lines with flexible lines routed through the telescope axes.

TABLE 3

1.2-m, b = 29 TELESCOPE CHARACTERISTICS

Aperture	1.22-m (48 inches)
Focal Ratio	f/20
Focal Length	24.5-m (967 inches)
Type	Conventional Cassegrain
Instrument Working Distance	28 cm (11 inches)
Optical Quality	5 x Diffraction Limit
Primary Support	Air Bag - Axial
	Mercury Belt - Radial
Secondary	Remote Focus Drive
Thermal Control	Invar Rods
Instrumentation:	
a) AMTA* - Type	LWIR (25 Ge:Cd Detectors)
- Bandpass (7 Filter Selections)	3-21 μm
- FOV (of array)	114″ x 114″ (diagonal meas.)
b) CMP** - Type	Visible
- Bandpass (5 Filter Selections)	0.38 - 0.70 μm
- FOV (5 Selectable)	10″ to 160″
- Sensitivity	+ 15 M_v
c) Boresight	
TV - Type	ISIT
- Bandpass	0.38 - 0.70 μm
- FOV	90″
- Sensitivity	+ 14 M_v

Note: Simultaneous operation achieved by use of dichroic beamsplitter and selectable pellicles.

*Advanced Multicolor Tracker for AMOS
**Contrast Mode Photometer

The following presents a brief background and description of the tasks.

Automatic Blackbody Calibration Fixture

One method used to calibrate an LWIR sensor which is mounted on a large aperture telescope focused for infinity is the "Jones" method. The method involves placing a blackbody source near the entrance aperture of the telescope to flood the detector. The resulting flux density incident at the detector plane can, with reasonable error bounds, be easily determined. The AMOS LWIR sensors have always used the "Jones" method for calibration. Initially, the blackbody had to be manually put in place each time the system was calibrated, prior to or immediately after a mission. The technique was cumbersome, time-consuming, and, additionally, it immobilized the telescope for a period of ~30 minutes for the setup and calibration. For these reasons, the blackbody fixture upgrade was undertaken.

The task included the design, fabrication and installation of a blackbody calibration fixture which is permanently installed on the b = 29 telescope and is remotely controlled, so that the LWIR sensor can be calibrated at any time, even during a mission, without interferring with any other mission-related activity. Tests conducted using the "Jones" calibration fixture indicate that it performs as designed and yields calibration data consistent with data acquired in the previous configuration. The fixture allows calibration of the AMTA LWIR sensor by one man without immobilizing the mount. The calibration can easily be accomplished in about five minutes.

Z-Axis Display Modification

Scan modulation renders the AMTA Z-axis display, which was provided with the system by the Hughes Aircraft Company (HAC), useless in any mode (see Reference 3 for details). As a consequence, operator display in the toggle-mode configuration was limited to four synchronous amplifier channels which are adjusted manually to null the scan modulation and provide a zero dc offset. Maintaining a zero dc offset during a mission, particularly when changing filters, proved to be an extremely difficult task for the AMTA operator and provided the primary impetus for the display upgrade.

The task included the modification of the HAC Z-axis display signal processing, to make it compatible with the toggle mode, and the fabrication of 25 channels of automatic scan modulation null circuitry to reduce the scan modulation to the point where the Z-axis display sensitivity is not limited by the amplitude of the scan modulation.

Limiting sensitivity tests using the modified Z-axis display were conducted and the results indicate that the scan modulation is now reduced to within a factor of 2 of statistical G-R noise. This is a reduction in some cases of more than two decades. Renulling detector outputs when switching filters is now routine, and the operator can maintain track throughout a filter-switching sequence.

AMTA Data Processing

During Phase II, a computerized technique for generating magnetic tape containing a digital record of AMTA data, as well as various housekeeping parameters, e.g., time, filter position and mirror state, was developed. Software written to process the digitized data proved to be inadequate, and consequently the task to complete the software was undertaken during Phase III. The main program developed was TOGLPLOT. This program processes data from an AMTA digital data tape and displays the result on the plotter. The basic plot is a function of detector output vs time, with a time scale of 10 sec/inch. The function may be any one of the following four choices:

1. Difference voltage (mirror state 1-mirror state 0), smoothed by an N-point sliding average and a second-order Butterworth low pass filter, and biased by the complement of the filtered result for the first N points.

2. Function 1 times inverse responsivity; i.e., irradiance at the telescope entrance aperture.

3. Function 2 divided by atmospheric transmission - exoatmospheric irradiance.

4. Function 3 times square of slant range - target radiant intensity.

Responsivity as a function of filter number and detector number is provided by programs JONES. Transmission as a function of filter and elevation is computed from a user-supplied state vector by integration to the data time with PROPY and coordinate transformation with XFORM5. The scale factor for the ordinate axis is automatically determined by the plotting subroutine, YVST. Filter wheel changes are detected and cause suitable reinitialization of the plot, filters and bias. Plots may be up to 320 sec long. User control of program options is via punched cards.

Recording dc Detector Outputs

In 1973, a demonstration showed that the apparent radiance of a clear sky can be determined using the AMTA detector dc outputs. It was proposed during Phase III that such measurements might develop into a technique for estimating attenuation in realtime because radiance and transmission are related, albeit in a complicated way. In June of 1975, authorization was given to develop hardware capable of recording the dc output for any ten of the twenty-five AMTA detector channels with sufficient resolution to permit observing a 0.07 air mass change in the 10-20 μm band and 0.1 air mass in the 3-5 μm band.

The hardware was developed at the Avco Everett facility, delivered to AMOS in December of 1975, and integrated into the AMTA system. The delivered hardware provides the capability for recording the dc detector output, in addition to long term averaging of the detector ac output.

Additionally, the hardware provides for the recording of the detector bias voltage, filter number, universal time and a typed-in initializing statement which identifies the mission name, date and detector channel assignments. Proof of concept experiments were conducted early in 1976[5] which verified the hardware capabilities. The integrated system is now used routinely in support of AMOS missions and IR atmospheric studies.

Gas Lines

The AMTA sensor utilizes a cryogenic system which uses gaseous helium as the working fluid. The stainless steel bellows gas lines originally supplied with the system were too large and not sufficiently flexible to be routed through the telescope axes. Instead, the lines had to be run through an opening in the dome floor and draped from a point where the polar axis intersects the declination axis housing. Attaching the gas lines at this point does not affect telescope balance, however, in certain mount configurations, the lines interfere with telescope tracking. Additionally, the stainless steel lines were difficult for the dome operator to handle and were subject to fatigue fracture causing gas leaks and system downtime. For these reasons the gas line upgrade task was undertaken.

The task included replacement of the stainless steel lines with PVC tubing and the verification of its satisfactory performance. It was also the intent to route the PVC lines through the telescope axes to minimize interference with telescope tracking. This aspect of the task was not completed, due to insufficient room in the telescope axes. The lines still remain in the draped configuration; however, they are considerably more flexible and easier handled such that interference with telescope tracking has been minimized. Downtime of the system due to gas leakage has been eliminated.

2.1.3.2 Contrast Mode Photometer

Background

Early in the Phase III contract, AMOS near-term plans required establishing the capability for routinely observing satellites simultaneously by self-emitted and reflected radiation. The AMTA sensor installed on the 1.2-m, b = 29 telescope provided the capability for routinely measuring the self-emitted radiation, while a photometer mounted on the 1.2-m, b = 30 provided the capability for measuring the reflected radiation. As a consequence of strabismus and static misalignment of the two 1.2-m telescopes, it was not possible to achieve the simultaneous measurement capability. An interim photometric sensor (the b = 29 photometer, [1]), developed to provide AMOS with a continuing photometric capability during the b = 30 telescope conversion, was capable of simultaneous operation with the AMTA but not on a routine basis.

In an effort to provide a truly routine simultaneous photometric and radiometric capability, it was decided to develop a new photometer which would mount on the 1.2-m b = 29 telescope and share the visible beam with the AMTA boresight TV camera. Although sufficient sensitivity for deep space measurements was desirable for this instrument, such capability was the objective of a separate development. Deep space photometric observations allow an observer to wait for low background conditions, whereas nearby objects of current interest must frequently be observed during twilight or with an unfavorable moon. Since the bulk of AMOS observations are made with the sky background between +20 and +16 M_v/arcsec^2, contrast mode photometry was selected to provide continuum rejection.

System Description

The Contrast Mode Photometer (CMP) is designed to simultaneously share the 1.2-m, b = 29 telescope beam with the AMTA LWIR sensor. A schematic of the CMP telescope mounted sensor package is shown in Figure 3. The sensor utilizes two uncooled, magnetically focused EMI 9658A (S-20R) photomultiplier tubes. A specially designed chopper/aperture wheel combination (Figure 4) located at the image plane of the AMTA relay optics is arranged such that one of the PMT's receives the reflected beam, the other the transmitted beam. In this configuration, both PMT's see identical background but view the target on alternate segments of the chopper. This dual channel capability provides a $\sqrt{2}$ improvement in signal/noise over a single channel system and, additionally, provides a mechanism for parity check. The two PMT channels can also be operated individually, each with a different spectral filter option, which allows simultaneous two-color measurements to be made. The sensor also has polarization diversity, neutral density filter and FOV options, all remotely programmable from the control console. The beamsplitter provides several options for splitting the visible beam between the boresight TV and CMP.

The principal features of the Contrast Mode Photometer (CMP) are given in Table 4. These features are intended to provide the CMP with the capability of measuring a target's spectral, temporal, polarization and brightness characteristics under varying background conditions without necessity to purposely mistrack to acquire background data.

Performance estimate curves for the CMP are shown in Figure 5. A measured performance point, shown on the figure, indicates that the system is about one stellar magnitude from achieving the estimated performance. The reduced performance is attributed to a less than estimated optical transmission.

The CMP is operational and routinely supports MOTIF missions. An interim computer data handling capability has been developed which allows CMP data to be processed, formatted and transmitted to SDC upon request.

2.1.3.3 Video/Imaging Systems

At the start of the AMOS Phase III Program, the video sensors used on the two 1.2-m telescopes were older cameras which were not representative of the current state of video technology. The AMTA visual boresight

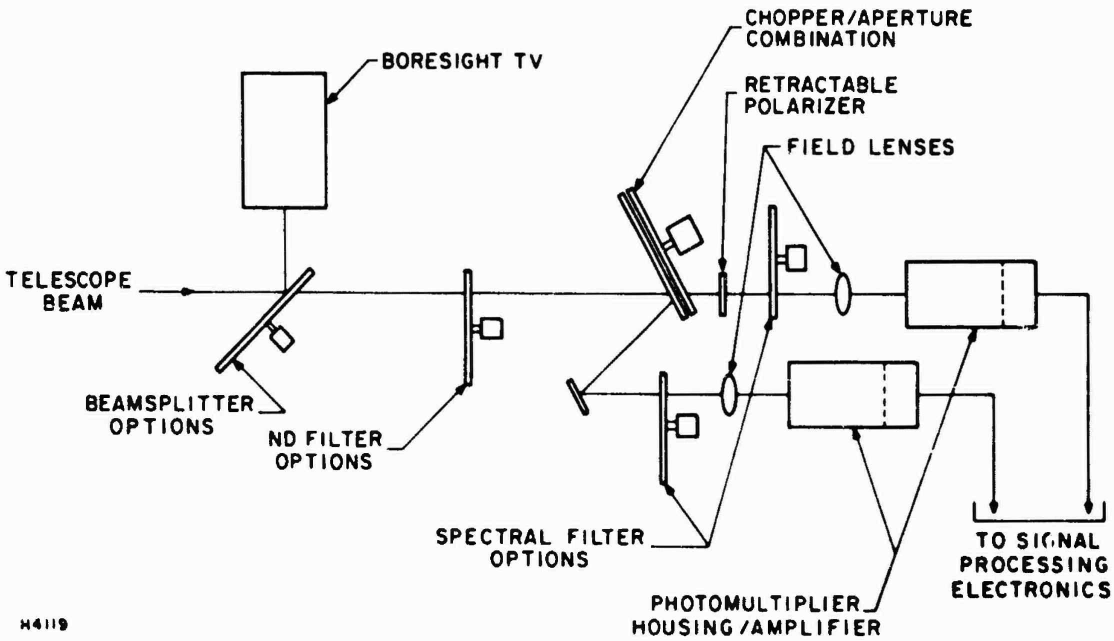
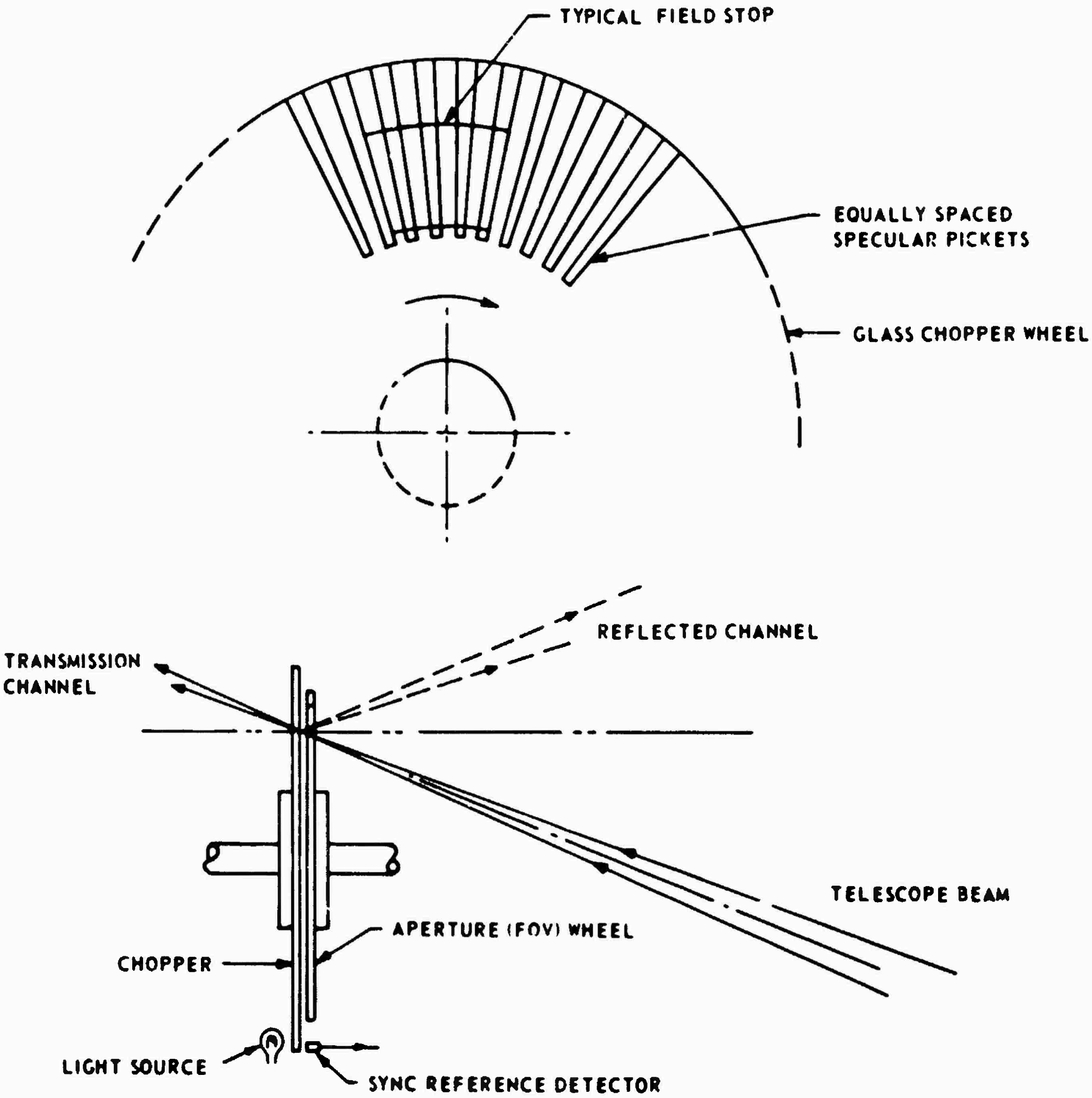


Figure 3 Contrast Mode Photometer Layout



E4342-1

Figure 4 Chopper/Aperture Wheel Combination

TABLE 4

PRINCIPAL CONTRAST MODE PHOTOMETER FEATURES

1. Contrast mode operation with specially designed chopper/aperture wheel to provide high background rejection.
2. Dual, uncooled, magnetically focused, EMI 9658A (S-20R) photomultipliers to achieve maximum efficiency.
3. Simultaneous two-color capability, including UBV measurements.
4. Polarization analyzer.
5. Variable field-of-view in binary steps from 10 arcsec to 160 arcsec.
6. Dynamic range of $\sim 10^8$ (20 stellar magnitudes) utilizing pulse mode operation, augmented by use of neutral density filters.
7. Variable data rate (chopper frequency) to 1 kHz maximum.
8. All system functions controllable from control console.
9. Analog, digital and strip chart recorder outputs provided.

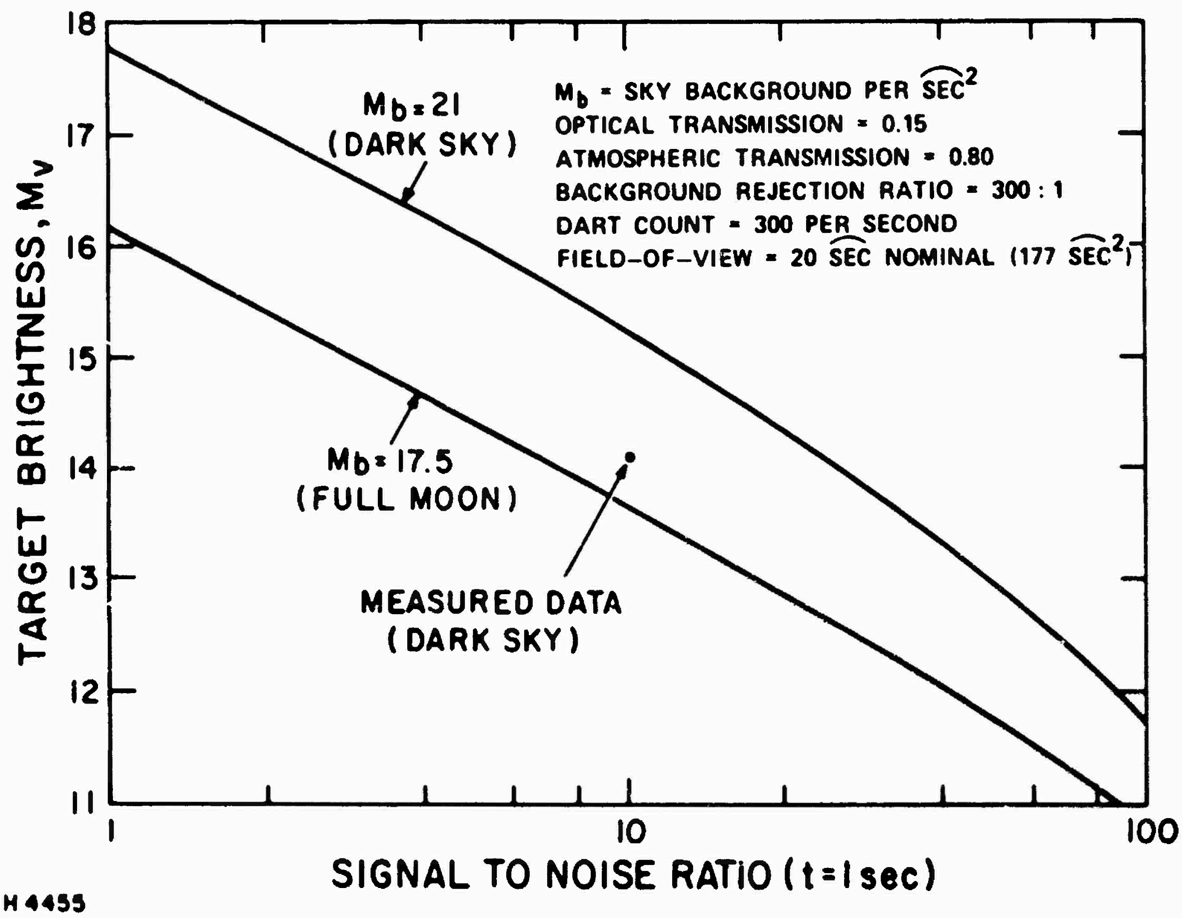


Figure 5 Contrast Mode Photometer Performance Estimate

camera was an Intensified Image Isocon camera which had significantly deteriorated from its original performance. The b = 30 telescope (prior to modification to b = 37) contained the Interim Visible Sensor Package (IVSP), which used two video cameras, an Image Isocon and a Plumbicon. The 18.6-inch finder telescope was equipped with an Image Orthicon camera.

All these cameras had sensitivity limitations which prevented AMOS from observing and tracking faint satellites. To correct this deficiency in sensitivity, AERL procured a number of new, modern video cameras. A COHU SIT camera was procured as a boresight TV for the Teal Blue sensor, but was used on an interim basis as the AMTA visual boresight TV. This resulted in a marked improvement in the ability to track faint targets with AMTA.

A COHU ISIT camera was procured for the Laser Beam Director. When the Beam Director was temporarily removed from operation, this ISIT camera was moved to the b = 29 telescope as the AMTA visual boresight TV. This provided further improvement in sensitivity for this telescope.

The IVSP was removed from the b = 30 telescope when the optical conversion to b = 37 took place. This package was succeeded by the Interim Low-Light-Level TV package which uses the Quantex QX-10 Integrating Digital TV Camera originally procured for supporting the SAMSO Evaluation Program in 1976. This camera has provided an enormous gain in sensitivity over previous TV sensors and is now the most sensitive TV camera in the AMOS inventory.

The 18.6-inch finder telescope is still equipped with an older Image Orthcon camera; however, the new acquisition telescope being built for AMOS will replace the 18.6-inch telescope and will be equipped with a Quantex QX-11 large format (40 mm) Integrating Digital TV camera, which represents the best that current video technology has to offer.

No new photographic imaging capability was added to the 1.2-m mount during this period. Some classical photography was done on a sporadic basis, but the reduced requirement for imaging on resolved targets with this mount did not warrant additional developments. Existing cine or single frame cameras were employed as necessary.

2.1.4 Support Systems

2.1.4.1 Dome Azimuth and Windscreen Drive Upgrade

The original drive systems for the dome azimuth and windscreen were designed, fabricated and installed as part of the Rohr Corporation subcontract for the Observatory domes. These systems exhibited a great deal of vibration, adverse effects on the Observatory power system, bothersome maintenance characteristics, and severe reliability problems. All of the above, coupled with ten years of obsolescence, prompted the dome upgrade program.

The dome upgrade task was initiated with an evaluation and test of the existing system. This involved an independent consultant, Mr. Ed Sweo of Sweo Engineering, who spent four days on site. Results of the tests and evaluations showed the following:

1. The existing drive sprockets did not mesh well with the chain due, primarily, to the out-of-round condition of the dome. This condition caused rough operation (vibration) and could develop fatigue failures in components due to following teeth impacting the chain rollers.

2. Peak motor torque for the existing Fincor system could be up to 10 times the 10 hp rating. These high peak torques, which might occur under sharp command changes, may have caused the persistent mechanical failures.

3. The angled guide rollers carried a significant portion of the vertical load.

4. Measurements were made of the vertical load on each of the 16 support trucks. It was concluded that load varied as the dome was rotated by at least 2:1 on any wheel pair and that truck load variations were most likely due to track level variations.

5. Friction breakaway torque was measured to be 30 lb-ft at the drive sprocket.

6. The existing externally mounted azimuth drive motors represented a severe maintenance problem as well as a personnel safety hazard.

To correct these problems a conceptual design for the upgrade was formulated. The basic concept was a system to drive the wheels that support the dome. Due to the loading characteristics on the existing trucks and the downtime that would be required to modify each truck to add a drive capability, it was decided that adding 8 new 8-inch diameter drive wheels, each spring loaded to give a constant 5000 lb load on the rail, would be the best approach. Each wheel would be driven by a separate 3-hp dc motor with a standard 5:1 right angle gearbox. Motors would be matched and circuitry would be provided to insure load sharing among each of the drive wheels.

To provide commonality of components, similar drive system characteristics and simplification of the circuitry, it was decided that the same type of drive system should be installed for the windscreen.

The above described concepts were formulated into a system specification for procurement. Randtronics, Inc. of Menlo Park, California was selected to supply the basic drive system consisting of a control cabinet containing the azimuth motor controller, windscreen motor controller, isolation transformer, motor matching networks and miscellaneous circuits and contactors; the 8 azimuth motors with 5:1 right angle gearbox assemblies; and the windscreen motor. All necessary interface engineering for this system was accomplished by AMOS site personnel while design and fabrication of the new drive wheel assemblies was done at Everett.

The major hardware components of the dome azimuth and windscreen drive upgrade were installed early in 1976. Upon completing this installation the new system was tested to insure proper operation and the existing Rohr Corporation drive system was then removed. (Since the new hardware could be installed without impacting the existing drive, no operational downtime was incurred.) Operation of the new system showed no adverse effects either on the power line or the equipment during rapid acceleration or deceleration (including reversal from full speed). A marked reduction in the frequency and amplitude of dome induced vibrations has been realized with the system.

The new equipment consists of 8 3-hp dc permanent magnet motors coupled to 5:1 gearbox assemblies (Figure 6), which drive spring loaded steel wheels on a steel hexagonal rail mounted on the top of the dome wall. The motor gearbox assemblies were purchased from Randtronics Incorporated while the wheel assemblies were fabricated at AERL. These 8 units provide the necessary drive power for dome azimuth rotation. The windscreen drive motor (Figure 7) is identical to the azimuth motor without the 5:1 gearbox. All nine motors are equipped with integral tachometers for rate feedback.

Figure 8 shows the Randtronics controller containing both azimuth and windscreen drive electronics. This unit is activated by pushbutton controls located on a pendant box and operates on ± 10 Vdc input signals to generate the azimuth and windscreen drive currents. Control signals can be generated using either a remote control box or switches located on the dome control panel.

The design of the system includes provision for automatic servo control of both dome azimuth and windscreen elevation. A dome servo analog computer receives position information from resolvers attached to each axis of the mount. Required dome azimuth and windscreen positions are calculated and applied to the appropriate drive controller. Position feedback for azimuth is provided by a synchro which is gear drive by the existing dome azimuth chain. A servo potentiometer attached to a cable drum provides windscreen position feedback.

2.1.4.2 Mount Control

Under the Phase II contracts at AMOS, Locked Missiles and Space Co. (LMSC) initiated a mount servo upgrade task at AERL direction. The purpose of this upgrade was the following:

1. Replace obsolete chopper stabilized operational amplifiers with more modern IC's to improve reliability and reduce noise.

2. Repackage servo units from separate 7 ft racks to chasses mounted in the main control console.

3. Add a third servo channel so that each axis has a separate channel (eliminate switching between polar and azimuth).

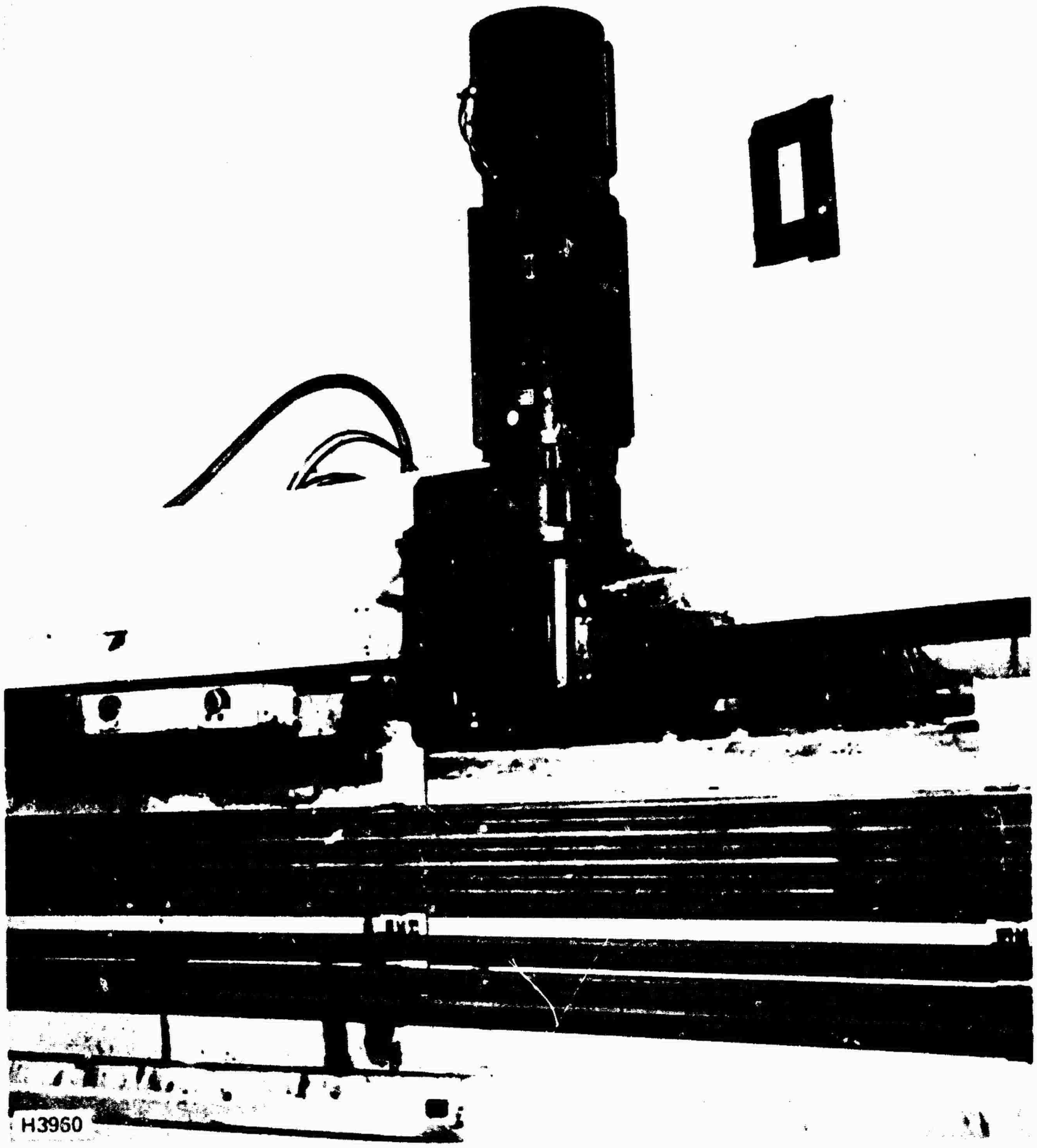


Figure 6 Dome Drive Assemblies, 1.2-m Telescope

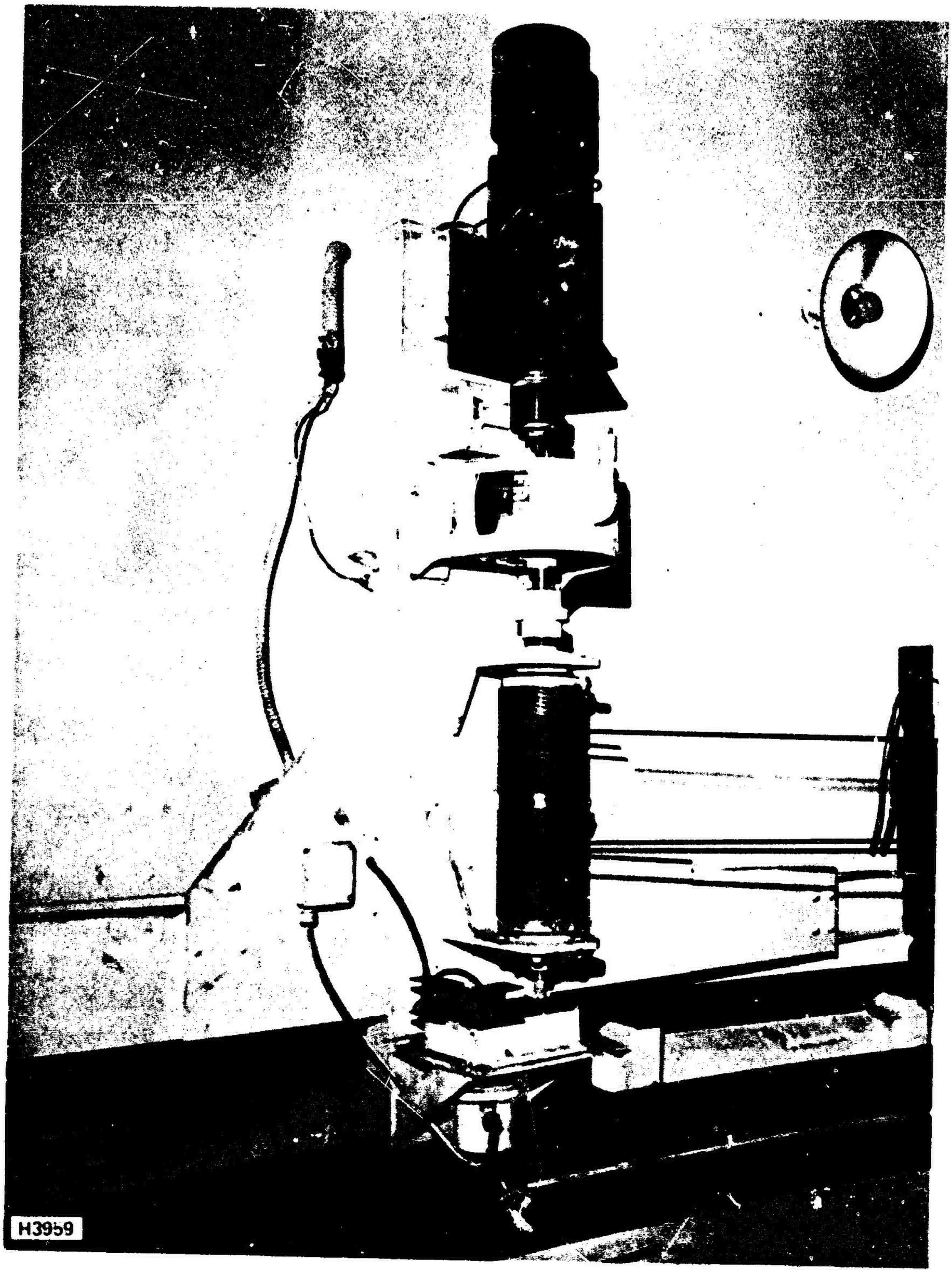


Figure 7 Windscreen Drive Motor, 1.2-m Telescope

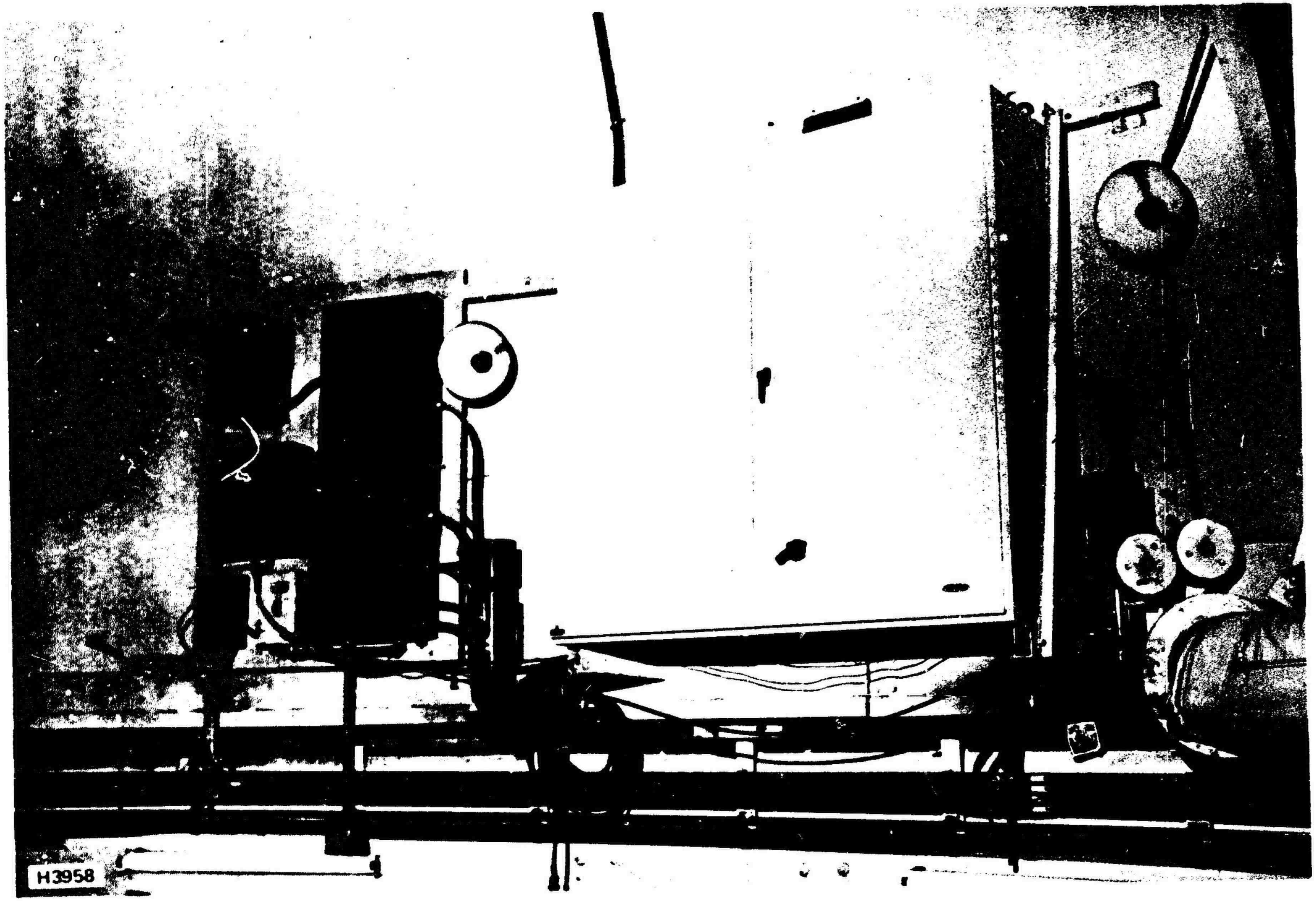


Figure 8 Randtronics Controller, 1.2-m Telescope

4. Eliminate poor grounding practices which were prevalent in the old servo.

5. Allow space for expansion and modification.

6. Attempt to achieve some measure of improved bandwidth performance to help combat the wind gust problem without necessitating a major redesign of the system.

This upgrade was started but was not completed due to work priority conflicts. It therefore carried over to the Phase III contract.

In addition, the mount control system did not preclude runaway motion which could potentially damage the telescope or sensor equipment. Consequently, a system of fail-safe mechanical and electrical stops had to be added to improve safety. This task was added to the mount control upgrade.

Figure 9 shows the basic block diagram of each channel of the servo for computer mode. The dashed lines define the portion of the servo involved in the upgrade. With three major exceptions, this section was rebuilt with more modern components to be identical to the old servo. The first was the addition of differential buffer amplifiers for all inputs to provide ground loop isolation. The second was the inclusion of the tachometer loop for both coarse and fine track modes, along with a slight change in the tach filter characteristics. (The tachometer loop was disconnected for fine track mode in the old system.) Third was the addition of a velocity feedforward signal from the computer.

The new servo chassis was built to allow for expansion by adding spare buffer amplifiers and spare input output calbes/connectors. Figure 10 shows a photograph of the new servo chassis. The meters on the front panel are meter-relays which serve dual purpose of indicating input voltage as well as providing the necessary switch between fine track and course track servo modes. The rotary switches shown allow test point selection for ease of troubleshooting.

An electrical emergency stop has been added to the servo loop for each axis. When activated, it applies maximum reverse torque for as long as the tachometer signals that the axis is moving. This condition remains active until manually turned off by an operator.

The fail-safe feature was implemented by the addition of shock absorbers on the polar and declination axes. Figure 11 shows the installation on the 1.2-m telescope mount. The stops permit motion of $\pm$ 85° from 0° about the polar axis; the declination axes can rotate from $+\bar{1}10°$ to -40°.

2.1.4.3 Balance System for 1.2-m Telescope

Since their original installation in 1965, both 1.2-m telescopes have undergone major modifications including structural changes to the secondary

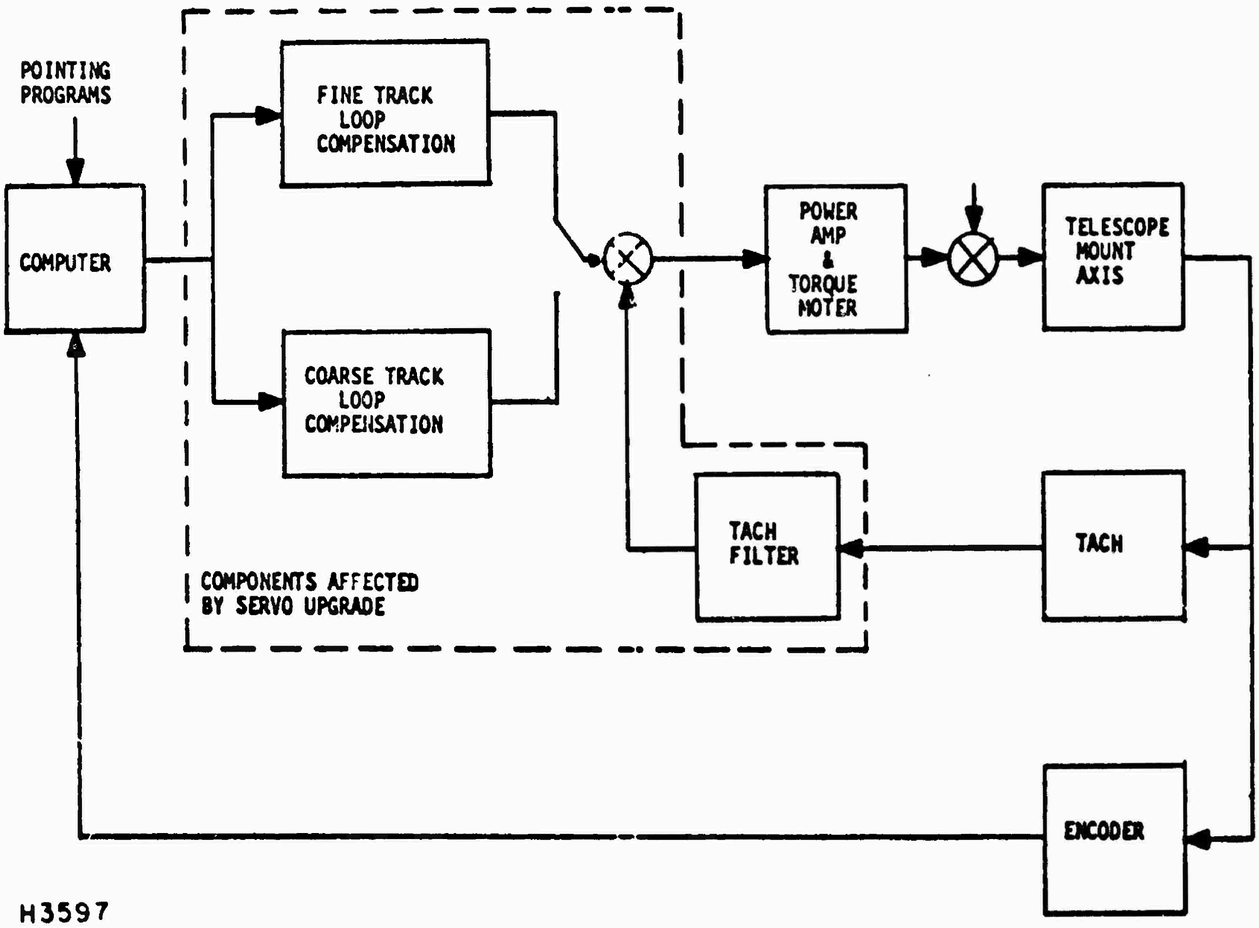


Figure 9 Simplified Servo Block Diagram

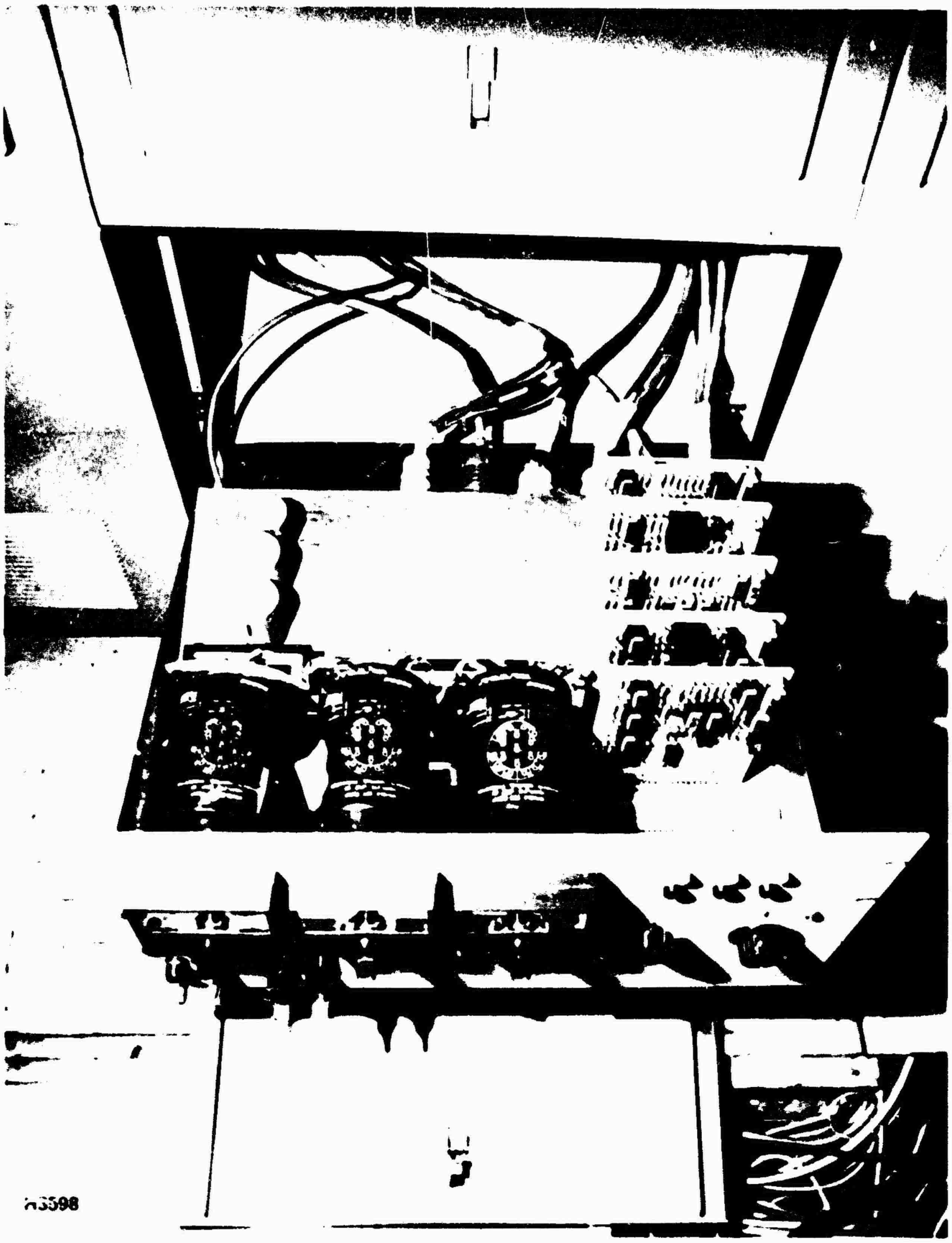


Figure 10 New Servo Chassis

Figure 11 Shock Absorber Stops on 1.2-m Mount

mirror supports to effect new focal lengths. Following each modification the mount was rebalanced to compensate moments about the declination axis. However, based on available records, it appears that little attention was given to the independent balance of each individual telescope. Since both telescopes are coupled to a common declination axis, moments could be compensated by adding weight to either telescope.

An analysis was performed in late 1975 to determine the weight and balance condition of each telescope individually (by uncoupling the declination axis). It was found that, neglecting instruments and sensor systems, both telescopes were front heavy with uncompensated moments (about the declination axis) as follows:

b = 29: 43,739 lb-inch

b = 37: 28,487 lb-inch

Until this time, large lead blocks had been bolted to the rear Blanchard instrument mounting surface to balance the system. The surface was not large enough, however, to accommodate planned instrument packages along with the weights now required to independently balance the telescopes. Consequently, a decision was made to design, procure/fabricate and install a new weight system that could accomplish the required balance without using instrument mounting space.

The design utilizes molded lead weights and special weight brackets. The mold was fabricated and the weights cast onsite (sufficient lead was already in the AMOS inventory). The brackets were fabricated by Carter Company, Inc. of Honolulu and delivered to the site in March 1976.

The weights, when installed on the telescope (see Figure 12), no longer utilize space on the rear Blanchard instrument surface. Each weight is ~35 lbs and, therefore, easier and safer to handle. Both the weights and the brackets have multiple mounting holes making it a straightforward and relatively simple task to add, delete or rearrange weights as required. This weight scheme also achieves the main goal of allowing an independent telescope balance.

Tests were performed on the declination axis coupling following the independent balance effort. The tests showed that the coupling had been the source of a persistently observed 7-Hz oscillation in telescope pointing. The aforementioned out of balance condition, with its resultant torsional moment, had acted as a driving force to set up the oscillation. The tests further indicated that servo performance, in terms of the 7-Hz oscillation, was very sensitive to the coupling adjustment.

Now with proper independent balance and coupling adjustment, the oscillation has been eliminated as a source of tracking jitter.

2.1.4.4 Beamsteering and Optical Alignment

A Beamsteering/Optical Alignment system was developed and implemented for the AMCS 1.2-m twin telescopes. The system performs two

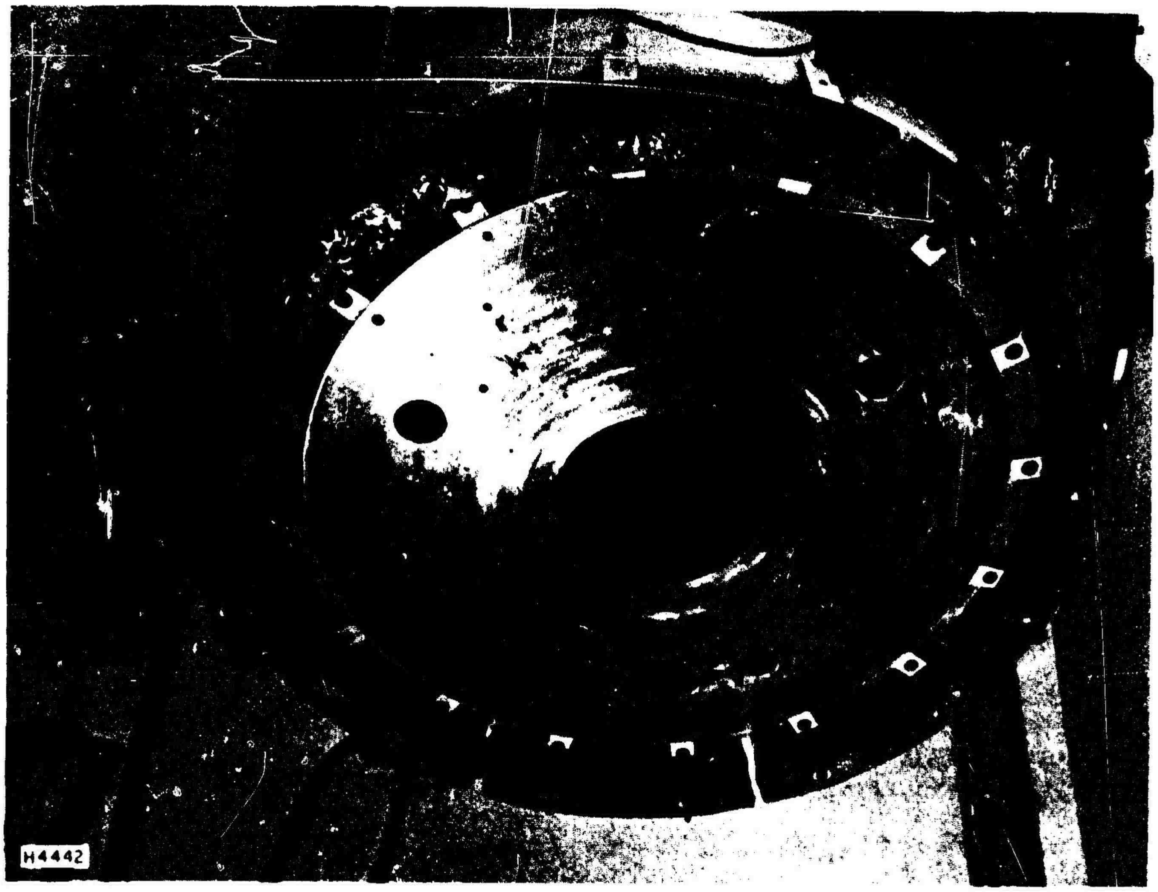


Figure 12 b = 37 Telescope Balance Weights major functions: 1) Allows simultaneous observation of the same field-of-view by the b = 29 and b = 37 telescopes by eliminating the strabismus (decollimation) errors between the two telescopes, and 2) Stabilizes target images on the b = 37 side (used for LLTV missions) in the presence of disturbance torques such as those caused by wind buffeting.

The strabismus corrections are made by dynamically aligning the b = 37 telescope optical axis to the b = 29. This alignment is performed via servo controlled tilt of the b = 37 secondary mirror. Detection of the strabismus error is accomplished by a realtime comparison of the mount models for the two telescopes. A second, higher speed servo system corrects pointing error in the b = 37 telescope due to the influence of external torque disturbances. This second system utilizes piezoelectric drive elements and derives its input command from the computer-generated mount position error signals.

The dynamic collimation errors between the lines of sight for the twin telescopes have been measured to be as high as $\pm$ 1.5 arcmin. The correction of pointing errors of this magnitude by secondary mirror tilts of a Cassegrain telescope can pose serious optical problems. Due to the demagnification effects of the secondary mirror, a physical tilt on the order of three to four times the required focal plane movement is necessary. Pure mirror tilts of this magnitude would introduce objectionable amounts of coma into the telescope image. Lateral translation of the secondary mirror also introduces coma while only slightly influencing the pointing position. The system design provides for a combination of both tilt and a counter-acting lateral shift to the secondary mirror to eliminate the possibility of introducing coma into the telescope system.

An AERL analysis of the b = 34 telescope showed that one wave of coma is introduced into the telescope by either 2.7 arcmin (0.000785 radian) of tilt or 0.022 inch of decentration. By applying equivalent amounts of coma (but of opposite sign) through a combination tilt and decenter movement, coma is cancelled. This movement can be achieved by rotation of the secondary mirror through an arc with a radius of 0.022 inch/ 0.000785 rads or 28 inches. The center of rotation turns out to be located slightly forward of the focus of the f/3 primary mirror.

The amount of secondary mirror tilt required to achieve a given focal plane movement is 4.3 arcmin/arcmin. A motor driven mechanical system was designed which provides the required motion with a focal plane dynamic range of $\pm$ 2 arcmin. The system uses dc servo motors with followup pots. The motion which corrects the collimation error between the b = 29 and b = 37 telescopes is connected in mechanical series with a faster responding piezoelectric drive system used for correction of disturbance torques. The piezoelectric system provides a focal plane movement of $\pm$ 10 arcsec.

As mentioned earlier, the drive for the piezoelectric correction is taken from the telescope servo error signal. Proper correction of the polar pointing errors requires they be modified by a cosine function of the declination angle. An analog cosine function pot has been coupled to the 1.2-m declination axis for this purpose.

A mechanical drawing of the system is shown in Figure 13. Care has been taken to mass balance the system mechanically to reduce required drive forces and minimize flexure with variations in telescope attitude. Symmetrical piezoelectric stacks are also used to eliminate pointing errors which could be introduced by thermal expansion.

Figure 14 shows a photograph of the completed system as it is mounted and as it supports the b = 37 telescope secondary mirror. The amplifiers and power supplies which provide the required drive (± 500 V) for the piezoelectric elements are mounted to the declination housing of the same telescope.

A simplified functional block diagram of the total system is shown in Figure 15. The strabismus correction requires two accurate telescope mount models (one for the b = 29 and one for the b = 37), which are computer compared to provide an analog polar and declination error voltage. This is used to drive the servo motors, which, in turn, position the b = 37 secondary mirror. Linearity of the system is assured through use of direct coupled, highly accurate followup potentiometers. In a similar manner, the voltages which drive the error correcting piezoelectric elements are derived by computer comparison between the telescope pointing commands and the actual telescope position as determined by the axes (polar and declination) encoders. A bias supply causes the telescope pointing to center about zero error when there are no disturbance torques to perturb the mount.

The operational controls for the entire system are housed in a rack panel located in the AMOS control room. These controls permit the system to be disabled for individual use of the twin telescopes or for the purpose of deriving individual mount model parameters. Provisions are also available to step target image positions (in polar and declination) on the b = 37 telescope independently of the b = 29 pointing. A photograph of the control console is provided in Figure 16.

Testing of the system was accomplished in June of 1977 following final installation of the hardware. 98 stellar marks were taken and were used to update the b = 29 and b = 37 parameter file. A sky map made up of 15 randomly selected stars was used to evaluate the following:

1. The absolute pointing of the b = 29 model.

2. The absolute pointing of the b = 37 model.

3. The absolute pointing of the b = 37 telescope, using the b = 29 model with beamsteering.

The covered sky area extended over a polar range of 124° and a declination range of 73° (the new mount safety stops restrict the declination coverage). Prior to initiation of the pointing test, the mount was prepressurized with temperature stabilized oil (which matched the mount temperature within 1°F) for a period of about two hours. The winds varied from 18 to 23 mph during the test. A synposis of the resulting test data is presented in Table 5.

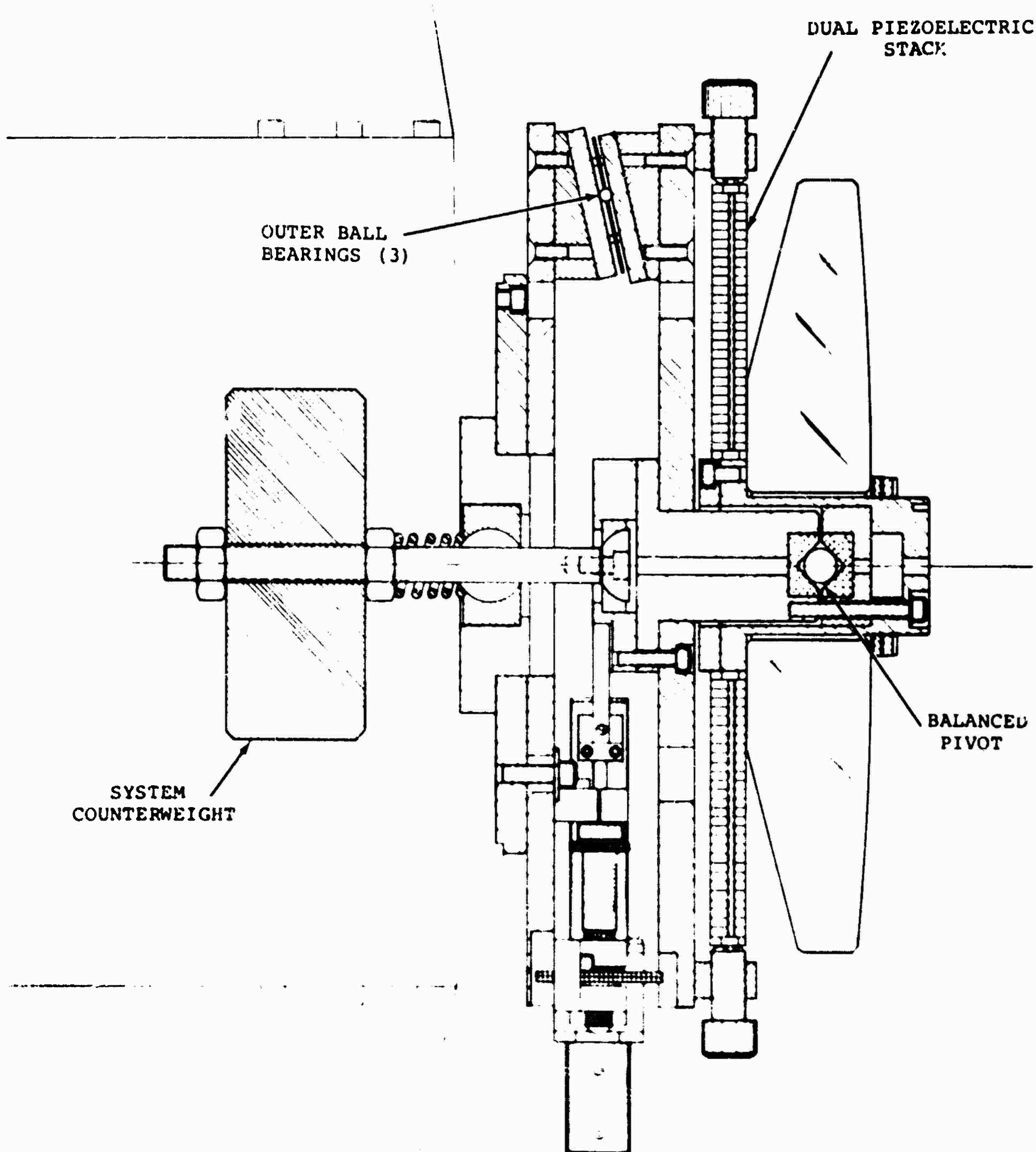


Figure 13 b = 37 Secondary Mirror Mount (Balanced Version)

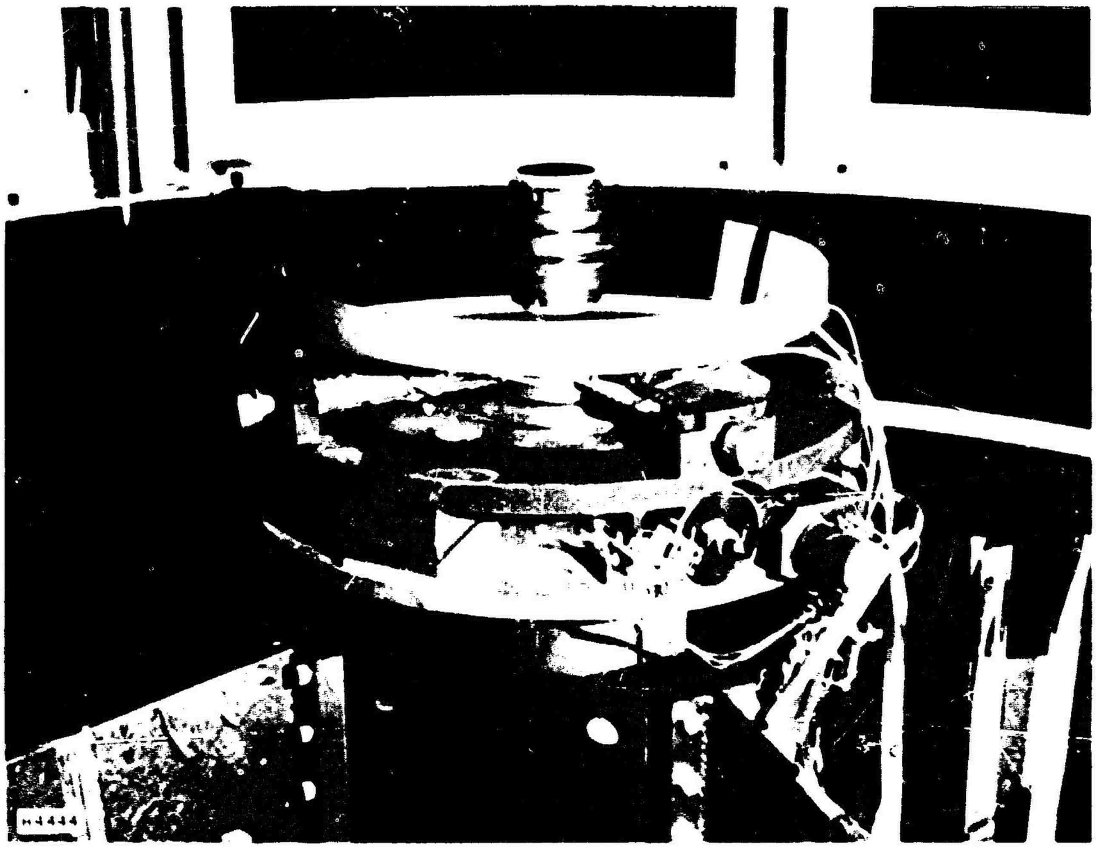


Figure 14   b = 37 Beamsteering System

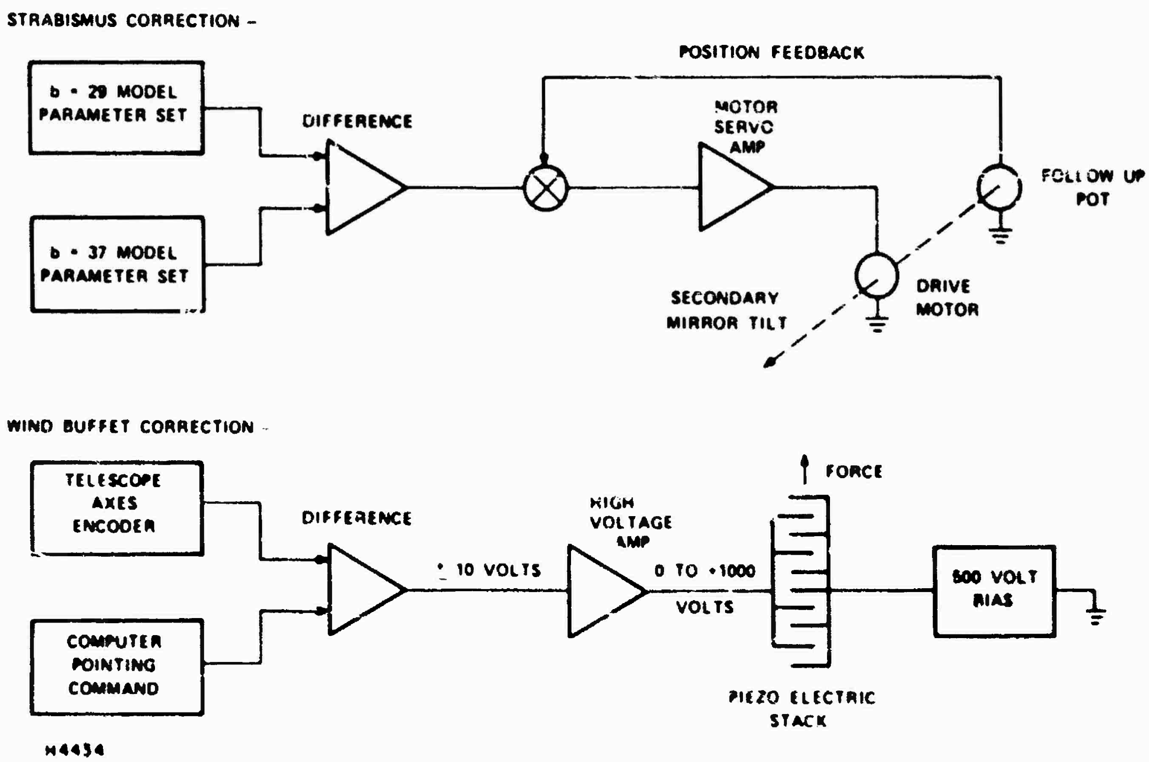
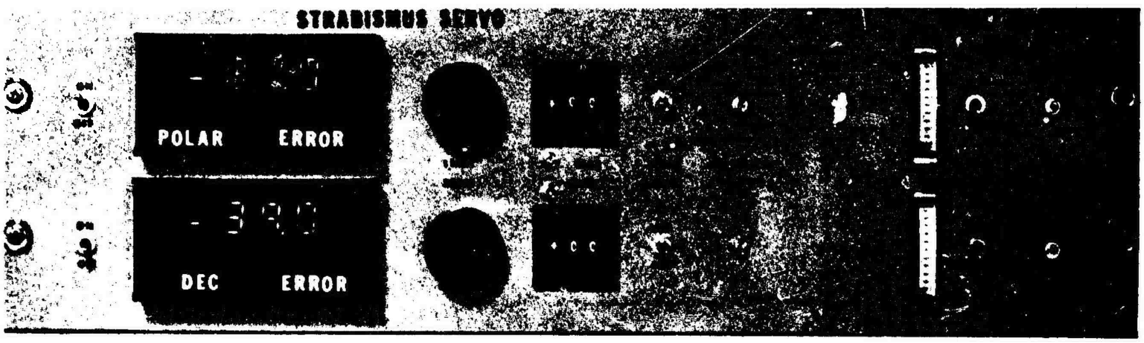


Figure 15 Beamsteering Functional Diagram



H4445

Figure 16 Beamsteering Control Console

TABLE 5

SUMMARY OF 1.2-m TELESCOPE POINTING ERROR
USING A 15 STAR AVERAGE

System Under Test	Average Error in ρ		Average Error in δ	
	bias	rms	bias	rms
Absolute Pointing of b = 29 Model	- 2.86 arcsec	1.64 arcsec	- 0.26 arcsec	1.44 arcsec
Absolute Pointing of b = 37 Model	+ 3.13 arcsec	2.61 arcsec	+ 0.53 arcsec	1.88 arcsec
Absolute Pointing of b = 37 Telescope with Beamsteering	- 5.0 arcsec	1.40 arcsec	- 3.13 arcsec	1.80 arcsec
Pointing of the b = 37 Telescope Relative to b = 29 with Beam-steering (residual strabismus error)	- 2.13 arcsec	1.41 arcsec	- 2.86 arcsec	1.40 arcsec

Table 5 indicates that the rms pointing errors in the b = 37 telescope with the beamsteering in operation are somewhat lower than that with the b = 37 telescope using its <u>own</u> model. This is somewhat surprising, since the voltages used for strabismus correction are derived from the two individual models. In addition, when offset steps are taken to center the star in the b = 29 reticle (as would be done during a mission), the strabismus corrected b = 37 achieves better pointing than the b = 29 model. Nevertheless, the system appears to be functioning properly, exhibiting an overall rms pointing error of < 2 arcsec. The majority of this error can be attributed to the residuals within the original models. The indicated bias of - 5.0 arcsec and - 3.13 arcsec results from the single stellar setup point and could have been eliminated following the 15 observations by resetting the bias offset potentiometers which are located on the strabismus system control panel. Following this adjustment, a rerun of a sufficient number of stars would have indicated a near zero offset; the rms errors would, however, not change.

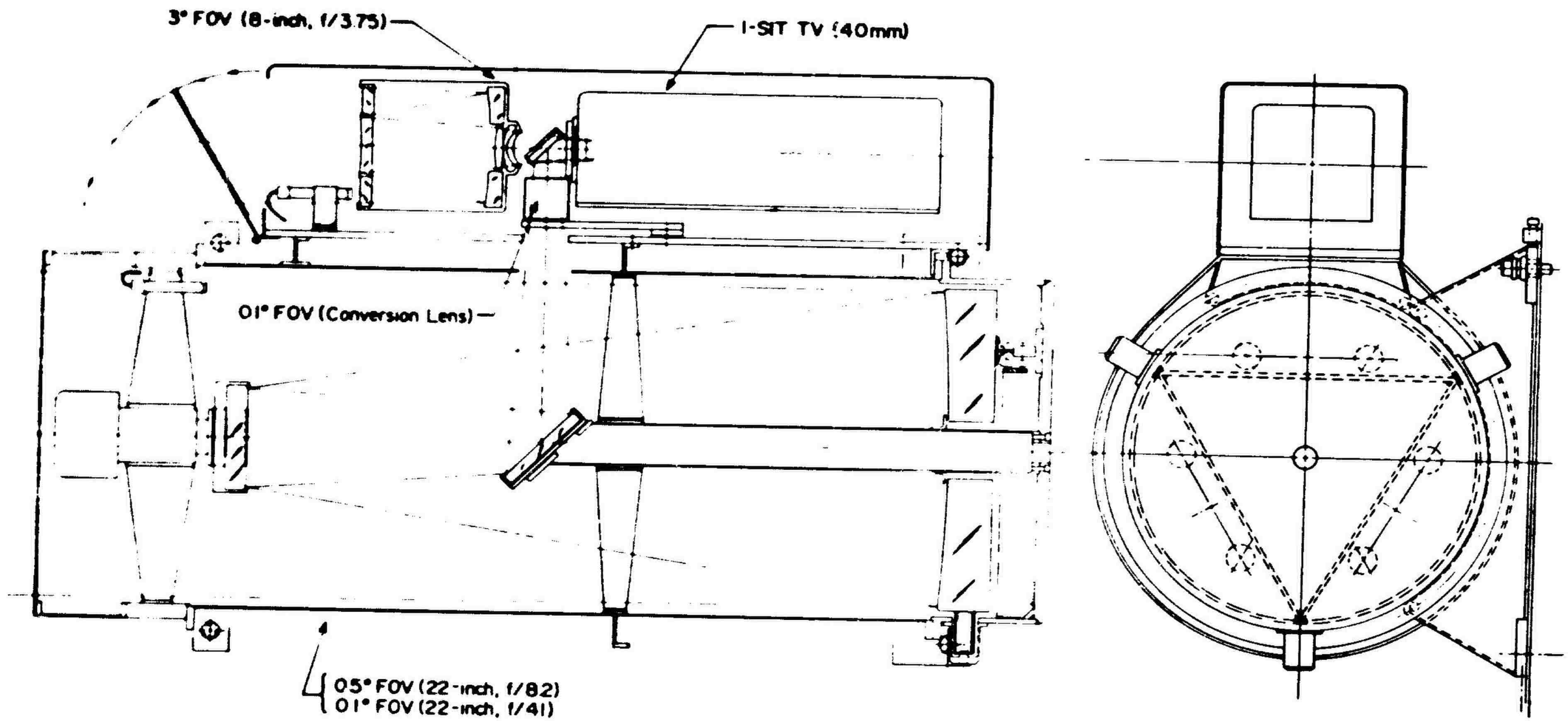
Tests were also performed to evaluate the ability of the wind buffet servo to stabilize optical images in the presence of disturbance torques which are external to the telescope system. A pendulum with a 15-lb weight was attached to the rear Blanchard surface of the b = 37 telescope and caused to swing while the mount was computer tracking a zenith star. The pendulum motion caused the stellar image to oscillate on the photocathode of a TV system which is located at the Cassegrain focus of the b = 37 telescope. Identical oscillations were simultaneously observed on the AMTA TV system located on the b = 29 side of the mount. With the wind buffet servo turned "on" and with the polar and declination corrective amplitudes (see Figure 16) properly adjusted, the image as observed with the b = 37 TV became near motionless, while the b = 29 image continued to oscillate. The frequency response of the system is presently limited to 60 Hz by band limiting the power drive amplifiers. The mechanical resonance of the piezoelectric drive system is above 200 Hz: however, the drive currents become excessive at these higher frequencies. The total beamsteering system is available for use on a routine basis.

2.1.4.5 Acquisition Telescope

The existing 18.6-inch acquisition telescope mounted on the 1.2-m, b = 29 telescope exhibits poor optical performance and low sensitivity. It does not meet the requirements for MOTIF operations and modifications to upgrade it are not feasible. An entirely new system is, therefore, to be provided.

The new system (see Figure 17) will consist of a 22-inch diameter Ritchey-Chretien telescope containing two, switch-selectable fields-of-view (FOV): 0.1° and 0.5°. A separate, 8-inch diameter, catadioptric system will provide a 3° FOV. All three FOV's will image on a single (40 mm diameter) video sensor (ISIT). Switching time between FOV's will be ~ one second. Ancillary systems will include remote controlled filters, shutters, boresight recticles, etc.

The optical system will be provided under a subcontract to Boller & Chivens. Quantex will supply the video system. This capability is scheduled to be operational by March 1978. Detailed performance specifications are shown in Table 6.



H4446

Figure 17 AMOS Acquisition Telescope System for the 1.6-m and 1.2-m Mounts

TABLE 6

AMOS ACQUISITION TELESCOPE SYSTEM PERFORMANCE

0.5^{o} FOV	85% of energy from a solar-type point source to be within a 30 μm diameter spot over the central ± 0.1^{o} (65 μm everywhere else). Throughput to be 0.6 or better. Sensitivity + 16 M_v (goal of + 17) with a dark sky bakcground and + 14 M_v (goal of + 15) with a full moon background. *
0.1^{o} FOV	85% of energy from a solar-type point source to be within 150 μm diameter spot anywhere in the field. Throughput to be 0.45 or better. Sensitivity of + 16 M_v with a dark sky background and + 14 M_v with a full moon background. *
3^{o} FOV	85% of energy from a solar-type point source to be within a 65 μm diameter spot anywhere in the field. Throughput to be 0.65 or better. Sensitivity of + 11 M_v

*Dark sky: + 21 $M_v/arcsec^2$

Full moon: + 17.5 $M_v/arcsec^2$

2.2 1.6-m TELESCOPE SYSTEM

Restoration of the large aperture telescope capability for conduct of research and development activities in optical measurement technology had been initiated in Phase II. Completion of the procurement and the installation, acceptance testing, evaluation and characterization of the 1.6-m telescope system was one of the major long term efforts of Phase III. Its successful accomplishment, in mid-1976, has significantly increased AMOS capabilities and has afforded a number of experimental activities the opportunity to exploit the superior quality of the resultant system.

In the near future the 1.6-m telescope system is to be used for field test of the Compensated Imaging (CI) System, currently under development for DARPA. As a result many of the specific requirements for the system were oriented to its use with CI. Other specifications resulted from prior operating experience, from the desire to provide versatility in the system, or out of concern for reliability, maintainability and safety.

2.2.1 Summary

2.2.1.1 Objectives

The principle objective of the 1.6-m telescope efforts was to provide a system with highest quality optical, mechanical and thermal performance. Recognizing that this telescope would be key to a number of DARPA program initiatives in large scale electro-optical systems, particularly Compensated Imaging, the goal was to provide a system that would not constrain or compromise such applications but, rather, enhance the potential for their success.

Specifications for the telescope called for total system all-attitude performance to be diffraction limited. To achieve this the optical elements, primary and secondary mirrors together, had to meet a $\lambda/25$ (rms) wavefront specification. Mirror support systems and tube stiffness had to assure that tilt and decenter of the optics would not significantly degrade performance at all telescope attitudes for all anticipated tracking rates. Thermal control was required to maintain intermirror spacing and alignment for anticipated temperature variations during operations.

Ancillary systems, such as the dome, windscreen, mount controls and mount balance system required upgrade or redesign to assure that they did not inhibit telescope utilization. Improved reliability, maintainability and operability were the fundamental goals.

Finally, to improve the capability to locate, acquire and establish track on target objects and position them within the limited field-of-view of anticipated sensors, it was necessary to provide an improved acquisition or finder telescope system.

2.2.1.2 Accomplishments

The AMOS 1.6-m aperture telescope is considered to be the finest optical instrument of its size. This system consists of diffraction limited optics installed on a high performance mount capable of angular accelerations of $2^o/sec^2$, absolute pointing to ~ 2 to 3 arcsec and tracking to ~ 1 arcsec rms. The overall system performance throughout this range of operating conditions has been shown to be $\lambda/16$ (rms wavefront error at $\lambda = 6328$ Å).

Versatility is built into the telescope in the form of two instrument mounting surfaces (classical and side Cassegrain) and secondary mirror drive/computer interface hardware to allow correction in realtime for non-infinite target ranges.

Excellent primary mirror support systems (airbag for axial and mercury belt for radial) result in an instrument that maintains its diffraction limited performance over all relevant mount attitudes. INVAR metering rods have been installed between the primary and secondary mirrors to minimize aberrations produced by changes in the ambient thermal environment.

The dome azimuth and windscreen drive system have been replaced by systems which are identical to those used in the 1.2-m dome. These have proven to be highly reliable, easily maintained and have resulted in minimizing induced vibration to the telescope during operation.

The servo control system for the mount has been upgraded, again comparably to the 1.2-m system, and mount safety concerns have resulted in mechanical and electronic systems being added to prevent potentially hazardous mount orientations. A safer, faster and more versatile mount balance system has also been added.

A new acquisition telescope system has been specified and is in the process of being procured. It is scheduled to be installed and operational during the first quarter of 1978.

2.2.2 Telescope Restoration

2.2.2.1 Optical Systems

Detailed specifications[6] for the 1.6-m optics had been prepared during Phase II and a subcontract for providing the system had been awarded to Boller and Chivens (B&C) Division of Perkin-Elmer Corp. Figure 18 is an optical schematic of the system and Table 7 shows relevant system specifications.

A careful evaluation of system requirements, based on anticipated uses, had resulted in the specification of the 1.6-m telescope an an f/16 Cassegrain system with a 25-m focal length, f/2.8 primary mirror, and stringent ($\lambda/25$ rms) requirements on system wavefront performance. Two instrument mounting surfaces, conventional and folded (or side) Cassegrain configurations, were to be provided thus necessitating a tertiary folding mirror.

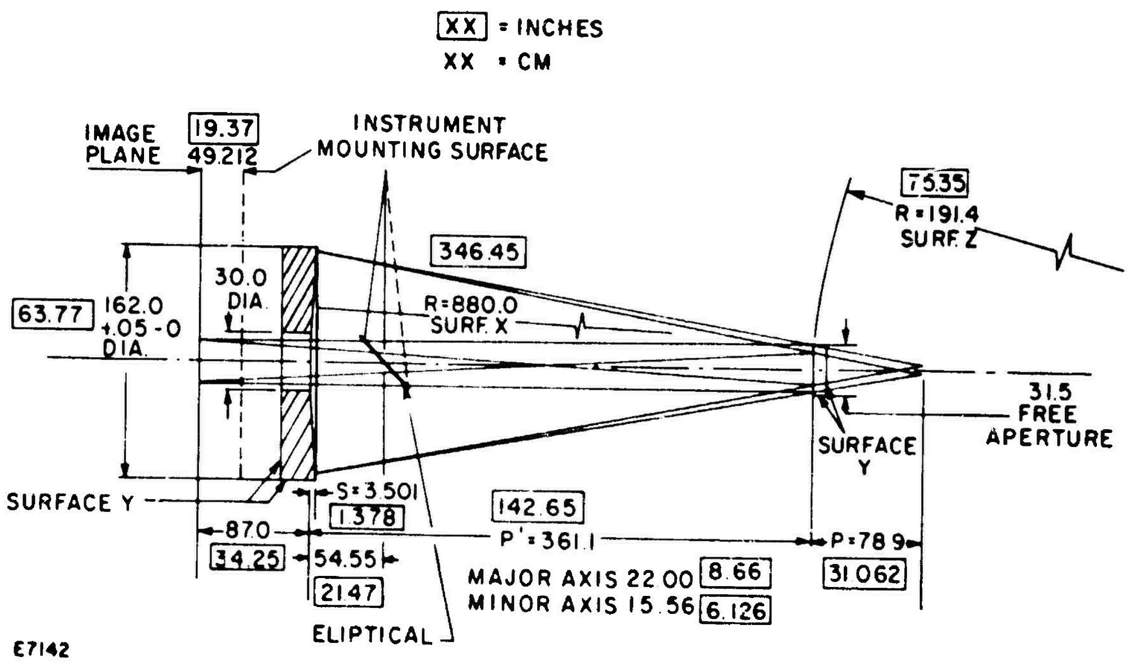


Figure 18 1.6-m Telescope Optical System

TABLE 7

1.6-m TELESCOPE OPTICAL SYSTEM SPECIFICATIONS

<u>Cassegrain System</u>

Clear Aperture	1.57 m (min)
Central Obscuration	36 cm (max)
Effective Focal Length	25 m
Backworking Distance	87 $\pm$ 0.5 cm
Intermirror Spacing	3.61 $\pm$ 0.02 m
Figure Contributions to Wavefront Error	$\leq \lambda/4$ p-v
Random Contributions to Wavefront Error	$\leq \lambda/25$ rms

<u>Primary Mirror (Mounted in Cell)</u>

Material	Premium Grade Cervit
Clear Aperture	1.57 m + 0.5 cm, - 0.0 cm
Focal Length	4.40 $\pm$ 0.02 m
Perforation	30 $\pm$ 0.5 cm
Figure Contributions to Wavefront Error	$\leq \lambda/6$ (zenith to horizon)
Random Contributions to Wavefront Error	$\leq \lambda/30$ (zenith to horizon)
Aluminized and Overcoated	$\simeq$ 0.12 μm SiO
Reflectance	$\geq$ 0.85 for 0.4 $\leq \lambda$ 0.75 μm

<u>Secondary Mirror</u>

Material	Premium Grade Cervit
Clear Aperture	31.5 cm (min)
Wavefront Performance	Mirror (in cell) does not degrade specified Cassegrain system performance
Aluminizing/Overcoating/ Reflectance	Same as primary

<u>Folding Flat Mirror and Cell</u>

Clear Aperture	15.56 $\pm$ 0.05 cm
Wavefront Errors (in cell)	$< \lambda/10$ p-v; $< \lambda/30$ rms
Aluminizing/Overcoating/ Reflectance	Same as primary (45° incidence)

To allow system testing during fabrication and to give AMOS the capability for on site optical testing of all its major telescope systems, a 1.6-m test flat was also to be provided with the system. The specification for surface figure of the flat called for λ/40 rms wavefront error.

The figure specifications for the mirrors, along with all-attitude performance specifications to be discussed later, clearly required extraordinary effort on the part of the B&C optician. It also mandated a continuing conscientious test effort to ensure that performance specifications could be met. A series of inprocess tests, at each critical process step, had been included in the B&C work statement. In the final analysis, the tests turned out to be the most difficult milestones to achieve.

Two factors contributed to testing difficulties. First, since specifications for the optics were so stringent, usual techniques for measuring the critical parameter were inadequate - they could not provide sufficient accuracy. Second, test procedures had to be carefully developed and followed or minor influences, like stratification of air in the test chamber, would distort results. To ensure that results were meaningful, multiple tests were required to show repeatability of the data. These measures were taken to reduce the possibility of a problem first appearing when the system was installed at AMOS and far removed from the point of fabrication. As a result the test program became the most critical aspect of the system procurement.

Once all the optics were figured and tested to show performance requirements could be achieved, the aluminizing and SiO overcoating had to be accomplished. This, too, presented a challenge since both maintaining figure and providing specified coating parameters (thickness, reflectance and broadband performance) for optical elements as large as the 1.6-m could not be done by routine techniques. AERL, working with B&C and Palomar (where the large elements were coated) personnel, generated technique improvements which resulted in successful accomplishment of the aluminizing and SiO overcoating.

In early 1976 Preliminary Acceptance Testing at B&C of the Cassegrain system was completed. A review of all inprocess test results, along with the system test results showed that all specifications had basically been met. Principle differences were: the 1.6-m test flat was slightly below wavefront performance requirements (λ/36 vice λ/40); reflectances of the primary and test flat were approximately 5% low at 7000 Å (the secondary was better than specified so the system met specifications); and overcoating thickness was not achieved on the 2 small mirrors. The telescope system, which was the most critical, was well within specifications in all cases. Table 8 shows optical parameter acceptance data while Table 9 shows aluminizing and overcoating acceptance data.

2.2.2.2 Mechanical/Support Systems

Along with the new optical systems, a new primary mirror cell and support system, a new secondary mirror cell and focus drive system, the

TABLE 8

ACCEPTANCE DATA SUMMARY
1.6-m OPTICAL SYSTEM

Description	Requirement	Actual
1. Cassegrain Optical System		
Figure Contribution to Wavefront Error	≤ .25 λ p-v	.24 λ p-v
Random Contribution to Wavefront Error	≤ .04 λ rms	.038 λ rms
2. Primary Mirror		
Figure Contribution to Wavefront Error	≤ .167 λ p-v	.164 λ p-v
Random Contribution to Wavefront Error	≤ .033 λ rms	.032 λ rms
3. Secondary Mirror	Figure as Required to meet system performance requirements	.167 λ p-v .021 λ rms
4. Folding Flat		
Reflected Wavefront Error	≤ .10 λ p-v	.093 λ p-v
Random Contributions to Wavefront Error	≤ .033 λ rms	.024 λ rms
5. Autocollimating Flat	.025 λ rms	.028 λ rms

TABLE 9

ACCEPTANCE DATA SUMMARY
1.6-m OPTICAL SYSTEM ALUMINIZING AND OVERCOATING

Description		Requirement	Actual
1.	Primary Mirror		
	A. Overcoat Thickness	0.12 μm	0.12 μm
	B. Spectral Reflectance from 0.4 μm to 0.75 μm for Unpolarized Light	≥ 85%	min. - 83% max. - 90% avg. - 87%
	C. Reflectance Data Out to 22 μm	For information only	min. - 70% max. - 99%
	D. Witness Samples	6 Required	6 Furnished
2.	Secondary Mirror		
	A. Overcoat Thickness	0.12 μm	0.03 μm
	B. Spectral Reflectance from 0.4 μm to 0.75 μm for Unpolarized Light	≥ 85%	min. - 87% max. - 90% avg. - 88%
	C. Reflectance Data Out to 22 μm	For information only	min. - 83% max. - 99%
	D. Witness Samples	2 Required	2 Furnished
3.	Folding Flat		
	A. Overcoat Thickness	0.12 μm	0.03 μm
	B. Spectral Reflectance from 0.4 μm to 0.75 μm for Unpolarized Light at 45° Angle of Incidence	85%	min. - 87% max. - 90% avg. - 88%
	C. Reflectance Data Out to 22 μm	For information only	min. - 83% max. - 99%
	D. Witness Samples	2 Required	2 Furnished

tertiary mirror cell and rotating mechanism and telescope baffles were also subcontracted to Boller and Chivens. Specifications for these items are included in Reference 6.

The goal for these mechanical/support systems can be summarized as maintaining the optical elements so as not to significantly degrade their performance when operated over the full range of relevant telescope attitudes and rates. The overall error budget for the telescope system called for $\lambda/11$ total rms aberration. Since the optics were specified as $\lambda/25$ and all sources were root-sum-squared to derive the total system value, contributions from both tilt and decenter for each element had to be rigidly controlled. Table 10 shows the error budget for the system. It results from specified parameters, calculations and expected performance based on previous experience with similar equipments. It should be emphasized that this budget was "worst case" for all-attitude performance. For any attitude the system could be optimized and provide near to the $\lambda/25$ optics value.

The requirements for primary mirror stability resulted in a rigid weldment mirror cell containing an active pneumatic airbag axial support system and a mercury tube radial support. (The operation of these supports is identical to the 1.2-m system as described in Section 2.1.) The secondary mirror is cell mounted (as opposed to the 1.2-m secondaries which are hub mounted on a central post) with elastomer pads radially and behind the mirror and spring loaded clips to retain the mirror in position.

The secondary mirror drive system is a motorized support which provides 2 drive speeds, along with an electronic readout, to rapidly and accurately set intermirror spacing. This is used to refocus the telescope for noninfinite range targets. An AERL designed interface is used to automatically position the mirror during any mission pass by converting the computer-derived target range to mirror drive commands.

The tertiary mirror is cell mounted on a unique gear driven pivot arrangement, (see Figure 19) which allows the mirror to be rotated from a position parallel to the telescope axis and out of the returning light path from the secondary (dotted position in Figure) to a 45° on-axis location which diverts the beam from the secondary to the side-mounted Blanchard surface, as shown in the Figure. (This rotating mechanism was later motorized by AERL to allow remote positioning of the mirror. As supplied by B&C the mirror was handcrank driven which limited overall flexibility in using the side Blanchard.)

All mirrors, mounted in their respective cells, were given all-attitude testing by B&C early in the program to ensure that the cells, as-built, would meet performance requirements. (Mirrors were generally at a preliminary figuring stage, i.e., spherical - before parabolizing, for this testing.)

The principle telescope baffle is mounted, along with the tertiary mirror support, to the perforation in the primary and extends forward toward the secondary. A short baffle is also mounted to the secondary. The specified performance for the baffle system called for a reduction of scattered

TABLE 10

1.6-m TELESCOPE WAVEFRONT ABERRATION BUDGET

Aberration Source	Aberration (rms)
1. Primary Mirror	λ/30
2. Secondary Mirror	λ/45
3. Cassegrain System	λ/25
4. Primary Mirror Tilt	λ/76
5. Primary Mirror Decenter	λ/19
6. Secondary Mirror Tilt	λ/38
7. Secondary Mirror Decenter	λ/32
8. Tube Flexure (Tilt)	λ/28
9. Tube Flexure (Decenter)	λ/48
Total System (RSS of 3 thru 9)	λ/11

NOTE: If all specifications are achieved, a Strehl factor of 0.67 would be achieved for any telescope attitude.

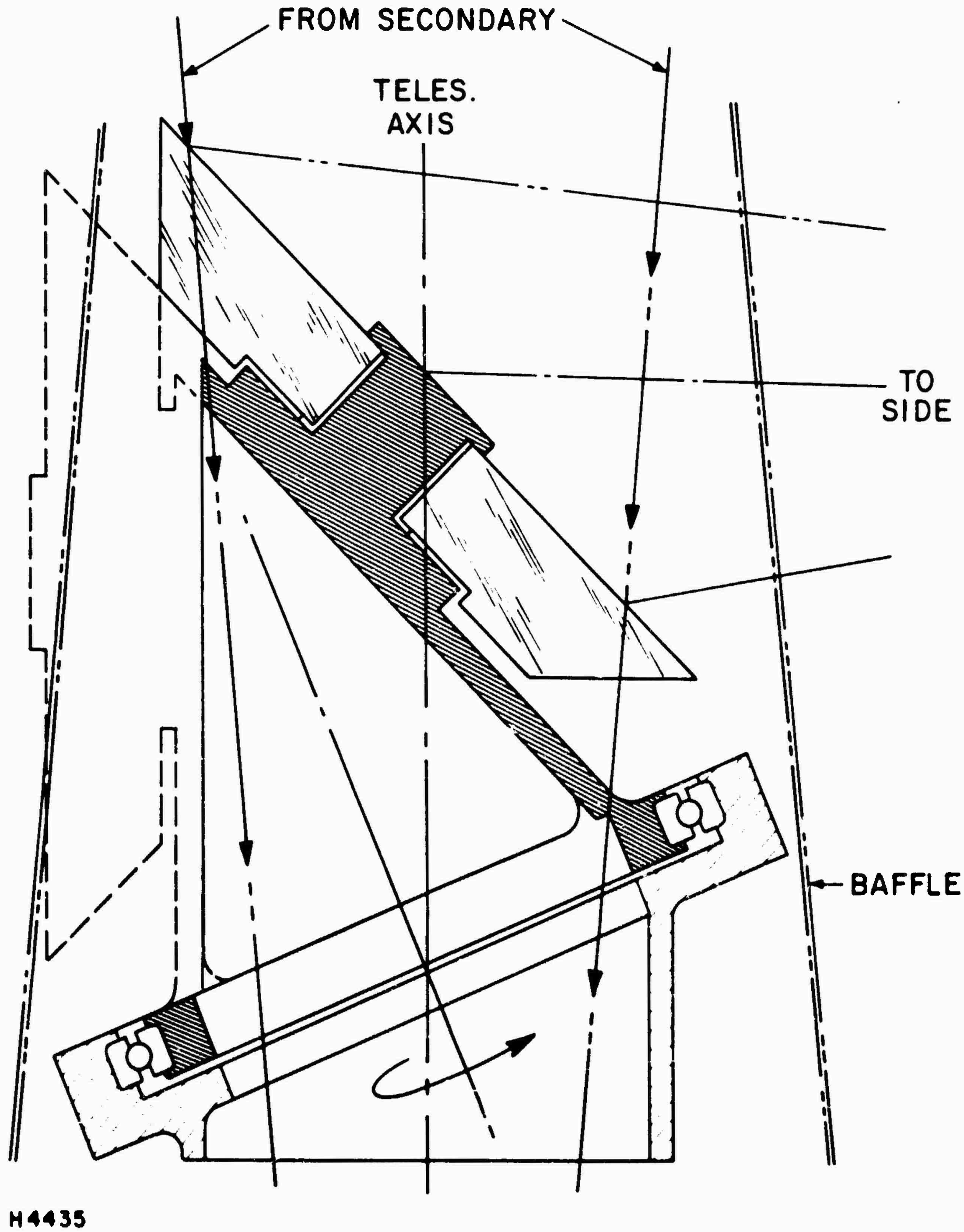


Figure 19 Folded Cassegrain Flat Mirror Pivot

sunlight by a factor of 10^4 when looking within 20° of the sun. While calculations show this has been met, what is more important is that under normal viewing conditions the baffling has been proven to significantly reduce veiling glare.

A final mechanical system was designed and built by AERL. This was the thermal metering rods. To maintain focus in spite of changing temperature conditions during a mission the intermirror spacing must be held constant. This is accomplished in the 1.6-m telescope by 4 Invar rods which position the secondary support ring with respect to the primary mirror cell. Figure 20 shows the thermal metering rods being installed. The resultant effect for the system is that telescope defocus does not noticeably affect the blur circle for a ± 5°C temperature change for "best seeing" conditions of 0.5 arcsec.

2.2.2.3 Acceptance Test Results

Once all systems had been delivered to AMOS and installed on the 1.6-m mount (see Figure 21), final acceptance tests were conducted. These tests were designed to show that all equipment properly interfaced with the mount, that all systems operated properly, and that system performance met the established criteria.

All test results showed success in meeting or exceeding specifications. Based on the test data, the 1.6-m telescope system can provide diffraction limited performance, $\lambda/16$, for all relevant mount attitudes. Table 11 shows achieved results for critical performance parameters. Table 12 shows the resultant wavefront aberration budget for elevations greater than 15°.

2.2.3 Telescope Evaluation

To verify the "diffraction limited performance" conclusion reached from acceptance test data, a 1.6-m telescope performance evaluation program was initiated in March 1976. Evaluation was to include optical testing (Ronchi, Foucault and Hartmann) as well as visual, stellar and photographic observations.

2.2.3.1 Optical Testing

Ronchi testing involves observing a point source (star) through a grating placed close to the instrument focus. The number of grating lines over which the image extends, and hence the sensitivity of the test, is determined by the location of the grating with respect to the focal plane and the grating frequency. This test is a relatively simple way of identifying the types of aberration present in an optical system.

Using a 200 lp/inch grating, Ronchi tests were performed frequently throughout the evaluation program to align, or realign, the telescope in an attempt to optimize other test results. Other than coma associated with alignment, no system defects were observed in Ronchi testing.

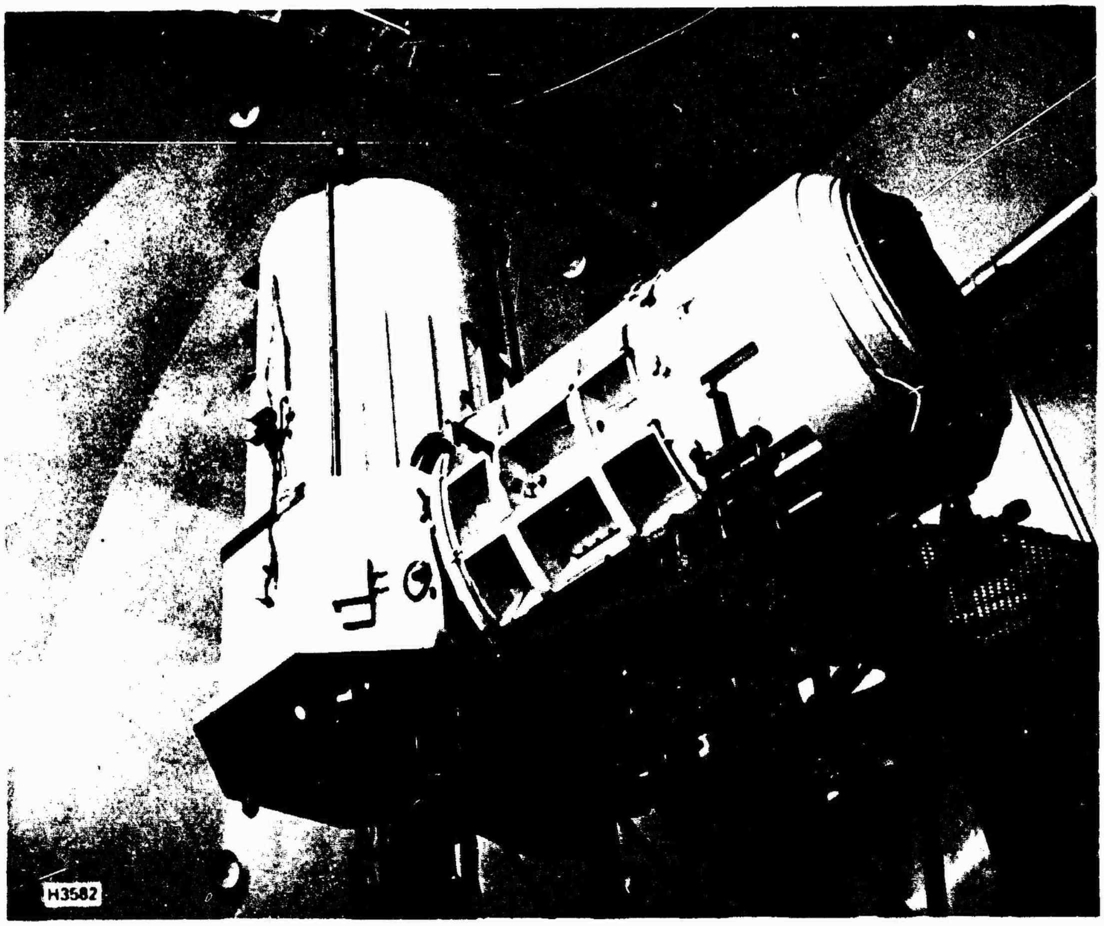


Figure 20 Invar Thermal Metering Rods During Installation in the 1.6-m Telescope

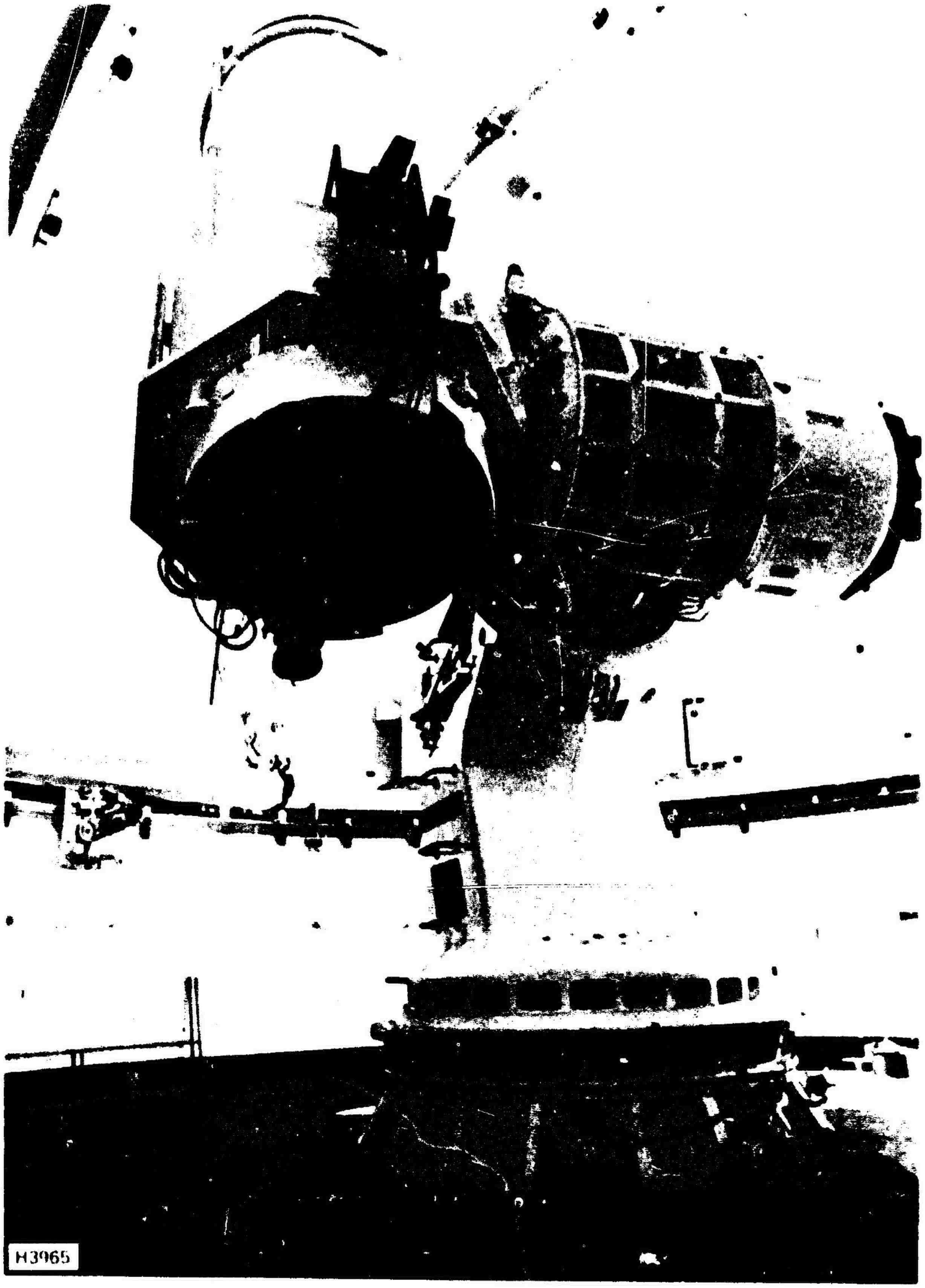


Figure 21 1.6-m Telescope Fully Assembled

TABLE 11

CRITICAL PERFORMANCE PARAMETERS 1.6-m OPTICS

Parameter	Specified	Achieved
Cass Wavefront Error	$\lambda/25$ rms $\lambda/4$ p-v	$\lambda/26$ rms $\lambda/4$ p-v
#3 Flat Wavefront Error	$\lambda/30$ rms	$\lambda/40$ rms
Cass System Reflectance	$> (0.85)^2 = 0.72$	$> (0.83) \times (0.87) = 0.72$
Primary Tilt (All Attitudes)	$\pm 5 \times 10^{-6}$ rad	$\pm 2.5 \times 10^{-6}$ rad
Primary Decenter (All Attitudes)	$\pm 2 \times 10^{-3}$ cm	$\pm 0.8 \times 10^{-3}$ cm
Primary Axial Shift (All Attitudes)	$\pm 5 \times 10^{-3}$ cm	$\pm 2 \times 10^{-3}$ cm
Secondary Tilt Tube Flexure Tilt	$\pm 1 \times 10^{-4}$ rad	$\pm 0.5 \times 10^{-4}$ rad
Secondary Decenter Tube Flexure Decenter	$\pm 1 \times 10^{-2}$	$\pm 1 \times 10^{-2}$ cm

TABLE 12

1.6-m TELESCOPE ABERRATION BUDGET (ZENITH ANGLE $\leq 75^{\circ}$)

Parameter	Value	Wavefront Aberration	
Cassegrain Optics	$\lambda/26$	$(\lambda/25)$	$\lambda/26$
Primary Tilt	$\pm 2.5 \times 10^{-6}$ R	$(\lambda/76)$	$\lambda/140$
Primary Decenter	$\pm 7.6 \times 10^{-4}$ cm	$(\lambda/19)$	$\lambda/50$
Secondary Tilt Tube Flexure (Tilt)	$\pm 5 \times 10^{-5}$ rad	$(\lambda/25)$	$\lambda/50$
Secondary Decenter Tube Flexure Decenter	$\pm 1 \times 10^{-2}$ cm	$(\lambda/25)$	$\lambda/25$
Cassegrain System		$(\lambda/11)$	$\lambda/16$

Entries in ( ) were original predictions based on specifications

Foucault, or knife-edge, tests are widely used in evaluating telescope quality. A sharp-edge, typically a razor blade, is used to cut across the image of a point source at the instruments' focus. Nonuniformity of fadeouts, as the knife cuts the image, can be attributed to various aberrations by an observer who has experience or expertise with the technique.

The Foucault technique uncovered no large zonal irregularities in the optics. A small ring, about 1/4 of the way out from the primary mirror center, was observed. This ring, which was generated in mirror grinding, had been identified in optics testing by B&C and found to be $< \lambda/6$ p-v and small enough to have negligible effect. Observing the ring, however, gave confidence in the sensitivity of the Foucault testing.

Hartmann testing employs a perforated screen at the telescope entrance aperture. Stars, viewed through the screen, are photographed with a Hartmann camera attached to the rear Blanchard. Four photographic plates are exposed (typically for one to four minutes) at fixed distances ahead of and behind best focus. By readout of the plates with an optical comparator, spot locations can be established and input to a computer analysis program. This data forms the basis for detailed determination of aberrations, misalignment, best focus, encircled energy, wavefront deformation, etc.

Over 40 sets of Hartmann plates were taken during the evaluation. About 1/4 of these were carried through the full reduction and analysis process. Insufficient exposure times, wind buffeting of the telescope, mistrack, and suspected adverse seeing conditions made many plate sets of marginal value. Only the better quality sets were used.

It is axiomatic in Hartmann testing that a 'good' telescope many only seldom produce a good test result, however, a 'bad' telescope will never produce a good result. It is justified then to consider the best results obtained as being indicative of telescope quality (it could be even better than measured but conditions may not permit measurements to verify the ultimate quality). On this basis, Figure 22 which represents the best Hartmann result obtained, is presented. This shows 80% of the energy within a diameter of .290 arcsec, near the theoretical limit of ~ .2 (depending on how the limit is calculated).

Analysis of this set of plates, set number 38, shows a residual offset between inner and outer holes of .078 arcsec and a separation in best focus of .054 inches, again for inner and outer holes. If the secondary mirror were accurately positioned as indicated by the analysis, resulting motion (accounting for the power of the secondary) would be about .01 inches in tilt and 300 μm axially. Were these adjustments made, the resultant blur diameter can be calculated to be .2 arcsec or at the theoretical limit.

2.2.3.2 Visual, Stellar and Photographic Observations

While observational testing is clearly influenced by seeing conditions which prevail at the time of observation, it can again by recognized that the best observations are indicative of the quality which a telescope must have or exceed. In all cases of observational data there was never an indication that the 1.6-m telescope was other than seeing limited.

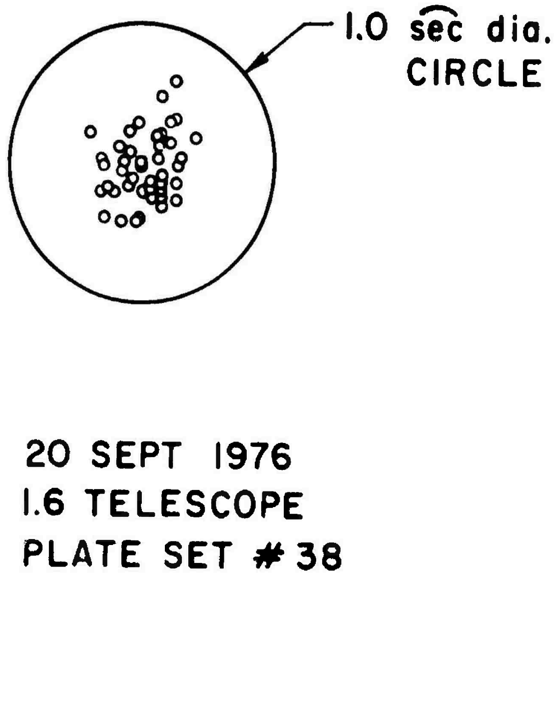


Figure 22 Hartmann Images After Telescope Realignment

Photographs of stellar and planetary objects are valuable to show telescope performance in real, as opposed to test, use. Typical results from such tests have clearly resolved a .6 arcsec double star, Figure 23, and have shown Cassini's division in the ring of the planet Saturn, Figure 24, which is reported to be a 1/2 arcsec detail.

2.2.4 Support Systems

2.2.4.1 Dome Drive and Windscreen Control

As was the case with the 1.2-m telescope system (see Section 2.1), the dome drive and windscreen systems in the 1.6-m dome also suffered from frequent failure, high vibration, poor maintainability and age. As a result a new system, identical to the one installed in the 1.2-m dome, has been incorporated into the 1.6-m dome.

Eight new support trucks, with spring loaded 8 in. drive wheels, were added to the dome system. Each new drive wheel is provided with a gear coupled 3 hp dc motor. The motors are controlled by a Randtronics controller which allows pendant box or dome console command of dome position.

The windscreen drive similarly employs a gear coupled 3 hp dc motor operated through the Randtronics controller. Both dome azimuth and windscreen elevation can be driven by automatic servo control as well.

2.2.4.2 Mount Control

The 1.6-m mount servo system had been rebuilt prior to receipt of the new telescope hardware. Thus, it was first utilized during the 1.6-m test and evaluation program. The new system, after proper setup, shows average errors between actual and command angles of less than ± 1 arcsec for high speed tracking and ~ ± 1 encoder bit for stellar or low speed tracking. The servo chassis modifications are comparable to those discussed in Section 2.1.4.2.

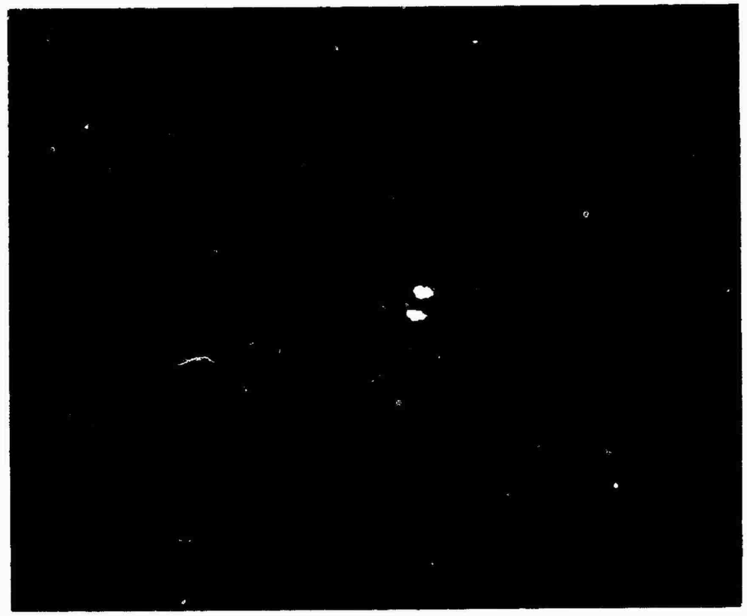
The other modification to the mount control system was to add emergency, or safety, stops to both the polar and declination axes. Electrical circuitry is used to reverse the torque motors if the safe operating limits are reached on either axis. As a backup, mechanical shock absorber stops absolutely limit motion so as not to allow damage producing mount orientations.

2.2.4.3 Balance System

To facilitate safe, rapid and versatile balancing of the 1.6-m mount when sensor packages are changed a new mount balance system has been installed. Balancing about the declination axis, similar to the 1.2-m system, utilizes small individual weights which attach outboard of the instrument mounting surface on the primary mirror cell.

H3961

ASN 2347
0.6 ARC SECOND SEPARATION



ASN 2343
0.8 ARC SECOND SEPARATION

Figure 23 Double Star Photographs

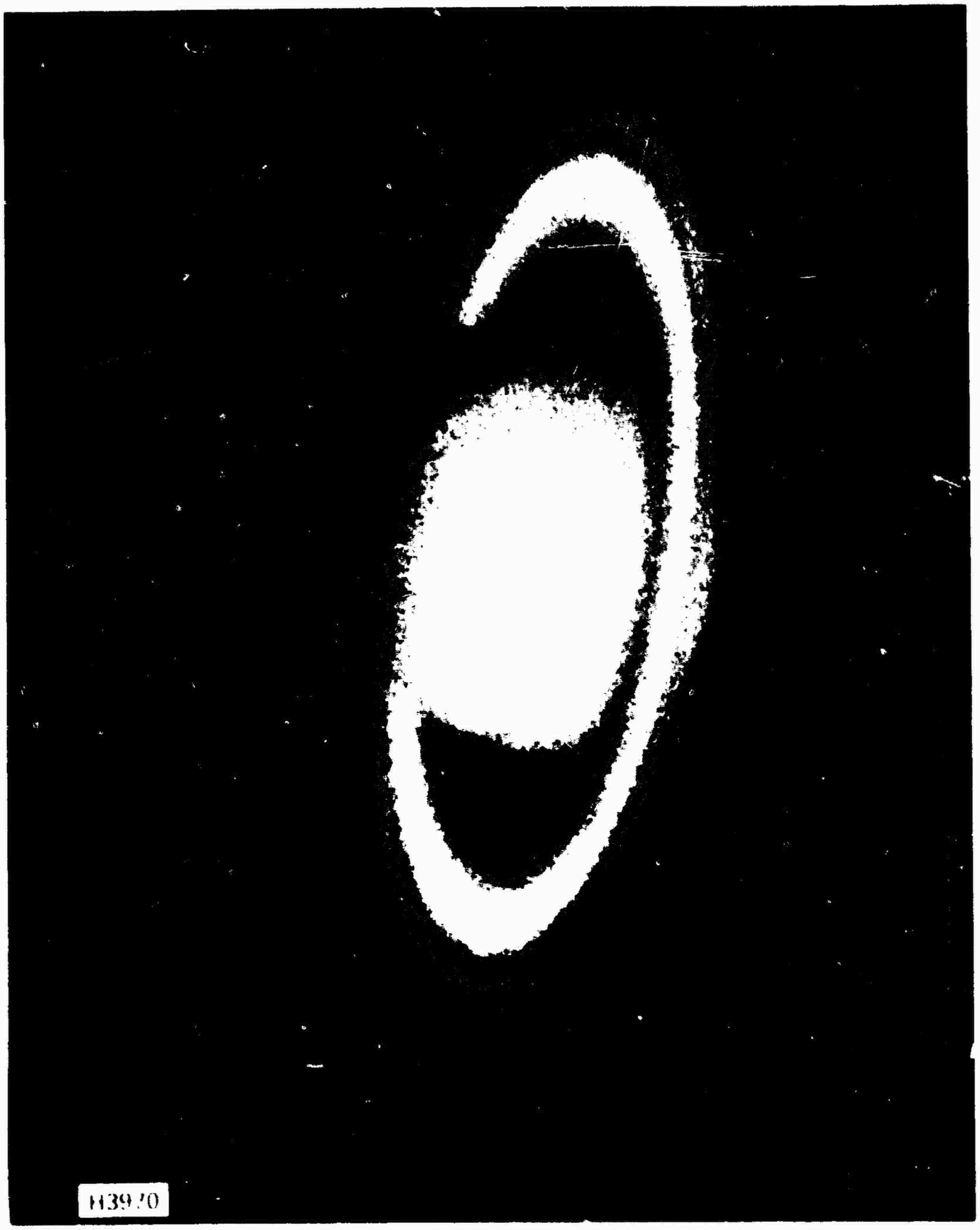


Figure 24 Saturn

An additional system was added to the end of the declination axis, opposite to the telescope, to provide for balancing about the polar axis. This system, as shown in Figure 25, uses movable plates to compensate for moments generated by packages mounted on the telescope. The weights are positioned by a threaded rod which can be turned to cause the movable plates to increase or reduce the moment about the polar axis. The total moment variation available can be increased or decreased by changing the number of movable plates if significant weight is added or removed from the telescope.

The weight system has been configured to allow, as best as can presently be determined, for balancing the mount when the substantial weight of the Compensated Imaging System is added to the telescope.

2.2.4.4 Acquisition Telescope

The 1.6-m telescope currently employs a 10-inch diameter, 1° FOV telescope to acquire and establish track on targets. The system sensitivity, due to the aperture size, and acquisition capability, due to the field-of-view, are inadequate for present operations and would severely constrain CIS operations. As a result a new acquisition telescope system is to be provided.

The new system, being built under a subcontract to Boller and Chivens, will offer 3 fields-of-view, 3°, 0.5°, and 0.1°. (Operator experience has shown that steps of 5 or 6X are appropriate for handoff from one FOV to another.) The 3° field will be provided by an 8-inch diameter catadioptric telescope while the 0.5° and 0.1° fields will be switch-selectable in a 22-inch diameter Ritchey-Chretien telescope. All three FOV's will image on a single ISIT video sensor to be provided by Quantex Corp. The ancillary shutters, filters, covers, recticles, etc. will be included in the system.

The new acquisition telescope is scheduled to be operational in the first quarter of 1978.

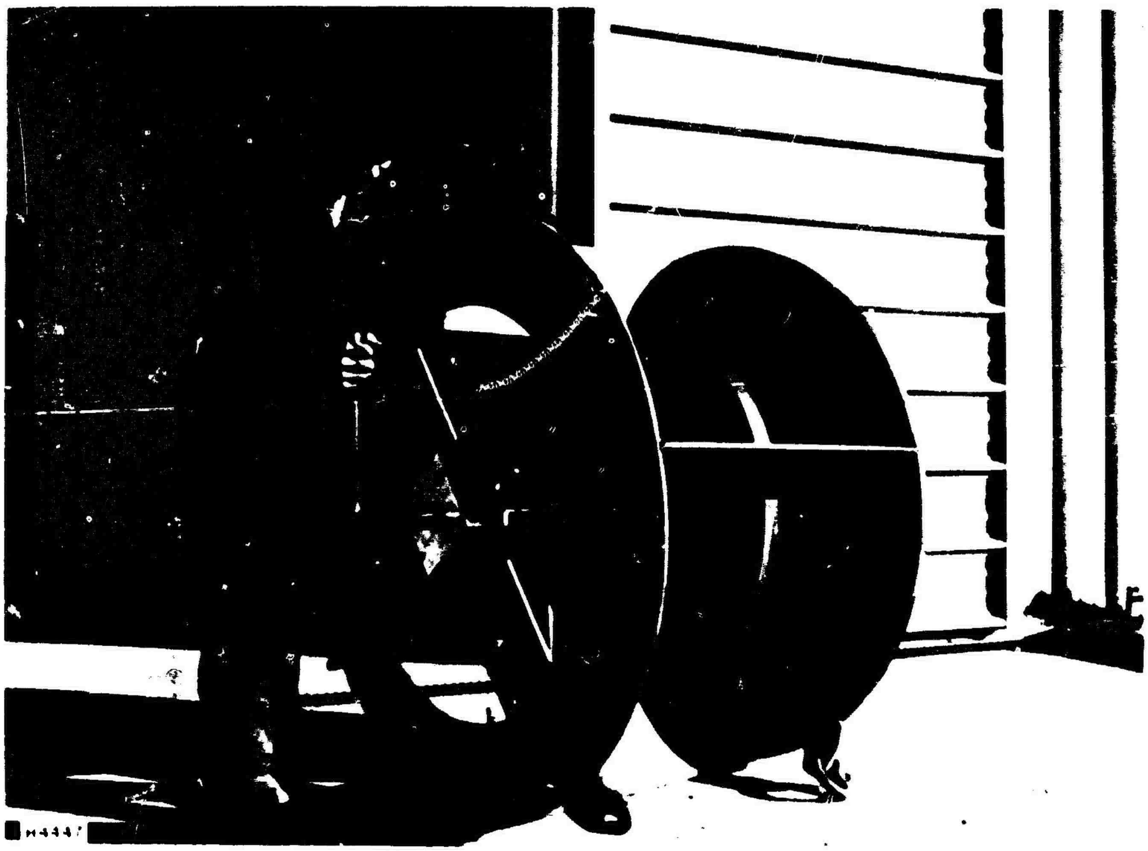


Figure 25   1.6-m Polar Balance Weight System

2.3 LASER BEAM DIRECTOR SYSTEM

AMOS measurement capabilities were greatly increased when the Laser Beam Director (LBD) complex became operational in late fall of 1975. The system interfaces both new (beam director, dome, software) and existing (pulsed ruby laser) subsystems into an integrated unit capable of very precise and accurate pointing and tracking.

The system is versatile. Only minor modifications would be required to allow use of lasers other than the existing ruby system. The LBD complex thus represents a state-of-the-art test bed for laser testing.

2.3.1 Summary

2.3.1.1 Objectives

Several existing and planned DoD laser-related programs require a ground based facility capable of pointing laser beams at targets with a precision of the order of a few arcsec and obtaining range measurements with a precision of a few meters. During the AMOS Phase II program it was decided to provide such a capability at AMOS.

Specific objectives of the program included the following:

1. The electromechanical and software systems should allow pointing and tracking to $\pm$ 1 arcsec rms for typical target velocities and provide "all-sky" coverage.

2. The optical system should be such that, when combined with laser sources having beam divergences of one arcmin or less, the resultant output beam divergence should approach the limit set by atmospheric decollimation ($\approx$ one arcsec).

3. The system should be optimized for the existing pulsed ruby laser but must be capable of supporting other laser syetems (at other wavelengths) with a minimum of modification.

4. The LBD should be completely interfaced to the rest of the AMOS complex to allow use of the AMOS Cassegrain telescopes for laser related missions (e.g., as receivers).

5. The AMOS pulsed ruby laser should be interfaced to the LBD and brought to initial operational capabilities.

These basic objectives led to the preparation of detailed specifications and the awarding of several subcontracts during Phase II. By the beginning of Phase III the program was well underway.

2.3.1.2 Accomplishments

Accomplishments during Phase III can be grouped into two categories: (1) activities associated with installing and evaluating the LBD and, (2) measurements performed to exploit the new AMOS capabilities.

During the spring and summer of 1975, installation and testing of the LBD was completed. This effort involved acceptance testing of subsystems at vendor facilities and at AMOS, modifications to the basic AMOS facility to allow installation of new hardware, removal of the pulsed ruby laser from the 48-inch mount and installation of the hardware in the LBD, generation of appropriate models and software for the new systems, etc.

By early fall of 1975 the system was ready for "operational certification." This was accomplished in October when the LBD/pulsed ruby laser was used to support the SANDIA program (see Volume II Section 5.8.7). This experiment demonstrated that the system would point and track to within specifications, that the ruby laser was fully operational and that all software and control systems were functioning as designed.

During January and February of 1976 a program was initiated to calibrate (e.g., range precision and accuracy) the ruby laser system by ranging to retroreflector satellites. For example, 86 returns (out of 95 firings) were obtained from GEOS B on a single pass. Preliminary data analysis showed that peak "jitter" in the measurements of up to ± 30-m was present.

In March of 1976 - at DARPA/SAMSO direction - all activities with the LBD/ruby laser complex were terminated. Except for a special test conducted in March of 1977 (which demonstrated the tracking capability of the LBD sans computer control) the "mothball" status of the system prevailed.

In the spring of 1977 interest in the system was renewed. In July of 1977 a program was initiated to reactivate and fully calibrate the system for use in a laser ranging program as described in Section 5.6.

2.3.2 Laser Beam Director Facility

The laser beam director facility is comprised of the control room which contains the beam director and ruby laser operator's consoles, the laser room which contains the ruby laser transmitter and the platform support pedestal, and a 16-ft diameter domed area covering the azimuth platform, the beam forming system and the gimbaled tracking flat.

The platform support pedestal and the ruby laser transmitter sit on a "seismic" concrete slab which isolates them from the rest of the facility. Space is available for other laser systems on this slab.

The tracking mirror is ~ 20 ft above ground level, which allows it to scan the entire sky above 15° elevation without encountering the other AMOS domes Figure 26 shows the basic configuration of the system.

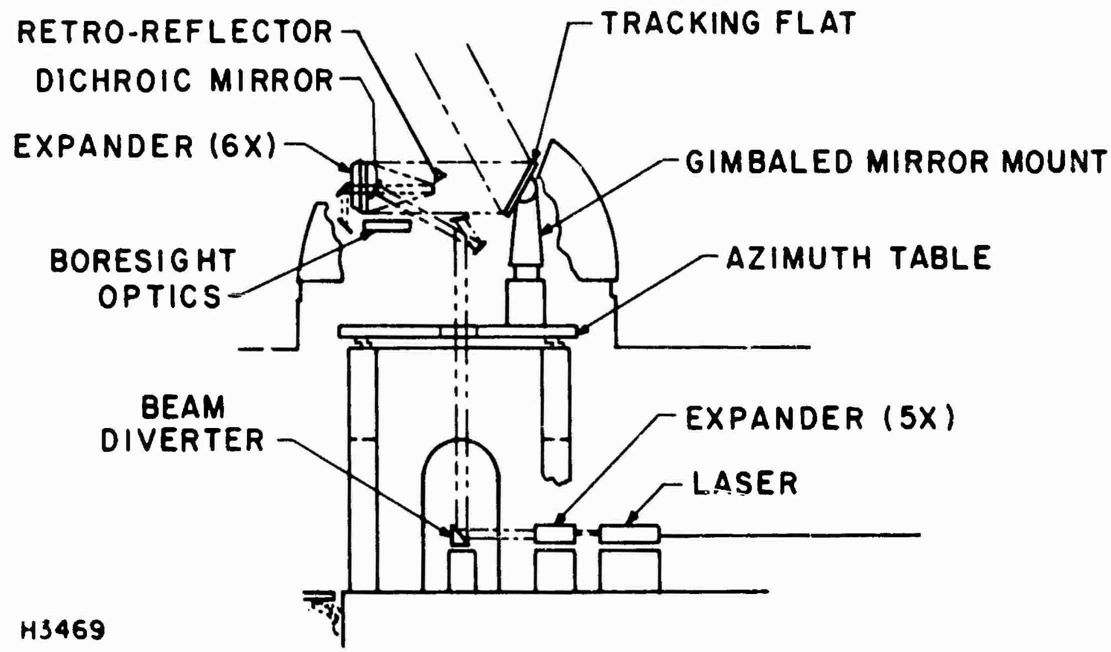


Figure 26 Laser Beam Director Schematic

The LBD area (except the control room) is airconditioned to a temperature approximating nighttime outside air temperature to reduce thermal "seeing" disturbances. An electronic airpurifier assists in maintaining optical surface cleanliness.

2.3.3 Optical System

The LBD optical system consists of the Beryllium tracking flat, the 24-inch beam expander, Coude mirrors and a boresight channel.

2.3.3.1 Tracking Flat

The lightweight Beryllium tracking flat is 36 inches in diameter. It is mounted in a cell and supported by the gimbal as described in Section 2.3.4.2. The flat has a wavefront performance of $\lambda/12$ rms at $\lambda = 6328$ Å. It is aluminized and overcoated with SiO.

2.3.3.2 Beam Forming System/Coude Optics

The basic design of the beam expander is shown in Figure 27. It will accept a beam of 4 inches in diameter and expand it to 24 inches. This 24-inch beam then impinges on the tracking flat and is directed to the target.

The 24-inch primary mirror ($\lambda/25$ rms wavefront error at $\lambda = 6328$ Å) is aluminized and overcoated with SiO. The secondary mirror spacing is maintained by means of CERVIT bars which limit defocus to $\lambda/2$ over a temperature change of 30°C.

The two Coude mirrors (15° angle of incidence with respect to the entering laser beam) are dielectric coated for $\lambda = 6943$ Å.

The dichroic mirror (in the perforation of the 24-inch primary) has a reflectance of 0.88 for $\lambda = 6943$ Å at the 15° angle of incidence.

Figure 28 is a photograph of the beam forming system.

2.3.3.3 Boresight TV System

The dichroic mirror described above has two functions: reflection of the outgoing ruby laser beam to the secondary mirror and transmission of visible light collected by the beam forming system (e.g., from a solar illuminated target).

The visible radiation passes through the dichroic and is focused by appropriate optics onto the cathode of an ISIT camera system. This system allows the LBD to acquire and track targets as faint as + 11 stellar magnitudes, with a field-of-view of about 3 arcmin, independently of the other AMOS telescopes.

As is described in Section 2.3.5.2, the ISIT also receives light from small retroreflectors which pick off a portion of the outgoing ruby laser beam,

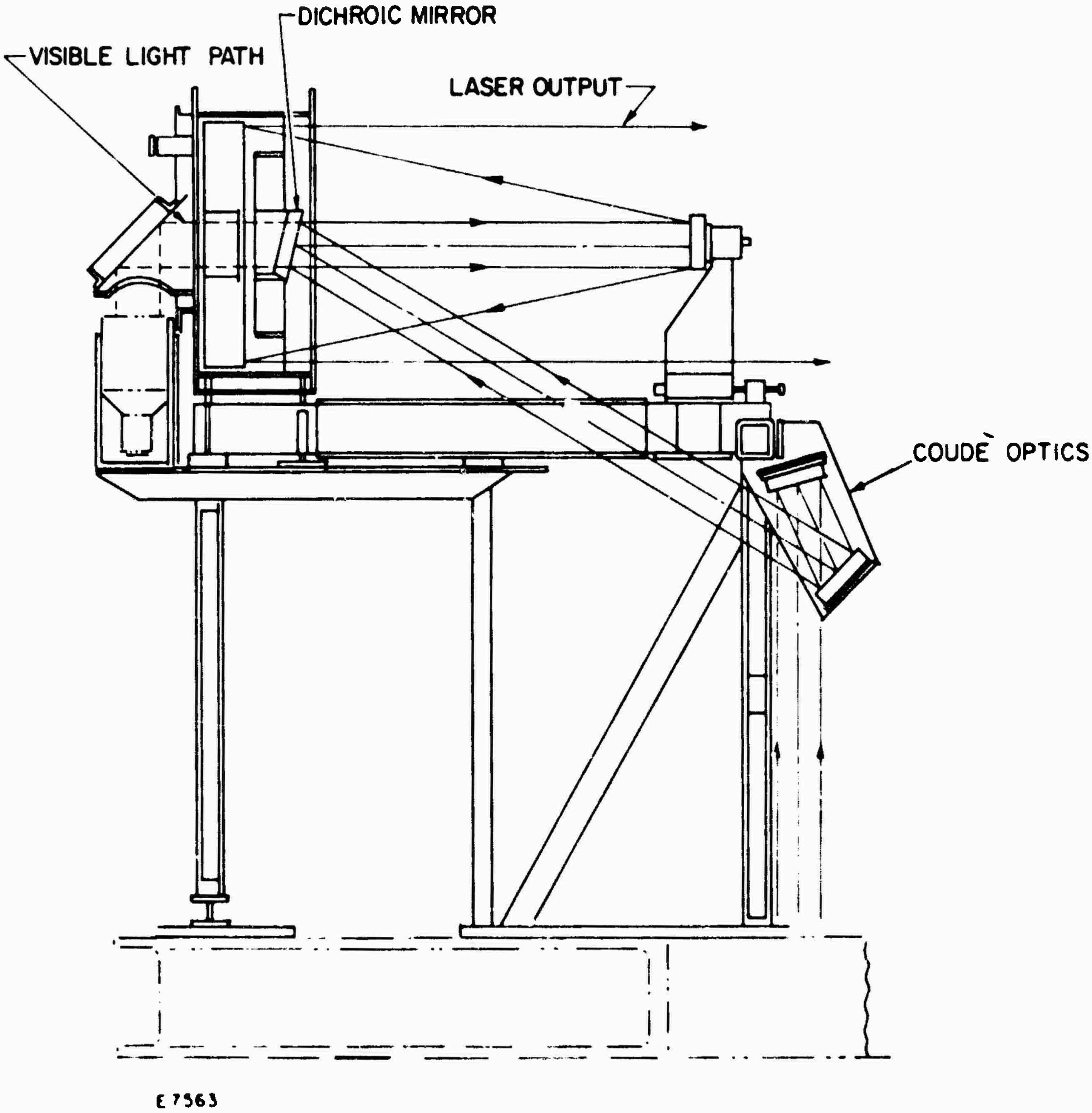


Figure 27 Beam Forming System

Figure 28 Beam Forming System (Coude Optics in Foreground, Boresight TV Beneath Table)

thereby serving as an aiming aid in realtime. For a visible target, therefore, the operator superimposes the target over the retroreflector reference.

The boresight system is also equipped with spectral and neutral density filters.

2.3.4 Electromechanical System

2.3.4.1 Azimuth Table Systems

The beam expanding and tracking flat optical components are mounted on a rotating azimuth platform. This platform allows prepositioning of the system to achieve optimum tracking geometry.

The azimuth table itself is a 12-ft diameter casting mounted on a 10-ft diameter ring bearing. The 4-inch laser beam enters vertically through the center of the platform before being diverted to the beam expander.

Positioning of the platform is accomplished by means of a permanent magnet stepper motor. A 40:1 speed reducer is coupled to the drive motor and is fitted with a pinion on the output shaft which engages a gear machined into the inner race of the bearing. An 1800:1 speed reducer is coupled to the other output shaft of the motor to drive a synchro transmitter for a remote position indicator. The position indicator and the control for the motor are located at the operator's console.

The stepper motor used in the drive system produces a shaft motion of 1.8° for each step commanded from the indexer. With the 1800:1 gear ratio between motor and platform rotation, each motor step corresponds to 0.001° (or 3.6 arcsec) movement of the platform. The maximum rotation rate is 1° per sec.

To aid the operator in positioning the table at the desired station, an up/down pulse counter has been installed to "encode" the platform position to the nearest stepper motor increment.

A second system of platform position indication employing a digital display is also provided. For missions, the platform is positioned at one of 24 discrete stations, located at 15° intervals. The position is sensed by 24 reed proximity switches situated at the 15° points. When the platform is within a nominal $\pm 1^{\circ}$ of the 15° location, the station number (from 0 to 24) is illuminated on the Control Panel. The reed swiches have also been incorporated into logic circuitry to cutoff motor power if the platform exceeds $\pm 180^{\circ}$ of rotation, and to illuminate the appropriate travel limit signal lamp.

The original system used an x-y autocollimator to obtaine "fine" platform position indication. The autocollimator looked at mirrors attached to the grout ring for each of the 24 stations. This system was found to be unreliable and was replaced during the latter part of Phase III with a He:Ne laser/x-y detector system. The 24 mirrors, of course, remained. When the platform is stopped within the range (± 50 arcsec) of the laser/x-y detector, an anlog signal, which is proportional to the platform error from the center of a given platform station, is digitized and transmitted to the AMOS computer system. This error signal is used as one of the realtime inputs for the pointing and modeling programs of the computer. The platform station number is also transmitted to the computer.

2.3.4.2 Gimbal System

The gimbal system is shown in Figure 29. The system has two axes in an elevation over azimuth configuration. The angular displacements of both axes are limited electrically as well as mechanically. The support for the flat tracking mirror is gimbaled about the elevation axis. The elevation axis assembly is supported by the azimuth yoke which, in turn, is positioned by the stationary base that is attached to the platform.

Each axis of the gimbal system is designed to meet its performance requirement over the following ranges:

Azimuth Axis: $\pm 45\ 1/4^{\circ}$

Elevation Axis: -15° to $+75^{\circ}$ from its vertical position

Actual performance is given in Table 13.

TABLE 13

GIMBAL PERFORMANCE

Parameter	Performance	
Encoder Accuracy	Elevation:	± 0.83 arcsec
	Azimuth:	± 0.64 arcsec
Axis Orthogonality	4.5 arcsec	
Tracking Velocity (Max)	5°/sec	
Tracking Acceleration	Azimuth:	$55^{\circ}/sec^{2}$
	Elevation:	$111^{\circ}/sec^{2}$

2.3.4.3 Control System

The basic control system is shown in Figure 30. It is designed so that the gimbal follows (within ± 1/2 arcsec) computer-generated 23-bit binary angle position commands. This computer input is based on a prediction of the desired gimbal position. A mount model, similar to those used for the AMOS Cassegrain telescopes, corrects systematic pointing

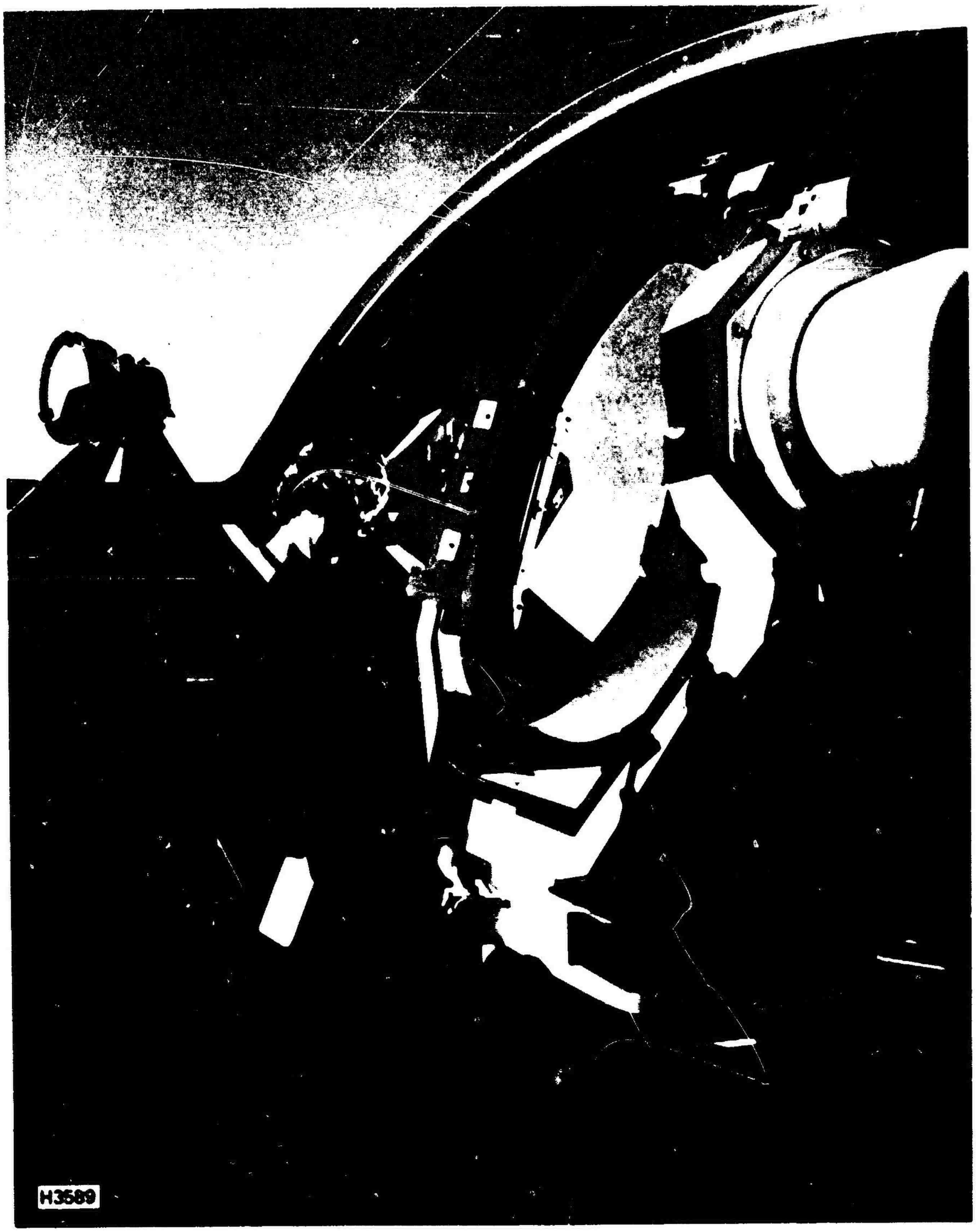


Figure 29 Gimbal and Tracking Flat

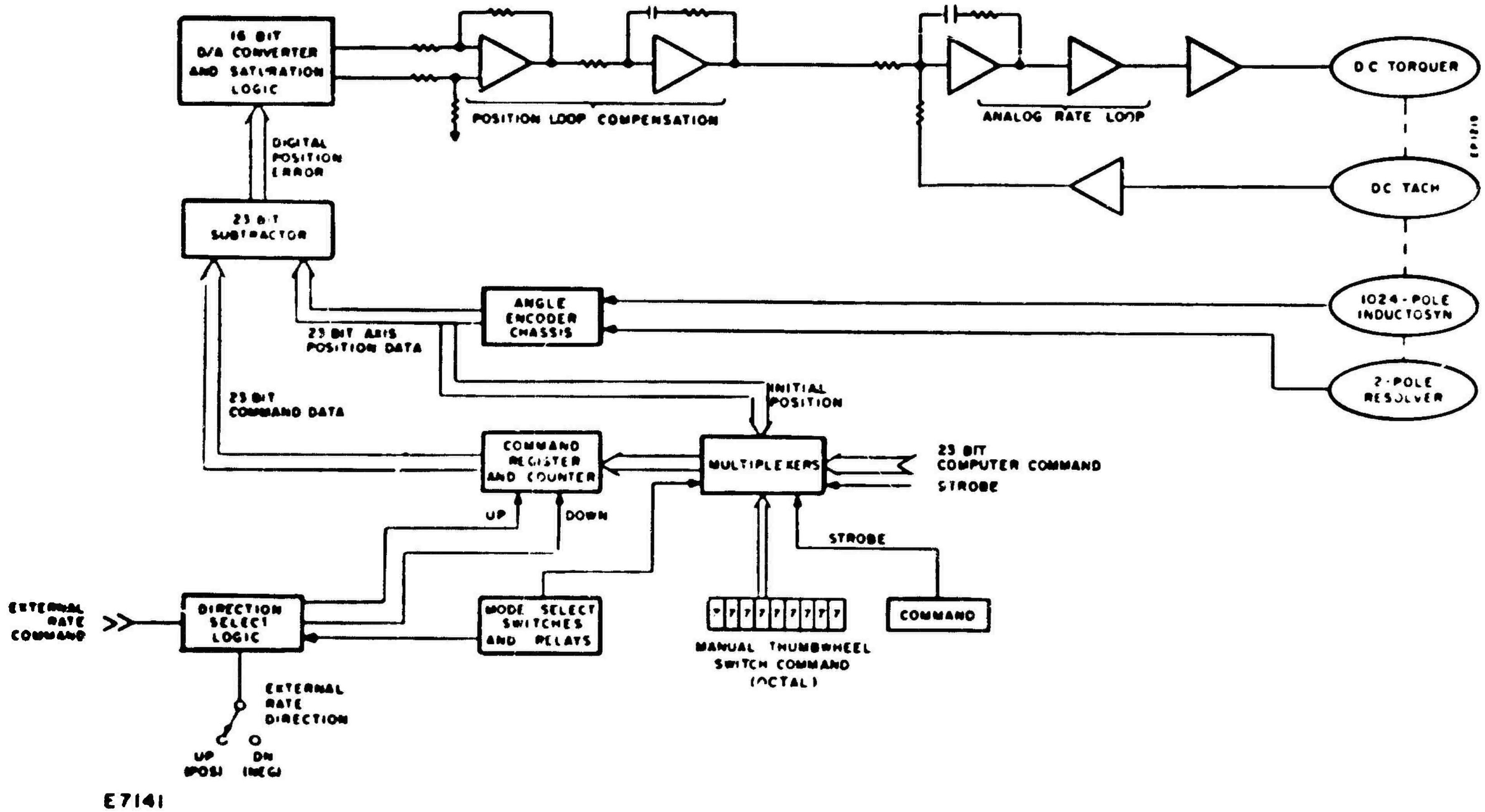


Figure 30 Pointing and Tracking System Block Diagram

errors when generating the command word. Types of systematic errors are: repeatable bending, encoder offsets, cyclical Inductosyn errors, lack of orthogonality of axes, etc. The servo system makes a digital comparison of this word with the latest 23-bit output of gimbal position from the Inductosyn shaft angle encoders. An error signal is generated to reposition the mirror. The servo system update occurs at a rate of 100 Hz. Operationally, the control system reduces to a digital position loop around an analog rate loop. The position loop is closed on the command signal from the AMOS computer. The digital error is converted to an analog signal with a dynamic range of + 10 Vdc. This signal is then fed to the gimbal electronics as shown. Function checking of the position loop employs the axis-mounted potentiometer and panel display meter.

The output signal from the position loop compensation amplifier forms the command signal to the inner rate loop. The rate loop compensation amplifier is designed to provide an output which is both proportional to and the integral of the rate error. This provides the rate loop with Type 1 characteristics, i.e., the steady-state rate error to a step command will be zero. At high tracking rates, the input is best represented as a staircase. The servo system follows the best linear approximation to this staircase to achieve smooth tracking.

The gimbal/computer interface consists of line driver and line receiver circuits capable of driving digital signals over long distances. The interface allows the CDC 1700 computer to transfer and receive gimbal position data. Analog signals indicating platform position require conversion to digital form before being transferred to the computer.

An analog to digital conversion section was designed and installed by AERL during Phase III. Modifications to some of the Fecker Systems equipment were also required.

2.3.5 Laser System

2.3.5.1 Korad K2500A Pulsed Ruby Laser

The heart of the AMOS laser system is a Korad K2500A three-stage pulsed ruby laser, as shown in Figure 31. The oscillator cavity includes a 6.5-inch long by 0.375-inch diameter ruby, a KD*P Pockels cell and a Brewster tentstack polarizer. Both Q-switched and conventional modes are achievable. A pinhole aperture in the cavity produces a single transverse mode (TEM_{01}*), which provides an ideal spatial distribution for coupling to the annular amplifier rubies.

The 1.7 mm diameter oscillator beam is expanded by a Galilean telescope to 0.8-inch in diameter which matches the preamplifier and amplifier apertures and, in the process of expanding and collimating the beam, reduces the divergence angle by a factor equal to the magnification.

The preamplifier stage contains a 9.0-inch long by 0.8-inch diameter ruby with a central 0.25-inch diameter hole to reduce thermal mass.

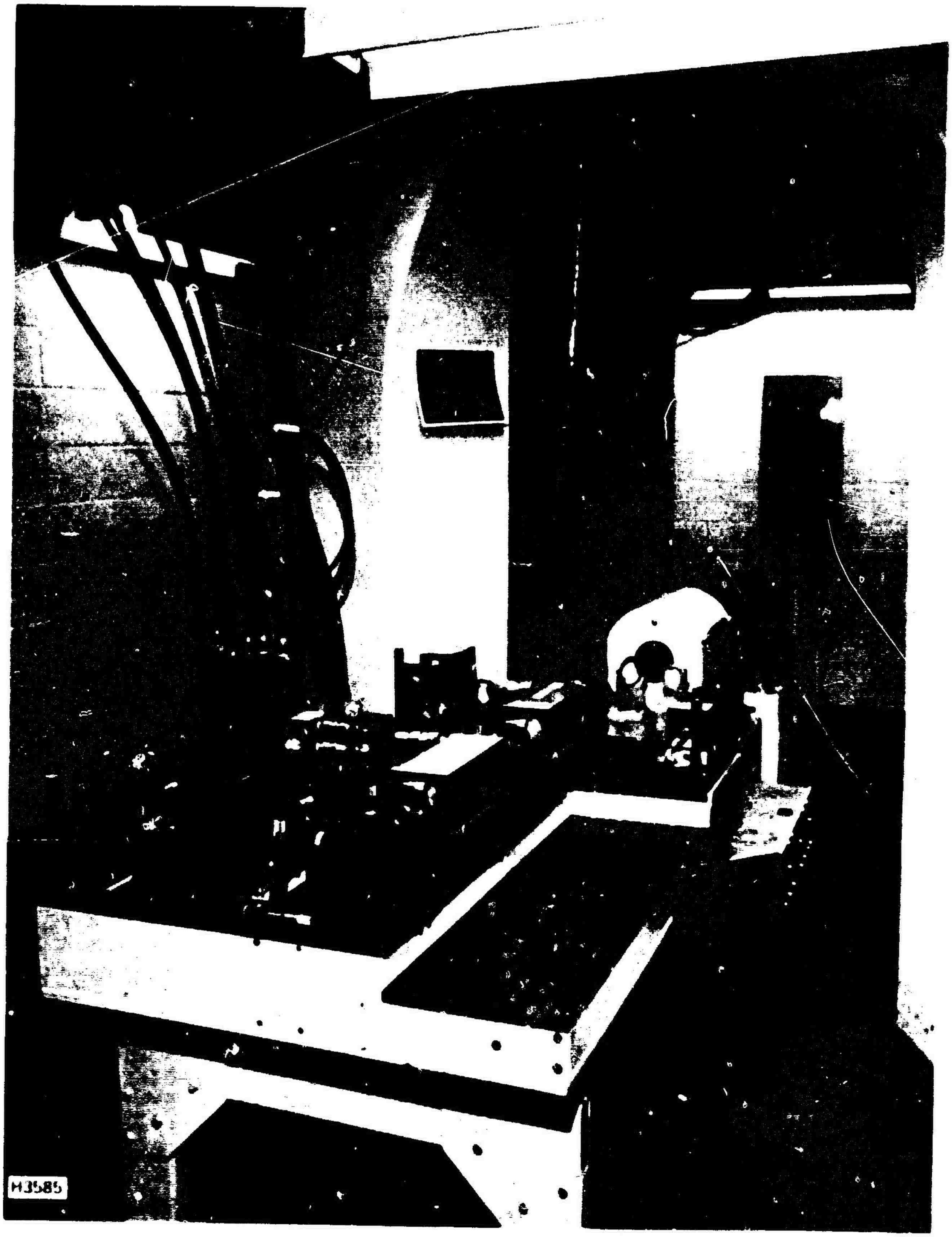


Figure 31 Ruby Laser (View Looking Toward 5X Expander and Beam Diverter)

The final amplifier ruby is identical to the preamplifier except that the output surface is cut at Brewster's angle to eliminate back reflections. This Brewster cut produces an elliptical beam which is then restored to a circular one by a sapphire Brewster corrector (which also has a 2^{o} angle on the output face).

A small portion of the output beam is sampled to monitor transmitter performance and to provide a trigger pulse for the ranging electronics.

Table 14 lists the important laser transmitter performance parameters.

The laser pulse from the amplifier ruby is expanded to a 4-inch diameter beam by an afocal optical system, reflected vertically upwards by a dielectric mirror and then enters the beam director optical system which has been described previously.

2.3.5.2 Ancillary Systems

Several ancillary systems are, of course, required for the pulsed ruby laser described above.

The rubies are water-cooled. This is accomplished by forcing filtered, deionized water through the heads (14 gpm for the amps and 5 gpm for the oscillator). The water-cooling lines can be seen in Figure 31. Holding tanks and a Freon chiller are included in the system.

A large power supply (enclosed in a "screen room" for EMI suppression) charges the individual capacitors for each head. The power supply itself is capable of charging the capacitors to required voltage levels in one second.

Alignment of the laser internally and alignment of the laser/LBD are accomplished by means of a He:Ne gas laser. The He:Ne beam can be inserted into the oscillator cavity and simulates the ruby laser beam as it passes through the entire optical system.

As mentioned previously, a boresight TV system is incorporated into the LBD. In addition, retroreflectors pick off a portion of the outgoing 24-inch diameter beam and reflect this energy onto the boresight TV. The retroreflectors produce line images and, since more than one is used, provide a monitor of output beam divergence as well as laser beam direction for aiming purposes.

Laser ranging -- the primary purpose of the AMOS laser/LBD system -- is accomplished as described in Section 5.6. Ancillary systems required for ranging include an electronic interface between the detector (located on the 1.6-m telescope) and the CDC 3500 computer (which is used for data acquisition and processing).

TABLE 14

PULSED RUBY LASER TRANSMITTER PERFORMANCE

Rep-Rate	20 PPM, Single Shot
Wavelength	6943 Å at Room Temperature
Energy*	≃ 80 J (Conventional)
	≃ 10 J (Q-Switched)
Pulsewidth	≃ 10^{-3} sec (Conventional)
	≃ 25 x 10^{-9} sec (Q-Switched)
Beam Divergence*	≃ 60 arcsec from 0.8-inch Diameter Output Ruby (2 arcsec from LBD)
Stability*	± 5% After 7 Shots at 20 PPM

This performance obtained with 1.7 mm aperture in oscillator cavity (TEM_{01}).

2.3.5.3 Laser Control System

The laser control console (Figure 32) is located in the LBD control room. During a ranging mission, the laser operator is able to initiate firing and adjust relevant system parameters from this console. Monitors and controls for bank voltages, Pockels cell delay, range gates, etc., are available. A processed display of laser range returns is shown on an oscilloscope to aid in realtime decision making. Output pulse energy is also displayed as a monitor of system performance.

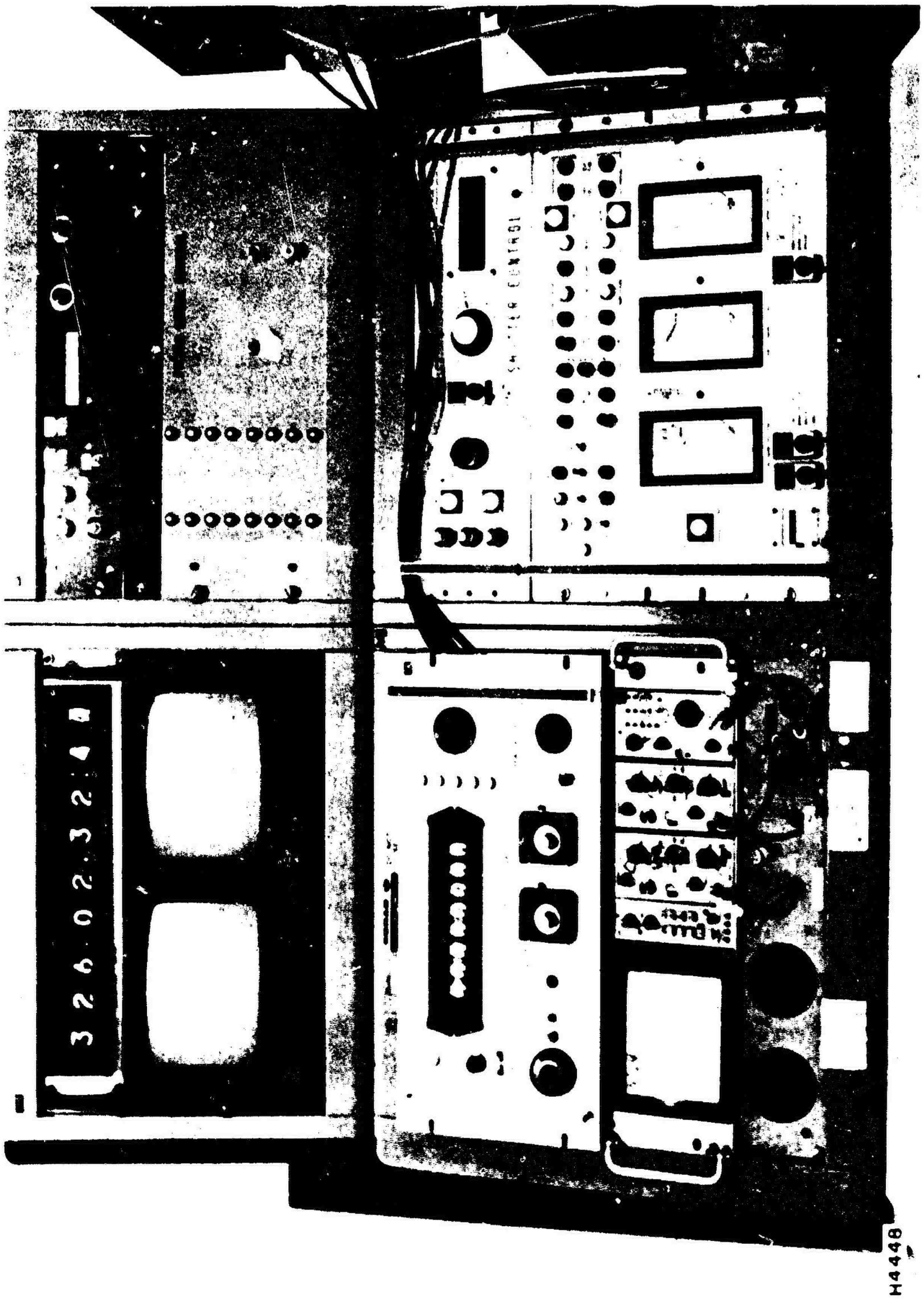


Figure 32 Laser Control Console

2.4 COMPUTER SYSTEM

The Control Data Corporation CDC 3500 is the primary computer supporting AMOS Observatory functions. The CDC 3500, coupled with the CDC SC-17 computer and the Extended Realtime Operating System (EROS), form the computer constituents of the AMOS mount control system.

This system is capable of providing indepen 'ent and simultaneous control of the 1.2-m, 1.6-.n and LBD mounts for the purposes of performing mount checks and calibrations, target acquisition, tracking and data collection.

The CDC 3500 computer is also used to satisfy nonrealtime mission support functions. These functions consist primarily of the target availability program used for mission planning, satellite and missile ephemeris programs used to generate initial condition state vectors for EROS and post mission report generation programs. These programs are executed as batch modules under the Control Data general purpose monitor system, MSOS.

2.4.1 Summary

2.4.1.1 Objectives

The primary objectives of the AMOS phase III software development efforts have been in direct support of the upgrade or addition of hardware systems, for support of mission experimental requirements and to improve pointing and tracking performance. Enhancements to operational capabilities, improvements in reliability, expandability and maintainability of all software modules were secondary objectives underlying all software development efforts.

Control and support functions for the Laser Beam Director were a major effort. Control functions for the video trackers, 1.2-m strabismus correction and improved joystick interface are examples of effort required in support of corresponding development activities.

Long wavelength infrared, laser, and metric measurement programs have required the development of additional control functions to improve data acquisition capabilities.

2.4.1.2 Accomplishments

During the latter stages of the Phase II contract, an evaluation of computer system capacity to support projected system development was completed. The principal deficiencies noted required the addition of memory to the CDC 3500 computer and floating point hardware for added Central Processing Unit (CPU) cycle capacity on the SC-17 computer.

The requirement to provide control functions for the Laser Beam Director and the implicit requirements imposed by the aforementioned hardware upgrade resulted in the development of a major new software system by AERL. EROS was developed in support of these fundamental hardware requirements. EROS was completed in time to support the LBD system testing in the latter part of 1975 and became operational, replacing the Phase II OMNICON system, for support of 1.2-m, 1.6-m and LBD missions in early 1976.

Improvements were not limited to the realtime operating system. New phase III program modules, for example the coordinate transformation routine XFORM5, were incorporated into all mission support programs to achieve an overall system compatability and modularity.

The missile data preparation routine, MISPREP, was completely rewritten and planetary, PLANET3, and lunar, MAHINA, ephemeris generation programs were developed. These programs, along with the SATPREP program upgrade completed during the later part of Phase II, provide a compatible set of data preparation programs for the Phase III system.

A major upgrade for extracting data from the realtime history tape was also accomplished. The EROS Report Generator, ERG, was developed to provide a capability for generating comprehensive printed reports as a function of the mount and mission objectives.

Improvements in system performance relative to pointing and tracking have been emphasized. Pointing improvements were achieved by refinements in the system mount and refraction models. Absolute pointing of 2-3 arcsec is possible with the Phase III system.

Improved servo performance was achieved as a function of the redesign of task scheduling, queuing and interrupt processing functions and with the incorporation of the floating point hardware device in the SC-17 computer. Tracking precision of 1 arcsec is not uncommon for near space targets and for deep space targets the precision is approaching that of the resolution of the shaft encoders (~ .2 arcsec).

The Phase III system has also demonstrated improved reliability and maintainability. This is due to the logical structure of the system, elegance of its design and conversion, where practical, from assembly language code to ANSI standard FORTRAN.

The Phase III software system, comprised of EROS and its support programs, represents a major contribution by AERL to DARPA's AMOS capabilities. The multiple capabilities of the system have been demonstrated by its success in supporting mission involving all three AMOS mounts and two remote radars, either collectively or independently, on targets consisting of multiple object missiles and near earth or deep space satellites.

2.4.2 EROS

The extended operating system, EROS, was developed as a requirement to support the LBD and to improve the tracking performance of the 1.2-m and 1.6-m mounts. In order to satisfy these requirements, it was necessary to increase the memory of the CDC 3500 and add a floating point hardware unit to the SC-17. From a design standpoint, EROS is more than an extension of the Phase II system. Due to the nature of the added hardware, major software changes were necessary; at the same time, other enhancements were incorporated which contribute to better performance, reliability, expandability, maintainability and overall elegance of the system. The major function of EROS are presented in Figure 33.

The more salient improvements in EROS, over its Phase II predecessor, are:

Extended Memory Logic

Multipriority Interrupt Processing

Improved Task Scheduling and Queuing

Greater Efficiency and CPU Utilization

Laser Beam Director Control

Video Tracker Function

Improved Joystick Interface

Improved Data Recording Process

Improved Servo Performance

Improved Pointing

Ephemeris Track Mode

1.2-m Strabismus Correction

Off/On Target Sequence

Automatic Elevation Scan Sequence

Improved ATN File Format

Automatic Day Update

Improved Operator Messages

Right Ascension and Declination Input by Operator

Extended Memory Logic - The CDC 3500 memory was expanded from a one module 32K memory to a two module 65K memory for the development of the EROS system. The design of the 3500 computer is such that expansion of software to make use of the additional module is not automatic. The computer must be operated in a separate mode, EXECUTIVE, controlled by a switch on the computer console. EXECUTIVE mode requires that software be partitioned into two states, Monitor State and Program State. Two registers, the ISR and OSR, are required to designate memory references for instructions and operands. An additional interrupt line is required for transition from Program State to Monitor State and the instruction repertoire is augmented in accordance with the additional modes, registers and interrupt line.

SIMULTANEOUS & INDEPENDENT CONTROL OF 1.2–m, 1.6–m & LBD

DYNAMICALLY SELECTABLE TRACK MODES
BALLISTIC – SIDEREAL – EPHEMERIS – STATIC

ANALYTIC MOUNT MODEL – MULTIPLE SENSORS

REMOTE RADAR DATA LINKS
KAENA PT (FPQ–14) – KOKEE PARK (FPS–16)

TRAJECTORY ESTIMATION – KALMAN FILTER
AMOS LOOK ANGLES & RADAR OBSERVATIONS

VIDEO TRACKER (S)

OPERATOR INTERFACES
FFK – ANK – JOYSTICK – DISPLAY

ON LINE DATA FILES – STARS
– BALLISTIC INITIAL CONDITIONS

Figure 33 Principal EROS Functions

Multipriority Interrupt Processing - The CDC 3500 interrupt dispatcher was designed to provide three priority levels for interrupt processing:

1. Servo update interrupt
2. All external device channel interrupts and arithmetic fault interrupts
3. Executive (programmed) interrupts

The highest possible priority is given to the CDC 3500 internal clock interrupt. This interrupt is programmed to intercede every 10 msec and serves to initiate the process which updates the mount servo error signals or command angles. Placing the servo update interrupt at a higher priority than all other interrupts allows for the minimum possible system response time to servo update requirements. This response time has been measured to be less than 45 μsec.

All interrupt processors are kept to a minimum. This is achieved by scheduling tasks which are in turn executed by the realtime task scheduler (RTTS) according to assigned priorities.

Task Scheduling and Queuing - The RTTS is a Monitor State routine which causes both Monitor and Program State Tasks to be executed according to priorities.

All asynchronous functions generated by operator inputs from control consoles are placed in circular queues at interrupt level and then processed at the defined priority. This assures that inputs are never lost and includes:

1. Keyboard Multiplexer inputs for both Fixed Function Keys (FFK's) and Alphanumeric Keys (ANK's).

2. Buffer Transfer Unit (BTU) transfers from the SC-17 to the 3500 defining inputs from external devices to the 3500.

The SC-17 system makes extensive use of the Parallel Floating Arithmetic (PFA) unit. The PFA operates in parallel to the SC-17 CPU on a cycle sharing basis, obtaining both commands and data from task buffers defined in memory. A RTTS was developed for the PFA. Its principal feature is that it allows for a set of PFA tasks to be defined and executed according to priority. Lower priority tasks are interrupted, if necessary, and queued when higher priority task activity is requested or in progress.

Central Processing Unit (CPU) Utilization - A reduction in CPU utilization of the SC-17 computer was achieved by effective use of the Parallel Floating Arithmetic (PFA) unit. The Phase II system performed servo error calculations in double precision arithmetic; a process which consumed 33% of the SC-17 CPU. In the Phase III system, all servo arithmetic processing is performed by the PFA.

All mount dependent functions have been organized such that calculations are only performed when mount activity has been requested.

LBD Control - All mount dependent algorithms have been generalized to multiple mount logic and expanded to include the LBD.

For ballistic tracking (satellites or missiles) the system provides for two independent reference trajectories defined by the state vectors and associated target differential vectors. The two references represent the option for two completely independent, yet simultaneous ballistic (satellite or missile) missions. The target differentials provide for up to six variational trajectories (targets) associated with each reference.

All three mounts (1.2-m, 1.6-m and LBD) have the option of following the trajectories defined by either of the two available reference vectors. In other words, two different satellites (or missiles) may be tracked simultaneously by the three mounts including dynamic switching from one satellite to the other. The target differential vectors may be used to provide independent capability for two or three mounts tracking the same satellite. Also, any particular mount may follow the track of another by selecting the same reference and target vectors as the other.

Sidereal and Ephemeris tracking are achieved by assigning separate values of Right Ascension and Declination to each mount. This means that redundant calculations are performed if more than one mount is tracking the same star; however, the amount of CPU time involved is negligible.

The realtime subroutine which computes pointing corrections for the LBD is SMODEL. Coefficients for the expressions evaluated by SMODEL are estimated by the nonrealtime program SCONDET. Data (the coefficients) are stored in a special realtime disc data structure called the mount parameter file.

The LBD error model assumes a perfectly rigid structure. The error transformation has two coefficients for gimbal encoder bias, and four coefficients associated with nonorthogonality of collimator line-of-sight, gimbal azimuth, axis gimbal elevation axis, and mirror normal. In addition, each of the 24 turntable positions has three coefficients defining orientation of the turntable axis.

Video Tracker - EROS allows for operation of the two DBA systems video trackers. Principal features of the software implementation are:

1. Simultaneous operation of both trackers
2. Computer controlled sensor boresight compensation
3. Dynamic sensor (video) selection
4. Operation in all track modes of EROS

A FFK is used by the operator to make the tracker-to-sensor assignment. During an operation, the operator may dynamically select any of the six video sensors for use with the tracker.

Improved Joystick Interface - The joystick inputs from the 1.2-m and the 1.6-m mounts are no longer input through the multiverter as in the Phase II system. The multiverter was interfaced via a synchronous digital input channel in the time and encoder chaining buffer. A failure of the multiverter would cause termination of time and encoder updates to the system. The new interface provides for a separate 8-bit a/d converter for each axis. Both pol and dec inputs are packed into one digital input word for each mount and are synchronized by use of the time code generator.

Improved Data Recording Process - The Phase II system recorded a standard data record on magnetic tape at a period of 100 msec, regardless of the varying data rates of the information contained in the record. For the Phase III system, a set of logical records have been defined such that there exists a unique logical record for each data type. These logical records are then recorded at a rate appropriate for the data type. Every attempt has been made to define tape and record formats to facilitate data processing and to provide for expanding capability without creating obsolete history tapes.

Improved Servo Performance - The Phase II system had a problem in the servo control logic which caused discontinuities in the error signal. The discontinuities were brought about by timing delays in the 10 msec servo update period of the SC-17 system which, in turn, were caused by timing conflicts between the servo and graphics update logic. It should be noted that mount inertia filters most of this noise except for very fast satellites.

The priority structure of the Phase III SC-17 system was redesigned to eliminate this problem. In addition, all error signals and command angle calculations, including the addition of both vernier and joystick offsets, has been developed to use the PFA unit.

More extensive modifications were developed to remove high frequency spikes. BTU buffers in both the 3500 and 1700 were completely reorganized. A new BTU driver was written so that BTU transfers from the 3500 to 1700 were queued and dequeued with command angles having ultimate priority. The BTU exchange jump protocol was also revised so that the 3500 controlled scheduling of exchange jumps. Servo update timing sequence was modified so that command angles and encoder readings were synchronized.

Gimbal angle velocity components are calculated at a 10 msec period for output to the mount servos. The velocities are calculated from second order coefficients used to generate gimbal angles at the 10 msec period.

Improved Pointing - Three mathematical models which influence pointing accuracy have been revised. Earth Model parameters have been updated from Improved Department of Defense World Geodetic System (DODWGS)

1966 to DODWGS 72. Correction for light transit time of geometric range (R_g), azimuth (A_z) and elevation (E_g) to apparent values is now performed for near earth targets (satellites and missiles). The astronomical refraction model has been modified to incorporate range and parallax corrections for near earth targets (satellites and missiles).

Ephemeris Mode - The ephemeris track mode, which was previously available only in the Phase II system, has been installed in the Phase III (EROS) system. The ephemeris track mode is a mount dependent mode analogous to the sidereal and ballistic modes. The primary intent of this mode is for tracking nonstellar celestial objects such as planets, asteroids or the moon. The ephemeris data, consisting of topocentric right ascension and declination, is retrieved from the AMOS Test Number (ATN) disc file by a request entered on the alphanumeric keyboard (ANK) just as for any other ATN.

There are currently two programs available for generating ephemeris ATN's. The MAHINA program generates lunar ATN's and the PLANET 3 program generates ephemeris ATN's for planets and asteroids.

Strabismus Correction - A capability has been developed which allows for the realtime system to command the position of the b = 37 secondary mirror to maintain optical alignment with the b = 29 telescope. This feature has been implemented in the EROS system and consists of a correction factor for each axis (polar and declination) output at a rate of 1/sec. The correction factors are computed as a function of the mount model offsets in realtime for the two sensors; thus, two realtime model determination are required. Current implementation does not allow for the operator to make a dynamic selection between models for the b = 37 back or side Blanchard. If experience demonstrates a need for this feature, it will then be added.

Periodic Step Off-Step On Target (SOSO) - A periodic square wave motion may be superimposed on top of the nominal trajectory while tracking ballistic or celestial objects. SOSO may be imposed on either or both the declination and polar axes of the 1.2-m or 1.6-m mounts. Control is by operator inputs on the ANK. The period and amplitude for each axis may be defined dynamically by the operator with additional inputs to control SOSO initiation and termination. This mode permits second order background compensation for photometry and LWIR radiometry, thereby simplifying the data reduction.

AMTA SCAN Mode - An automatic sky scanning mode was developed to expedite the AMTA sky survey experiment. This mode provides for automatic telescope positioning in elevation for a constant azimuth. Elevations are designated by defining a starting elevation and an elevation increment for one to four zones. A dwell time for all points is also defined. 90^o is imposed as the scan completion point. This mode has been implemented in the EROS system and is operator controlled by means of ANK and FFK inputs.

Improved ATN File Format - The ATN file contains state vector initial conditions for all ballistic operations. The file is generated by the satellite preparation program, SATPREP, the mission preparation program MISPREP, the lunar ephemeris generator, MAHINA, and the planet ephemeris generator, PLANET 3. The Phase III formats include orbital elements and other pertinent data from the satellite library for satellites and IRV offsets for missiles. Also, state vectors are in units of meters and m/sec, and time in units of seconds, to be compatible with the standard units convention of EROS. The Phase III ATN library has been reorganized such that missiles each require only 2 sectors instead of 10 required by Phase II, thus reducing the library by more than 50% (5120 words).

Day Number Update - BTU buffer modifications were required as part of the development of the new driver. The day number from the time code translator has been included in a buffer which is periodically updated as opposed to an initial singular transfer. Previously, EROS had to be reloaded from disk to properly reset internal time after a day change. This is now no longer necessary.

Enhanced Operator Messages - The first line on the Data Disc computer display is reserved for operator input text and computer messages to the operator. This line is input/output from any of the four display channels which are assigned to the ancillary, 1.2-m, or 1.6-m and LBD consoles, respectively. Previous messages did not contain quantitative information and were output to all four channels regardless of mount relevance. For example, when the operator requests early motion on a ballistic operation, the old message "GEEV-UM" was displayed on all four channels. The new message, "GEEV-UM AT HH: MM: SS.SS XXX SEC EARLY," with the appropriate times as indicated, is displayed only on affected mount consoles. Another good example of pertinent information displayed is the value of mount azimuth or LBD turntable position read by the computer. The selective channel feature eliminates the problem of computer messages for one mount overwriting incomplete input messages for another mount.

Right Ascension and Declination Input by Operator - A feature to allow the operator to input celestial object coordinates via the alphanumeric keyboard was developed and incorporated into EROS. Inputs consist of apparent right ascension and declination.

2.4.3 Computer Hardware

Figures 34 and 35 are simplified block diagrams of the CDC 3500 and CDC SC-17 computer systems. No major modifications were made to the system during the Phase III contracting period. System upgrade consisted of

1. the addition of a third disc drive
2. replacing seven track tape drives with nine track drives
3. the upgrade of the CDC 3500 console switches.

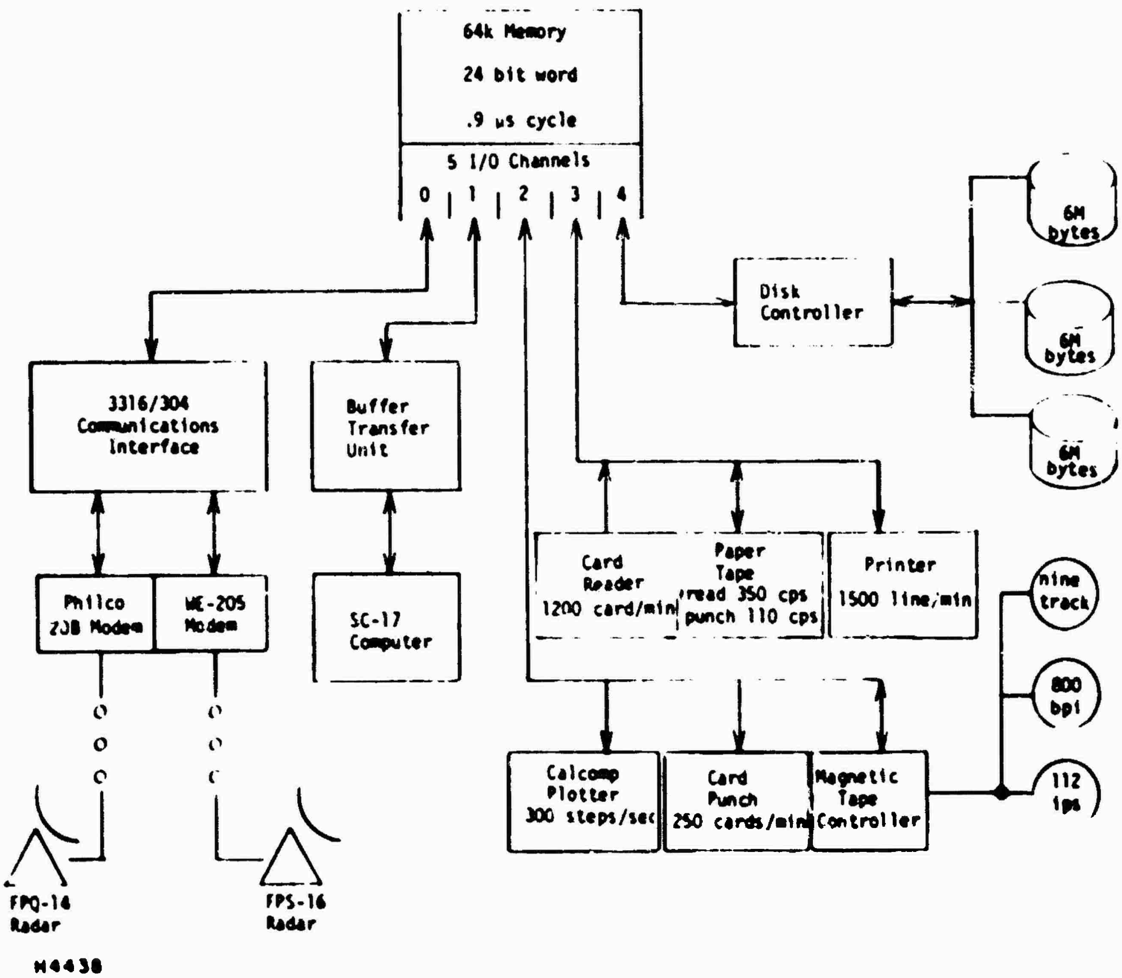


Figure 34 CDC - 3500 Computer

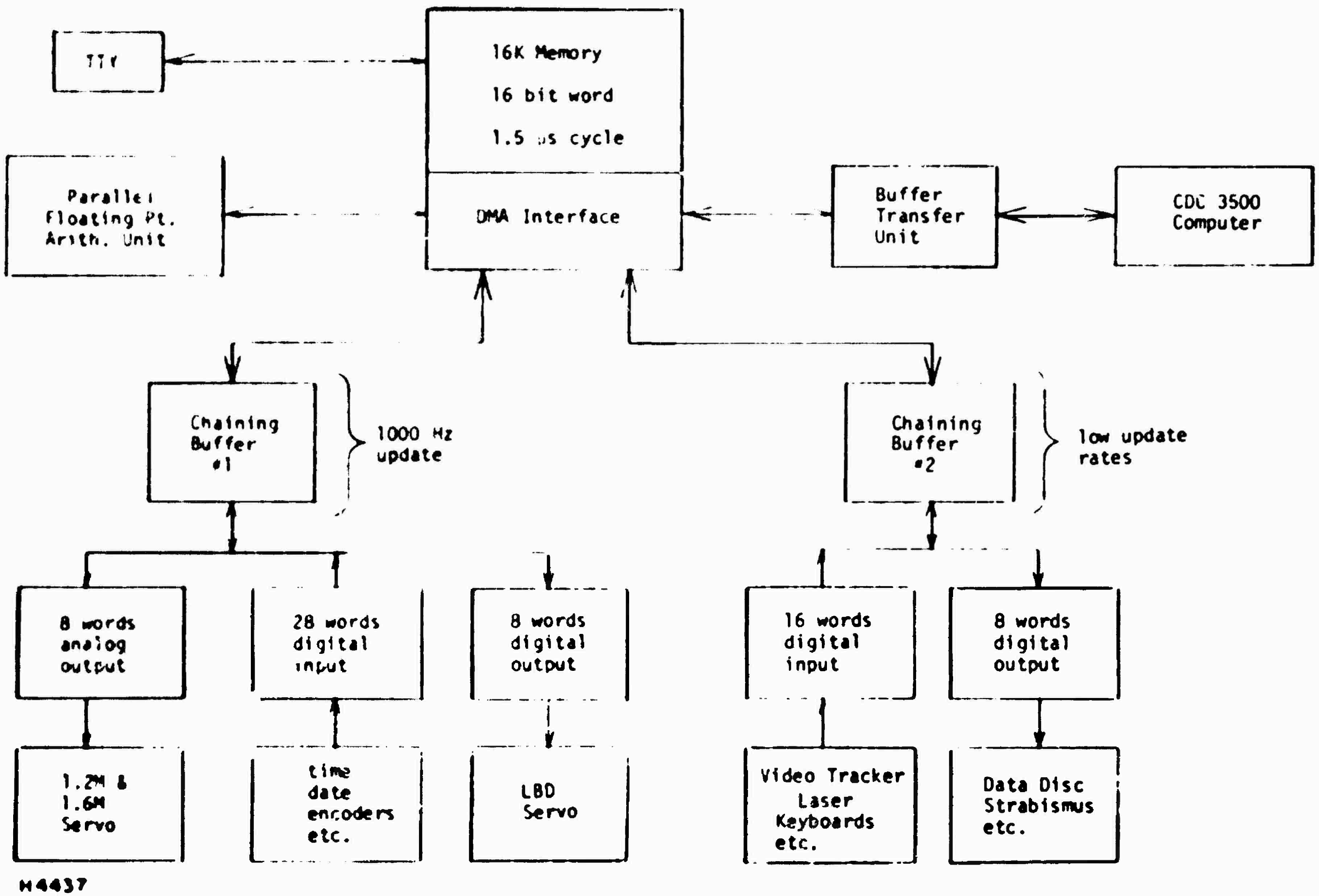


Figure 35 CDC SC-17 Computer

Added Disc Drive - Late in 1975, AERL purchased a 854 Disk Drive from Control Data Corporation to supplement the CDC 3500 computer peripheral configuration.

The additional disc was part of an overall upgrade of the CDC 3500 computer system which included increasing the memory capacity from 32K words to 64K words and converting to the MSOS5 operating system for batch mode operations. The added 854 disc was required to support a two-disc MSOS5 configuration, while retaining a third drive for exclusive use as the AMOS realtime data base.

The three disc configuration allows for one of the six megabyte 854 disc drives to be dedicated to the AMOS data base. The data base, consisting of star library, satellite library, mount parameter file, ATN file, site parameter and other physical constants, is accessed by both the realtime system EROS and nonrealtime programs running under MSOS. This "operational disc" also contains the current operational version of the realtime system as well as the backup and experimental versions. Therefore, the three disc configuration provides for the loading of either operating system in a matter of seconds using the console AUTOLOAD switches and either system always has access to the AMOS data base.

Nine Track Tape - Upgrade of the CDC 3500 magnetic tape peripherals from seven track to nine track configuration* is being accomplished in order to make the system compatible with other agencies and users.

The new configuration will consist of one for one replacement of existing seven track hardware with nine track equipment.

The new components will include the following CDC components:

one 3518-3 controller

three 659-3 tape drives

The replaced components are:

one 3228 controller

three 604 tape drives

CDC 3500 Console Switch - The CDC 3500 console provides a capability for display and/or modifying the contents of a memory cell and for stopping (break-pointing) the computer upon execution or reference to a particular instruction or data. For troubleshooting realtime systems, it is particularly important to be able to perform these functions while the computer is running. When the second 32K memory bank was added to the CDC 3500, it became impossible to perform these functions dynamically due to the inability of the hardware to distinquish between memory bank 0 and bank 1.

*Installation of the first nine track transport is scheduled for mid-December 1977.

The console switch modification reestablishes the use of these functions for dynamic troubleshooting of problems in the realtime system.

2.4.4 Software Systems

A computer system evaluation was conducted in October 1975 to ascertain the impact of autonomous operation of the 1.2-m telescope system. The question of how to partition the use of the computer system between two different agencies, each with independent scheduling requirements, led to the consideration of computer partitioning.

The evaluation pointed out that the major deficiency in the system would be created by the need to schedule computer functions to be run under two different operating systems; EROS for realtime mount control function, and MSOS4 for batch mission support programs. The conclusion was that, in order to satisfy both DARPA and USAF requirements, the computer system must be capable of simultaneous scheduling of realtime mount control functions and near realtime or batch mission support data processing. It was also noted that, though the CDC 3500 memory had been expanded from 32K to 64K words, the MSOS4 operating system was not capable of utilizing the added 32K words of memory. This was impacting development since some of the principal support programs had exceeded available memory (the satellite availability program, AESOP, and the satellite ephemeris program, SATPREP).

As a result of this evaluation, the Mass Storage Operating System was upgraded from MSOS4 to MSOS5. The principal advantages being:

1. MSOS5 supports the use of the added 32K of memory
2. The ANSI standard FORTRAN compiler, which was jury-rigged into MSOS4, was an integral part of MSOS5.
3. Many system level enhancements pertaining to multiprogramming partitions, input/output, error recovery, job control and interrupt processing were available.

Item 3 gives MSOS5 the potential for supporting a realtime activity scheduled simultaneously to lower priority batch jobs. It would, however, require extensive modifications to both EROS and MSOS5 to merge the two systems.

The MOTIF Data Transmission System MODCOMP IV computer will satisfy the requirement for simultaneous scheduling of realtime and batch; therefore, the concept of implementing EROS under control of MSOS5 has been dropped. The upgrade from MSOS4 to MSOS5, however, remains as a significant upgrade to the AMOS software systems.

In order to utilize the second 32K memory bank of the CDC 3500, the computer must be operated in Executive Mode. This imposes restrictions on batch programs and, thus, incompatibilities between programs run under MSOS4 and MSOS5.

A major effort was required to upgrade all nonrealtime programs to the MSOS5 system. Simultaneous with this required conversion of programs due to the change in the operating system, programs were also brought up to date with respect to the Phase III system subroutine library.

The upgrade to MSOS5, including all AMOS programs operating under it, along with the realtime system, EROS, represents a unified Phase III software capability for AMOS.

Missile Data Preparation (MISPREP) - MISPREP is the missile data preparation program. It is the Phase III replacement of MODMIP and is analogous to the Phase III satellite data preparation program SATPREP. MISPREP accepts initial conditions for missile trajectories in a variety of coordinate systems, computes initial state vectors required by the realtime EROS system, and generates an entry in the ATN data file for call-up by EROS.

PLANET 3 Ephemeris Program - The PLANET 3 program was developed to generate planet or asteroid ephemeris data for input to the realtime mount control system, EROS. Tabulated values of topocentric right ascension and declination are stored on the ATN disc file where they may be retrieved by EROS and used for tracking in ephemeris mode.

MAHINA Ephemeris Program - Program MAHINA generates an ephemeris of lunar topocentric right ascension and declination and creates a file on the ATN library. This file is accessible to the realtime tracking program for lunar pointing and tracking in Ephemeris Mode.

MAHINA requires geocentric right ascension, declination and polynominal coefficients for geocentric position as input. This data is obtainable from the American Ephemeris and Nautical Almanac.

The right ascension declination and geocentric distance from the epnemeris are converted to rectangular cartesian coordinates in the classical Earth Centered Inertial (ECI) system.

The AMOS site vector is computed as a function of earth model parameters on the data base. The site vector is expressed in Earth Centered Rotating (ECR) coordinates. The parallax correction is performed by rotating the AMOS site vector from ECR reference to the ECI reference for each epoch of time corresponding to the ECI moon vectors. Vector addition is performed to translate the coordinate system to the AMOS site and then AMOS topocentric right ascension and declination are computed.

ERG - The ERG system provides a capability for retrieving data from the EROS history tape and generating comprehensive printed reports. The system takes data from history tapes, reorganizes the data according to general report requirements and generates an interim file on disc for rapid random access. The data is then retrieved from disc according to specific report requirements which are then formed and output to the printer. The following reports are currently available to users:

1. Data Base: Earh Model and other important mathematical parameters and constants;

2. Mount Parameters: The mount model parameters;

3. Metric: Target observations flagged by computer interrupts when target is on boresight;

4. Mount Trajectory; Mount trajectory as defined by model corrected encoder data;

5. Desired Trajectory: Mount trajectory as defined by Kalman updated state vector.

Another class of reports is available to the systems programmers and engineers. These reports are intended for use in diagnosing system problems and are available only at special request. The following reports may be generated:

1. Lagragian Coefficients for servo update
2. Mount model corrections
3. Servo data
4. Kalman Filter state vector and covariance matrix
5. Ballistic target state vectors
6. FPQ-14 radar observations
7. History tape survey

Mount Calibration - AUTOCON3 determines coefficients for the EROS equatorial mount model. Normal use is automatic with observational data input from disc, edited, and processed by a Kalman filter to update the model coefficients, which are restored on disc. Printout and card control is provided for diagnosis or model development by an analyst.

The model for the equatorial mounts attempts to account for the effects of encoder zero point offset, nonorthogonality, and flexure on the telescopes' line of sight. The EROS model includes seven parameters for each mount, and eight more parameters for each telescope (up to three per mount). Thus, for each mount-telescope system, 31 parameters must be determined.

AUTOCON uses the Kalman filter algorithm to estimate the mount parameters. If certain statistical assumptions are valid, the estimates are the best attainable. Furthermore, the algorithm also provides an estimate of the covariance matrix associated with the state, which contains much useful information, as discussed below.

SCONDET - The error coefficient estimator uses a Kalman filter to process stellar observations for the LBD, in a manner which closely parallels that of AUTOCON3 (the estimator for the equatorial mount). SCONDET has two modes. The primary mode updates all coefficients for the first two table positions encountered in the observations file, and only turntable coefficients for subsequent positions. The secondary mode fixes all gimbal coefficients and updates only table coefficients, for all observations. This dual-mode scheme avoids difficulty with very large matrices, which would be required if all coefficients were unconstrained for each observation.

AMTA Data Processing - A system for quick look processing of digitized AMTA data (including Jones calibrations) has been completed. The JONES program computes responsivities of all detectors in parallel. The TOGPLOT program prepares plots of smoothed voltages, irradiance, exatmospheric irradiance, or radiant intensity, via the 3500 on-line plotter. The simple algorithms used permit easy assessment of sensor performance and data potential with reasonable accuracy and quick turnaround time.

2.5 ADDITIONAL DEVELOPMENT EFFORTS

Previous sections have described the development efforts and accomplishments for the four major AMOS systems. A number of additional activities were undertaken which involved improvement to individual sensor subsystems, the facility, or measurement support capabilities. These developments are described herein.

For example, descriptions of efforts applied to video sensors for a particular system, e.g., the 1.2-m telescope system, are discussed in the relevant section of this report. The more broadly scoped considerations for video systems and some specific developments which have contributed to overall site capabilities are treated below.

Development of the Fire Alarm and Control System is a specific facility-type item, and upgrade of the timing system represents an activity which improved overall measurement support capabilities.

2.5.1 Summary

A key element in utilization of large telescope systems is the use of closed-circuit video cameras to display what the telescope is viewing to the telescope, or sensor, operator. Having high quality video systems available is not only essential to achieving good measurements but is an underlying requirement to maintaining AMOS as a state-of-the-art optical site.

During Phase III a number of obsolete video cameras were replaced by equipments which more nearly represent state-of-the-art video technology. Silicon Intensifier Target (SIT) and Intensified SIT (ISIT) cameras are typical of the higher sensitivity and higher resolution systems now employed. Digital integrating electronics, to supplement the capability for acquiring low brightness objects, have also been added.

A video autotrack system has been incorporated into mount control to allow closed loop tracking of displayed targets from any selected video source. This capability reduces the reliance on man-in-the-loop telescope command.

In line with upgrading of video sources, an improved video recording capability has been added. Similarly, to allow testing, alignment and calibration of the video systems to assure optimal performance of both new and old systems, an electro-optical test and calibration facility has been implemented.

Program efforts were also devoted to interfacing the proposed Teal Blue Camera system. While development of this sensor was ultimately discontinued, the interface system which was prepared has been utilized for a number of other experiment applications.

As a result of the catastrophic fire in a building colocated on Mt. Haleakala, belonging to the Smithsonian Astrophysical Observatory, the AMOS capabilities for fire detection and control were assessed. Recommendations for upgrading the capability were implemented, and an alarm system, Halon extinguishing equipment and foam generating fire fighting apparatus were added.

Both inter- and intrasite communications systems have been upgraded. The equipment was made available through the Range Communications Control Center at SAMTEC and installed by Quintron Systems, Inc., a range communications contractor. The improvements offered by the new system have enhanced measurement support, both as far as station-to-station communication within the site and for external range links.

Similarly, improved timing system stability, accuracy and reliability were achieved to increase the validity of AMOS data measurement support by providing Universal Time to a precision of 0.1 μsec and an accuracy of 5 μsec.

Finally, development efforts were undertaken for a system to measure, every 10 minutes, the degree of cloud cover at AMOS. This data, taken by the All-Sky Camera system, is important as part of the Atmospheric Characterization efforts and to contribute to the data base being generated for the site by the Air Force.

2.5.2 Video Systems

At AMOS, the use of closed circuit video camera systems has become a vital constituent of the mission scenario. The operations personnel use these systems as tools to achieve reliable acquisition of targets as well as to fulfill the requirements of tracking, measurement and recording.

Closed circuit video camera systems provide three useful advantages in this application: they eliminate the awkwardness associated with a human observer looking through an ocular located on the telescope, which is the classical method of visually using a telescope; they provide greater sensitivity to light than the human eye; and they avoid the time delay in film processing from photographic observations.

The telescope operators acquire targets by searching an area of sky using one of two wide field-of-view telescopes equipped with video cameras. When the object has been visually acquired, the operator steps the telescope to position the target on a reticle which is optically projected onto the video sensor to designate the boresight of the prime telescope.

The object of interest may then be tracked using a narrow field-of-view video camera on the prime telescope. The operator again positions the target on a reticle locating the boresight of the prime sensor which may be visually blind (such as an infrared sensor). The video display provides him with a visual feedback of his manual adjustments and a clear indication of whether or not the computer-generated track remains stable.

If it is desired, a permanent record of the video portion of a mission can be made, using a video tape recorder, or the Teledyne MTR-1 Photorecorder can be used to obtain a 16-mm cine film record directly off a high resolution TV monitor.

The video camera systems at AMOS run the gamut from older technology to the best the present state-of-the-art has to offer. Table 15 lists the cameras now in the AMOS inventory.

It has remained a Phase III goal to maintain AMOS at the state-of-the-art in video technology. Consequently, over the period of this contract, a number of excellent, high-gain video cameras have been procurred to replace the older, inadequate cameras in the inventory. A Cohu SIT (Silicon Intensifier Target) vidicon camera was obtained as a boresight camera for the Teal Blue Camera System and subsequently has been used to support a number of programs, such as Speckle Imaging and Teal Onyx. A Cohu ISIT (Intensified Silicon Intensifier Target) vidicon camera was purchased as a boresight monitor for AMTA. A Quantex QX-10 Integrating Digital TV (ISIT) camera was obtained to support the SAMSO Evaluation Program and has been supporting Interim Tracking Operations for ADCOM. Recently, another Cohu ISIT camera was procurred for the boresight monitor of the laser beam director.

In addition, two Quantex QX-11 integrating cameras will be provided with the new AMOS Acquisition Telescope Systems (AATS) which should be received in early 1978.

A number of other pieces of video test equipment have been procurred to increase the AMOS capabilities to service and maintain the AMOS video system in an efficient manner and to perform calibrations traceable to the National Bureau of Standards. A new video tape recorder was purchased to replace an older, unreliable unit and a video autotrack system has been added to allow closed-loop tracking of visual targets.

2.5.2.1 Video/Imaging Systems

During Phase III, there was a de-emphasis of classical photographic imaging at AMOS and a corresponding decrease in photographic technology development and imaging missions. At the same time there was a greater emphasis on video sensor utilization for detection of faint objects.

With the addition of the Quantex Integrating Digital TV Camera to the AMOS inventory, the status of video technology at AMOS was brought up to the state-of-the-art in high-gain video sensors. Using this video camera on the 1.6-m telescope, AMOS personnel observed the faintest star ever detected at this facility, a star of 19.5 visual magnitude. Continued experience with this camera has demonstrated the value of digital image processing in the acquisition of very faint targets against a sky foreground. It was also demonstrated that the use of modern intensified SIT camera tubes for video acquisition and tracking is well suited to the particular applications at AMOS.

TABLE 15

AMOS VIDEO CAMERA SYSTEMS

Generic Type	Target Type	Manufacturer	S/N
Image Orthicon	Conductive Glass	Bendix	120
Image Orthicon	Conductive Glass	Bendix	122
Image Orthicon	Conductive Glass	Bendix	122A
Image Orthicon	Conductive Glass	Bendix	140
Image Isocon	Conductive Glass	MTI	264
Image Isocon	Conductive Glass	MTI	287
Intensified Image Isocon	Conductive Glass	MTI	290
Vidicon	Antimony Trisulfide	MTI	794
Vidicon	Lead Oxide (Plumbicon)	MTI	242
Vidicon	Silicon Diode Matrix	MTI	251
Vidicon	SIT (Silicon Intensifier Target)	COHU	5-0075
Intensified Vidicon	ISIT (Intensified SIT)	COHU	5-0091
Intensified Vidicon	ISIT	COHU	5-0035
Intensified Vidicon	ISIT	QUANTEX	None

Thus, AMOS served the dual purpose of a high-quality test bed for video camera systems and a source of new data and satellite mission support using the most modern video sensors.

The use of video sensors at AMOS during Phase III has emphasized high sensitivity and digital signal processing and noise reduction for the purpose of detecting faint, unresolved targets. No emphasis was placed on high-resolution imaging with video camera systems, partly because the Teal Blue development program promised to expand the state-of-the-art in this area to such an extent that all existing techniques would have been surpassed. This program failed to produce the expected results, however, so that existing high-resolution video techniques are still the best available to the satellite community, with the exception of direct classical photography.

2.5.2.2 Video Autotrack

An automatic television target tracker (video autotrack) was received from DBA Systems in late February, 1975, and was integrated into AMOS. This system provides AMOS with the capability to track, automatically with either or both mounts, targets which are observed with a closed circuit video system. The tracker is able to process and track two separate video signals (from different TV cameras) and provides as an output both analog and digital signals describing the position of a target in either system's video frame.

The tracker can be used in several ways, depending on the application: alternate video selection, dual mount for the same target, or multi-target tracking enhancement. In any of these cases, the tracker serves as an interface between the video sensor systems and the computer (realtime operating system) to provide a closed loop system for target tracking. The three operating modes listed above are described below.

1. Alternate Video Selection. The unit will accept two independent video signals (see Figure 36). For example: assume that wide and narrow field-of-view video signals are present. When the wide field-of-view tracker acquires a target, the computer (or operator) switches from radar to wide tracker target position data. When the narrow field-of-view tracker acquires and simultaneous tracking occurs, the computer switches to narrow field-of-view tracking without disruption of target position data.

Also, while tracking in one field, other video inputs may be switched to the alternate tracking gate. The computer may then choose to track the target using the new video source. Thus, any unstable target position data caused by video switching is avoided.

2. Dual Mount Single Target. The dual gate tracker allows each mount, 1.2-m and 1.6-m to track the target independently (see Figure 37). Individual target position data is available for each mount.

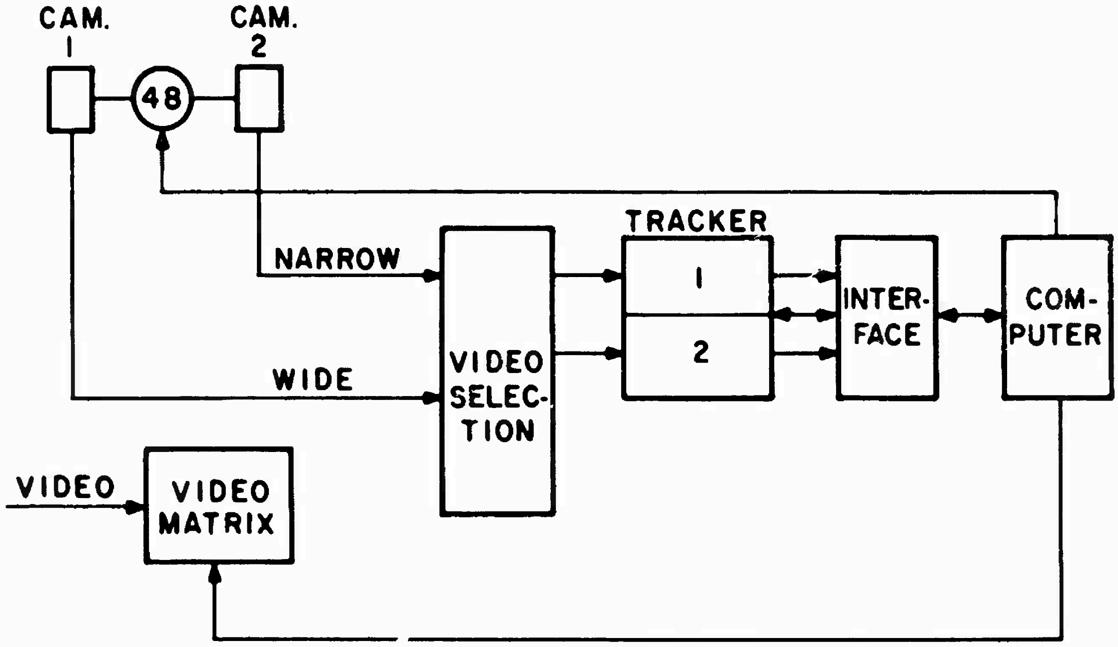
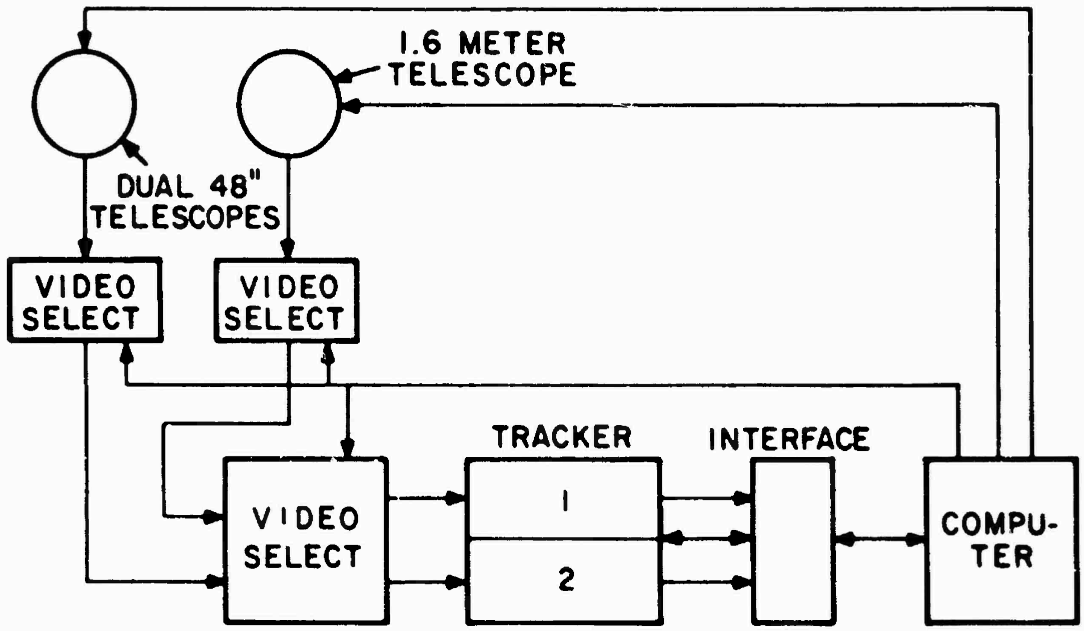


Figure 36 System Configuration for Video Autotrack (1)



H3612

Figure 37 System Configuration for Video Autotrack (2)

3. Multitarget Tracking Enhancement. Each mount tracks independently two unrelated targets. Individual target position data is available for each mount.

The video autotrack system is installed in the telescope control console in the main control room. Some experience has been obtained in the use of this device. In particular, it has been found to be susceptible to noise on the video inputs. Spurious noise, EMI pickup, and low signal-to-noise ratio inputs can cause loss of track and, occasionally, mount runaway conditions. Efforts have been undertaken to reduce spurious noise and EMI pickup. Low signal-to-noise ratio conditions may be unavoidable when high-gain sensors are required to detect faint targets against a sky foreground. The video autotrack, nevertheless, provides the potential for versatile applications and for reducing the man-in-the-loop requirements for routine tracking missions.

2.5.2.3 Video Recording Systems

There are two systems at AMOS dedicated to recording video information; the Teledyne MTR 1E Photorecorder and the Video Tape Recorder.

Teledyne MTR-1E Photorecorder

The Teledyne MTR-1E Photorecorder is designed as a high quality telecine recorder which produces a 16-mm film photographic record of the display on a high-resolution TV monitor. The pull-down rate of the cine film camera is synchronized to the 25 frames/sec rate of AMOS video, so that each successive frame of cine film records a frame of video information.

In December, 1975, a field engineer from Teledyne visited AMOS and performed maintenance work on the cine camera hardware of the MTR-1E. As a result, the mechanical performance of the camera has been significantly improved. The display picture quality of the Conrac high-resolution monitor had been degraded by electronic problems in the monitor, so the monitor was sent to the vendor's plant for an overhaul and adjustment.

Upon receipt of the monitor at AMOS after overhaul, it was discovered that the high-resolution CRT had been broken in transit, and hence a new CRT was procured and installed. The new CRT has solved the previous problem with poor resolution.

A problem which has existed in this photorecorder system has been resolved by the purchase and installation of six adjustable video distribution amplifiers. This problem involves the sequential recording of several video sources on the MTR-1E Cine Photorecorder using the AMOS Automatic Video Source Sequencer.

Normally, the sequencer switches a number of video sources in a selected sequence, via the Video Switch Matrix, to the MTR-1E Cine Recorder for sequential recording. Up to 10 frames of each source can be recorded before the next source is switched in. The various video sources can have a wide range of signal amplitudes, resulting in a sequence of displays on the cine recorder which exhibit a large range of luminances.

The cine recorder, however, is unable to record over such a wide latitude, hence some of the sources may be greatly overexposed or underexposed on the film record. The new adjustable video distribution amplifiers will be used to modify the signal amplitudes from up to six sources prior to the insertion of these signals into the Video Switch Matrix, so that the resulting displays on the cine recorder will be nearly matched in luminance. Then, all six sources will be recorded on the linear part of the film's exposure characteristic curve with no loss of information. Experience has shown that only rarely are more than six video sources recorded during one mission. Up to 10 different sources can be recorded in sequence, if this should become necessary.

Video Tape Recorder

AMOS had been experiencing problems with the existing Ampex Video Tape Recorder (VTR) for several years. Because the VTR was old and the same maintenance problems continued to recur, RADC was apprised of the problem and, as a solution, procurement of an International Video Corporation Model 711/p Video Tape Recorder was approved. This equipment was recommended by AERL as a result of an engineering survey of available units suitable to AMOS needs.

The unit was installed at AMOS in June, 1977. The VTR is a 1-inch helical scan videotape format recorder capable of recording and playback of up to one hour of composite 50 field monochrome video signals. The unit also records one channel of audio signal from either a microphone or audio line input.

In addition, the unit contains a power adapter unit which permits use of local 120 Vac, 60 Hz power input, instead of the normally required 240 Vac, 50 Hz power for this standard European recorder.

The IVC 711/p is integrated into the AMOS video distribution system such that all AMOS video signals are switch selectable as video input to the recorder, and the playback video is available at any AMOS TV monitor connected to the Video Switch Matrix.

A number of problems were encountered with the VTR following installation. It was returned to the factory for repairs under warranty and is now operating reliably.

2.5.2.4 Electro-Optical Test and Calibration Lab

Experience with the operating environment at AMOS has demonstrated a need for a facility where electro-optical sensor systems could be evaluated and calibrated under controlled conditions such that extraneous disturbances caused by the external environment could be eliminated. There are a number of video sensors, image intensifiers, and photomultiplier tubes in routine use at AMOS. These electro-optical devices are difficult to evaluate and calibrate in situations where they are mounted on telescopes. Because of the severe EMI environment at AMOS, there is a special need for a testing area which is shielded from EMI and which can provide a totally dark area for devices sensitive to light.

Appropriate test equipment suitable for evaluating electro-optical sensors was lacking at AMOS. Hence, efforts were initiated to secure the necessary test equipment and to provide an electro-optical test and calibration laboratory within AMOS.

A plan for utilization of the laboratory includes the following tasks:

1. Provide for routine calibration of all sensors which respond to light in the visible and near-IR regions of the spectrum, to record responsivity, noise levels, and detect any slumping trend;

2. Provide for calibration of these sensors at specific wavelength bands to determine performance and monitor life;

3. Provide an environmentally-controlled area, from the standpoint of low ambient light level, electrostatic shielding, and fairly constant temperature, in which to test sensors which respond to these variables that are poorly controlled elsewhere;

4. Provide a more suitable location for measuring the various performance criteria of sensors that cannot be easily measured on the telescopes, establishing baseline performance levels for each sensor, and maintaining a history of their characteristics;

5. Provide a source of photometric light standards, traceable to the National Bureau of Standards, which can be used to calibrate sensors which respond to light.

The necessary hardware was procured and temporarily installed and colocated with the AMOS optics laboratory. It became somewhat inconvenient to do testing of electro-optical devices in the same room where testing of optical systems was taking place, especially when the laser unequal path interferometer (LUPI) was in use. The LUPI requires a minimum of disturbances, particularly vibration, from other sources when it is used to test optics.

The electro-optical test and calibration lab, therefore, was subsequently moved to the former photography lab which is not currently required to support photographic processing. This area occupies rooms 11 and 11A in the main observatory building. Testing and calibration of light-sensitive devices can be performed in room 11A while room 11 may be used for storage of equipment, sensors, and photographic cameras and accessories. Room 11 is also used as a work area for performing repair and maintenance service on electro-optical sensors.

The laboratory is nearly completely configured in this new location; minor modifications are expected to result from experience gained in using the lab. Cables carry sync and video signals between the main control room and the new lab for convenient testing of all observatory video systems.

This lab has already proven itself to be a valuable asset to AMOS in the routine performance testing and optimization of sensitive video cameras. All electro-optical sensors at AMOS may now be calibrated and maintained in this lab, and a performance history log kept on each sensor.

2.5.3 Teal Blue Camera

The Teal Blue Camera was being developed for use with the Compensated Imaging System (CIS) to provide a means for recording high resolution, diffraction limited images. The camera was to be mounted on the 1.6-m telescope along with a short exposure video system for providing a realtime boresight capability. The camera was to be built by CBS Laboratories for testing at AMOS in the fall of 1975 prior to its use with the CIS.

The CBS Electronic SOI System consisted of a sensor unit and two boxes containing auxilliary electronics located on the telescope; a remote control unit in a room adjacent to the main AMOS control room, and an Electron Beam Recorder (EBR). The basic sensor unit was the heart of the system; the EBR was to produce a hard-copy output from the telescope-mounted sensor unit via the camera control unit.

AMOS personnel were responsible for the design and development of a boresight TV system to be used with the CBS Teal Blue Camera during its evaluation phase at AMOS. The integration of the Teal Blue Camera into the AMOS complex also required certain modifications to the facilities to house camera controls and recording systems. In addition, certain designs were performed in preparation for the physical mounting of the Teal Blue Camera and its electronics onto the AMOS telescopes.

Rooms 2 and 2A, located next to the AMOS main control room, were modified in April of 1975 to accept the Camera Control Unit (CCU) and a CBS Electron Beam Recorder. The modifications consisted of removing a wall separating the two rooms, addition of power outlets to operate the EBR, and necessary air conditioning ducts.

A small console, containing two TV monitors and controls for a boresight Silicon Intensifier Target (SIT) TV camera, was assembled in June of 1975 for use in Room 2. One of the monitors would provide the Teal Blue system operator with images from either the 18.6 inch (1.2-m mount) or 10-inch (1.6-m mount) finder telescopes. The second monitor would display images from the SIT camera and provide the necessary realtime display of the input to the CBS camera.

The boresight system, in part, consisted of an optical beam splitter, to reflect ~ 8% of the available light from the telescopes to a Cohu SIT camera. A SIT type camera was selected instead of the originally proposed

Intensified Silicon Intensifier Target (ISIT) because of the extra intensification was not required to match the lower sensitivity of the CBS Teal Blue Camera and the plain SIT sensor provided higher spatial resolution than the intensified version. The SIT boresight camera was purchased with a 10:1 zoom lens which provided a factor of up to 3.3 magnification for image evaluation, or a factor of up to 3.3 demagnification (larger field-of-view) for target acquisition. A Light Emitting Diode (LED) reticle projector was also included with the system to be used as a pointing aid. The camera was fitted with remotely changeable neutral density filters for tube protection. This boresight system was completed in mid-1975 and was used to support the University of Hawaii in their Lunar Ranging Program from August 1975 through February 1976.

Provisions were made for power connections and water cooling lines on both the 1.2-m and 1.6-m telescopes for operation of the CBS camera. Special mounting brackets were designed to support the Teal Blue telescope mounted electronics.

After experiencing several cycles of delays due to technical and manufacturing problems, the plans to deliver the Teal Blue Camera to AMOS were abandoned in January of 1977.

The boresight TV system and mounting package has been used to support several visiting experiments over the past two years. In addition to the University of Hawaii Lunar Ranging Program, the system was used for the ITEK Speckle Imaging experiments, and more recently the Teal Onyx Aircraft Measurement Program. The package will be kept intact to support the AMOS program as the need arises and other visiting experiments.

2.5.4 Fire Alarm and Control System

A reappraisal of the resources available at AMOS for fire detection and control were made following the destruction, by fire, of the nearby dormatory that was part of the Smithsonian Astrophysical Observatory. A design study was performed which recommended the installation of an early warning fire detection system and additional fire extinguishing equipment to supplement the existing fixed and portable CO_2 extinguishers.

Following approval of the AMOS Fire Alarm and Control System Design Study Report, the systems described below were implemented.

The fire detection system consists of an array of 42 smoke detectors, one 135°F thermal detector, three remote indicator lamps, six horn alarms and a master control panel containing the control unit and two zone units. The system is manufactured by the Pyrotronics Division of Baker Industries.

The smoke detectors operate on an ionization principle and react to the first traces of fire. Invisible combustion products entering the detector's outer chamber, disturb the balance between two ionization chambers and trigger a highly sensitive cold cathode tube. The firing of the tube transmits a signal to the control panel located at the guard station in the lobby of the main entrance to the Observatory building; it in turn activates the horns. A light built into each detector illuminates when it alarms. To assist in locating the alarmed detector the system is divided into eight zones (see Figure 38). When a detector alarms, a light on one of the zone indicator units indicate the zone that it is located in. The detectors located in the crypto vault, underground pump room, and above ground pump room have remote indicator lamps in readily observable locations. Lights on the control unit indicate "power on," "fire," and "trouble." The detector circuit is supervised to detect open or short circuits, loss of power, or under voltage. The alarm circuit is supervised to detect open or short circuits and ground faults.

A Halon system was installed in selected high value areas, see Figure 39. The extinguishing agent Halon 1301 is a halogenated methane compound, bromotrifluoromethane. Its chemical symbol is $CBrF_3$. Halon 1301 is stored under pressure as a liquid in steel cylinders. A pressurant gas, nitrogen, is used to improve the discharge of the agent from the fire extinguishing system. On discharge, the stored pressure acts as the propellant pushing the agent from the storage vessel through the system piping as a liquid under pressure to the nozzle outlet. Liquid expansion takes place at the nozzle orifice while the agent is directed at the hazard.

Halon 1301 extinguishes fires by acting as a negative catalyst interrupting the chemical combustion chain reaction of fuel with oxygen by blocking energy transfer from burning fuel to unburned fuel to a point where combustion ceases.

The Halon vapor has a low level of toxicity which allows the system to be activated prior to evacuation of personnel from the hazard area when design concentrations are $< 7\%$. The nozzle and pipe size are elected to allow the agent to be discharged in < 10 sec.

Each Halon subsystem is designed to conform with NFPA (National Fire Protection Association) Standard 12A-1973. The system design temperature is $70^{\circ}F$, and the maximum discharge time is 10 sec. The design concentrations are 5-6%.

The release of the agent is by manual activation of a mechanical device located on each cylinder. Shutdown of air conditioning systems can be manually activated by means of a switch located adjacent to the Halon release valve. Directions for system operation are located adjacent to the cylinder for each subsystem.

Portable foam generators may also be used to extinguish fires in the domes, and other areas not protected by Halon subsystems, when the fire cannot be extinguished with a portable CO_2 unit. A portable generator is located on the first floor of each dome adjacent to the double exit doors, see Figure 39. Each generator is provided with a discharge tube to conduct the foam to the hazard location, and a door adaptor tube, flared to a circumference of 25 ft, which allows a sealed connection to be made to a doorway. To extinguish a fire in the second level of the dome the discharge tube would

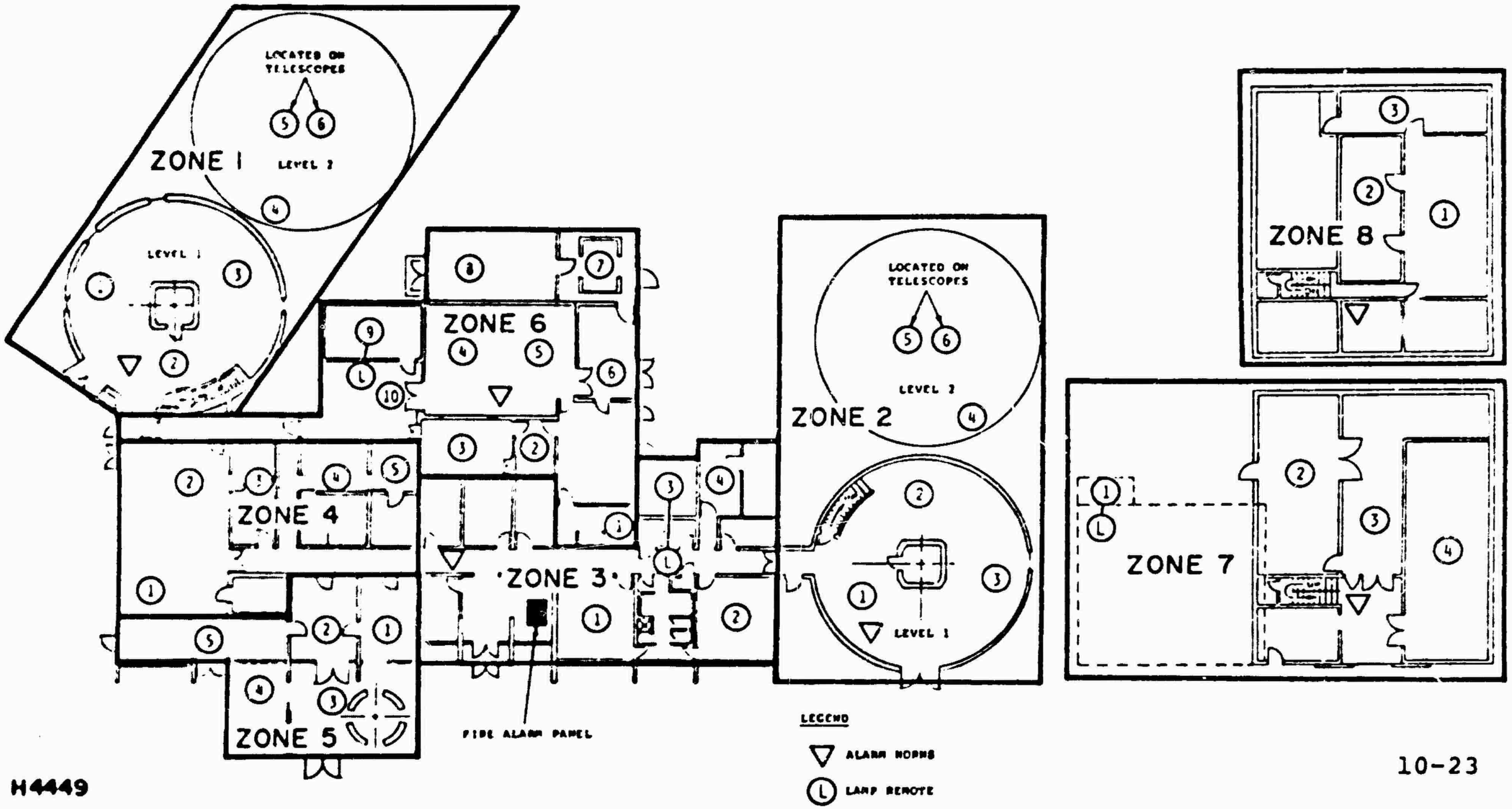


Figure 38 Fire Alarm System

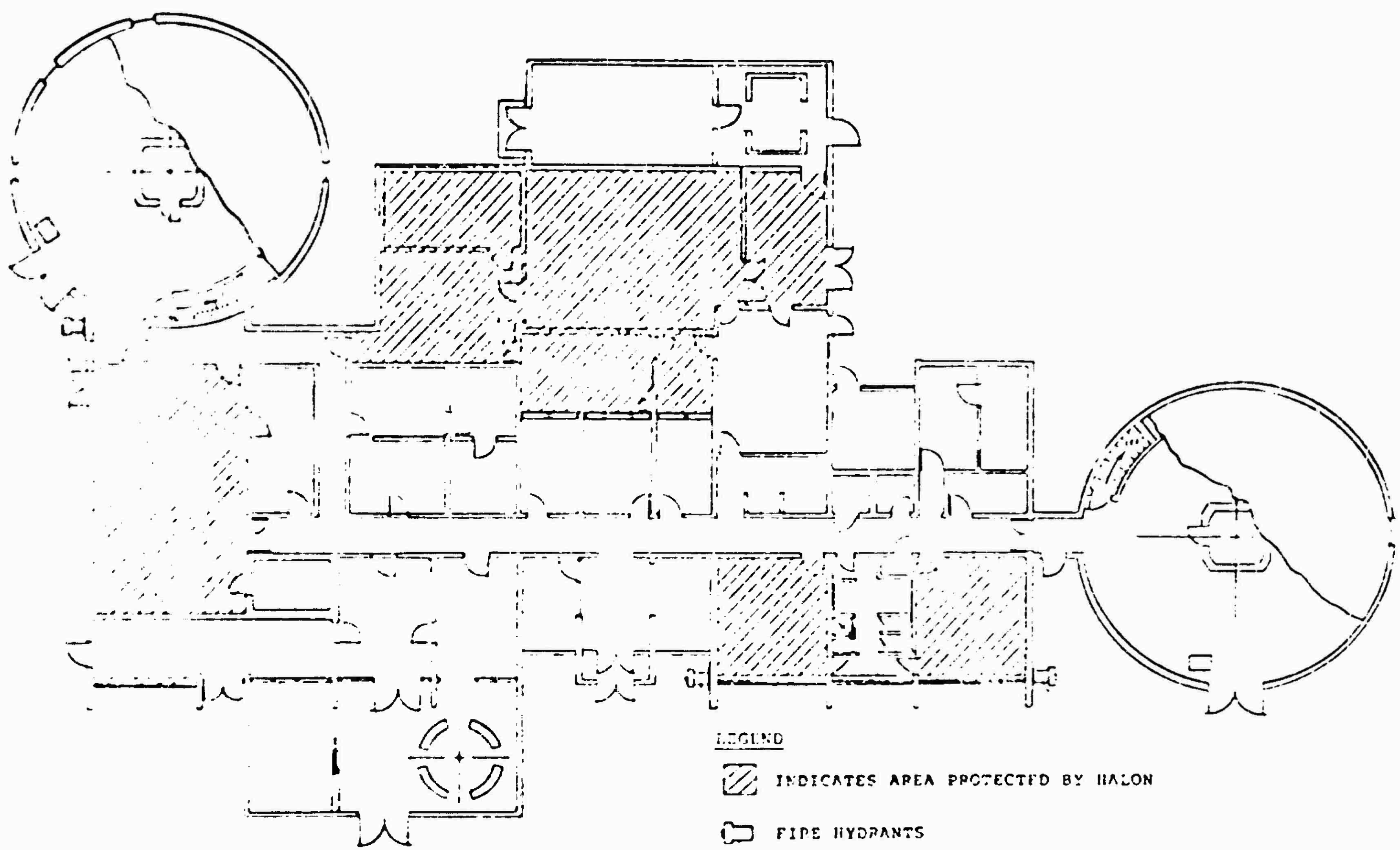


Figure 39 Fire Control System

be inserted into the stairwell leading to the second floor. To extinguish a fire on the first floor the tube would be inserted into one of the double exit doors.

Water is supplied to the foam generators from the 70,000 gallon facility underground storage tank. This tank serves as the only source of water for the Observatory, and hence, is used for other than fire fighting purposes. The water level in the tank will be monitored and maintained well above the amount required to fill the two domes with a foam/water mixture. A pump has been installed in the underground pump room adjacent to the water tank to supply water to three water hydrants. One is located outside of each dome, and the third just outside of the main entrance of the Observatory building, see Figure 39. Cabinets, located adjacent to each hydrant, contain hose to run from the hydrants to the foam generators.

2.5.5 Site Communications System

The station intercom in use at the AMOS Observatory for many years was highly unreliable and had restricting system limitations. During April and May of 1976, it was totally replaced with an intercom manufactured by Quintron Systems, Inc. Quintron personnel upgraded this GFE equipment to provide additional features required by AMOS. Since installation, the system has been used extensively during operations and found to be very versatile, highly reliable, easily maintainable and appears to totally satisfy the Observatory needs.

The intercom system main frame (Figure 40) incorporates the necessary electronics for seven operational nets, six voice direct lines (VDL); three dial lines, and access to the public address (PA) system.

Net: This refers to an integral communications network where any particular station can talk/listen to any other station which has the same net selected. Any number of stations can access a particular net with no adverse effects, since separate amplifiers are used for each station send/receive line.

VDL: This is a direct link between any particular station or group of stations and any other station or group of stations -- on or off site. Four of these VDL's comprise the four trunk lines connected to Wheeler AFB, Oahu, one VDL links the 1.2-m main control console with the West dome, and the last VDL links the 1.6-m main control console with the East dome. The VDL's have a signal capability in that, when accessed on one station, they "ring in" at the connected station.

Dial Line: These are identical to telephone extensions within the Observatory, with the added feature that all stations can access the same line at the same time.

PA: A spring loaded switch allows an operator to access the Observatory PA system for as long as the switch is held in the "talk" position.

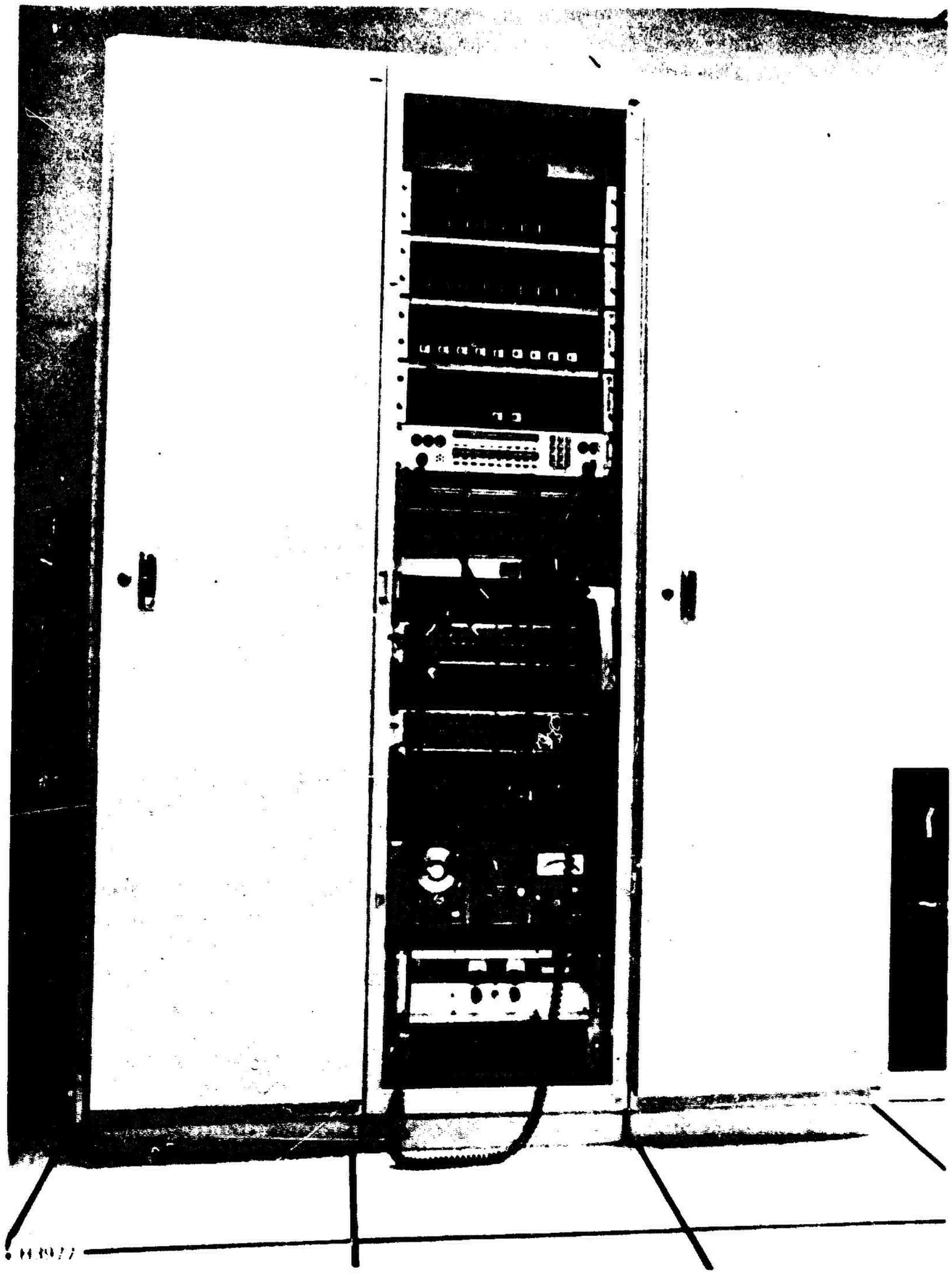


Figure 40 Intercom System Main Frame

Two types of intercom stations are provided: master and slave (Figure 41). The master station has all the features described above while the slave station has only headset connections and talk-monitor volume controls. The slave stations are permanently connected to a particular master and are therefore always connected to the same net, VDL or dial line that the master unit has selected.

Binaural headsets are provided which allows for separation of an active channel (talk-listen) and a monitor channel (listen only). An operator will hear any line(s) he has selected (switches depressed) in his left ear, and can monitor any other line (switches raised) in his right ear.

The intercom system is comprised of 12 master stations and 16 slave units along with an electronics main frame which is installed in the communications center. These units are identified in Table 16 which also lists their location and whether the particular unit is a master or a slave. For the case of a slave unit, the number in the alphanumeric designator indicates its particular master.

2.5.6 Timing System

The AMOS timing system has undergone a number of modifications under the Phase III program. These modifications were aimed at improving the stability of the system and increasing the reliability by making the system less dependent on commercial power. As a result of a timing system accuracy investigation, a new timing synchronization procedure was also generated.

The most significant change to the timing system occurred in 1976 when a Cesium Beam Frequency Standard (HP5060A) was added, replacing the previously employed quartz oscillator. The new unit provides an extremely stable frequency (better than 1 part in 3×10^{12}) and has an uninterruptible power supply in case commercial power is lost. An HP115BR Clock/Divider was also obtained and was incorporated into the system in late 1977.

During the latter part of 1976 and the early part of 1977 AMOS support of SAC metric missions yielded anomalous data. Small, yet significant, biases appeared in metric position data. The problem was traced to the timing system and proved to be an error in the synchronization procedure. A series of commercial power failures during this interval were contributory to the problem and made it more difficult to find, but the procedural error proved to be the overriding factor. This led to the generation of the above mentioned AMOS procedure. In addition, a number of steps were taken to ensure that the same sort of problem would not recur. These steps include the following:

1. Improvement of the WWVH antenna,

2. Procurement of a dc power supply for the LORAN-C receiver,

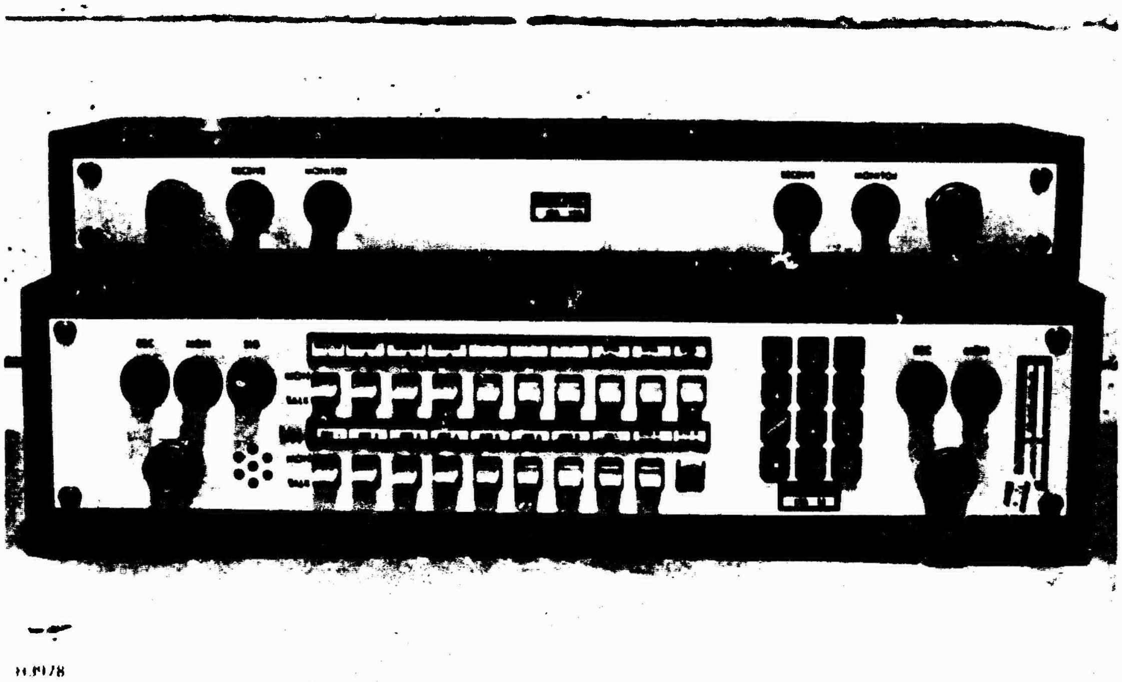


Figure 41   Intercom Stations (Master Station Below, Slave Station Above)

TABLE 16

INTERCOM STATION LOCATIONS

Station ID Master	Slave	Location
1		1.2-m Main Control Console
	1A	Photometer Control Console
	1B	AMTA Control Console
2		1.6-m Main Control Console
3		Video Systems Console
4		1.2-m Dome Control Console
	4A	1.2-m Mount
	4B	1.2-m Dome Pedestal
5		1.6-m Dome Control Console
	5A	1.6-m Mount
	5B	1.6-m Dome Pedestal
6		Communications Center
7		Computer Room
8		Laser Control Console
	8A	Laser Power Supply
	8B	Laser Transmitter
	8C	North Plane Watch Station
	8D	South Plane Watch Station
9		Laser Beam Director Control Console
	9A	Laser Beam Director
10		Atmospheric Measurement Control Console
	10A	Teal Amber Dome
	10B	North Weather Tower
	10C	South Weather Tower
	10D	Acoustic Sounder
11		Room 26 (Future Compensated Imaging Control Console)
	11A	Room 26 (Future Compensated Imaging DRS)
12		Spare (Initially Installed at SAO Site)

3. Procurement of a new time code generator (TCG) with dc power supply,

4. Crew training by a representative from the WWVH station on Kauai,

5. Establishment of a different standard configuration to facilitate checking the synchronization, and

6. Hook-up of the HP115BR clock/divider to serve as an independent check of the TCG.

Figure 42 is a block diagram of the AMOS Timing System as presently configured. As such, synchronization is independent of commercial power failures having a duration of one hour or less. Longer power failures may still result in loss of synchronization due to battery depletion, however, the timing synchronization procedure restores timing accuracy for these few cases. The primary goal of the improvements mentioned above was to increase reliability under the situation where a commercial power "glitch" occurs immediately prior to a mission. This increased reliability has been demonstrated by switching power off, then back on at the timing rack and verifying that synchronization was maintained.

2.5.7 AMOS All-Sky Camera System for Clear Line of Sight

The need of statistical data related to local atmospheric seeing conditions, i.e., percentage and the location of cloud cover, resulted in an AMOS engineered photographic system to record clear line of sight statistical data. The system employs an All-Sky lens (197° FOV), a 16-mm Automax Cine-Pulse Camera with data time clock, and a programmable exposure intervolometer.

The entire system is housed in a small cubicle equipped with a glass domed viewing port (Figure 43). The unit, located on the rooftop of the AMOS Observatory, operates once every 10 min, 24 hrs a day. The system is equipped with sensors located at the lens to sense both day or night conditions, to control shutter dwell duration, and to adjust lens settings for immediate changes in the ambient lighting conditions. The exposure range for the system can be varied from 1/100 sec to 101 sec, with lens aperture control ranging from f/16 to f/19.

The camera system was provided by L. W. International Corp. of Woodland Hills, California. Initial testing for proof-of-concept proved the system successful but also indicated that the shutter of the system failed to meet AMOS design criteria. A problem of shutter operation was also discovered so the camera was returned to the manufacturer for rework.

The housing for the system was fabricated during the cameras absence and, when the system was returned, film testing (choice, exposure, processing time/temperature) was conducted. This testing was done under the widest possible atmospheric conditions. As a result, the quality of data is now assured for nearly all circumstances.

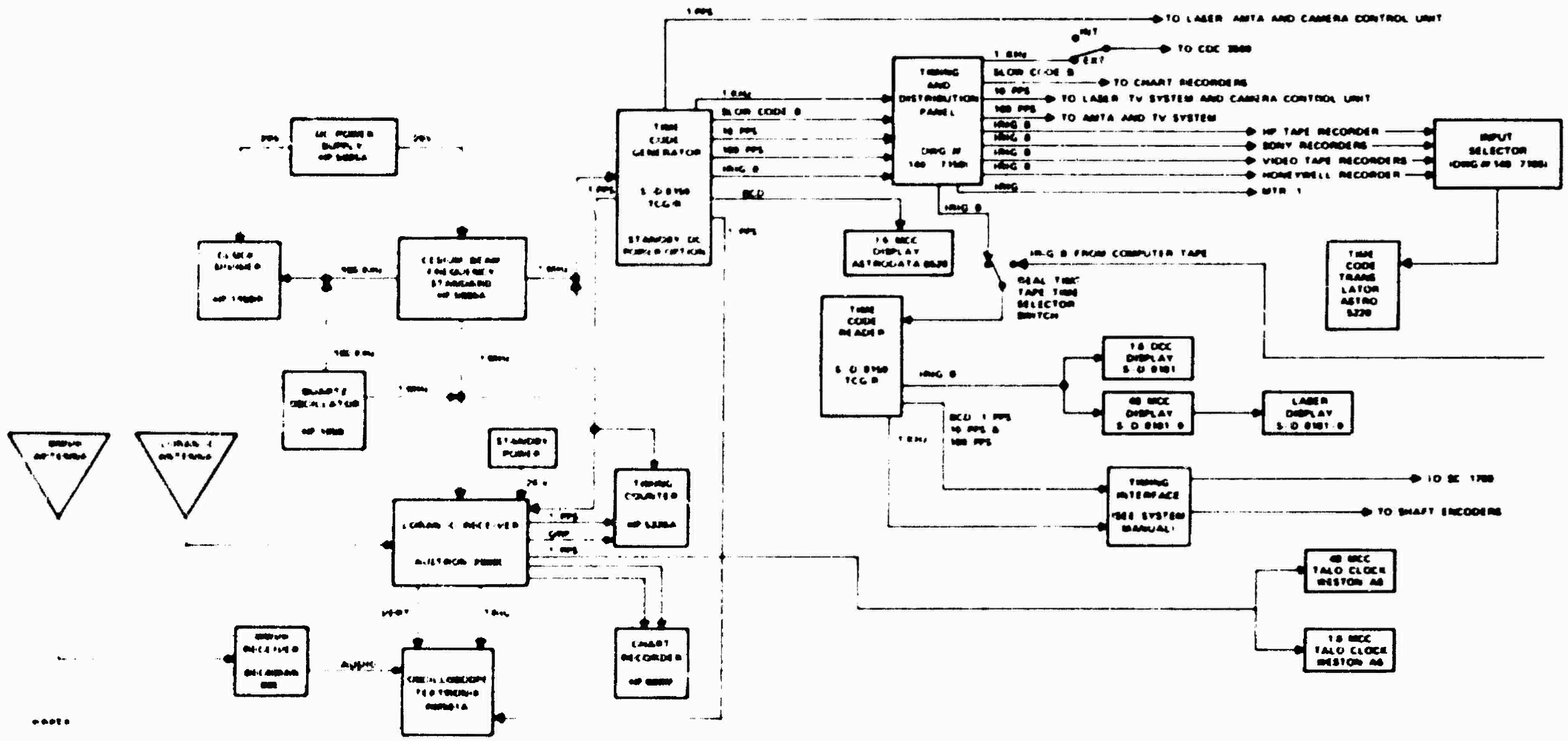


Figure 42 Timing System Block Diagram

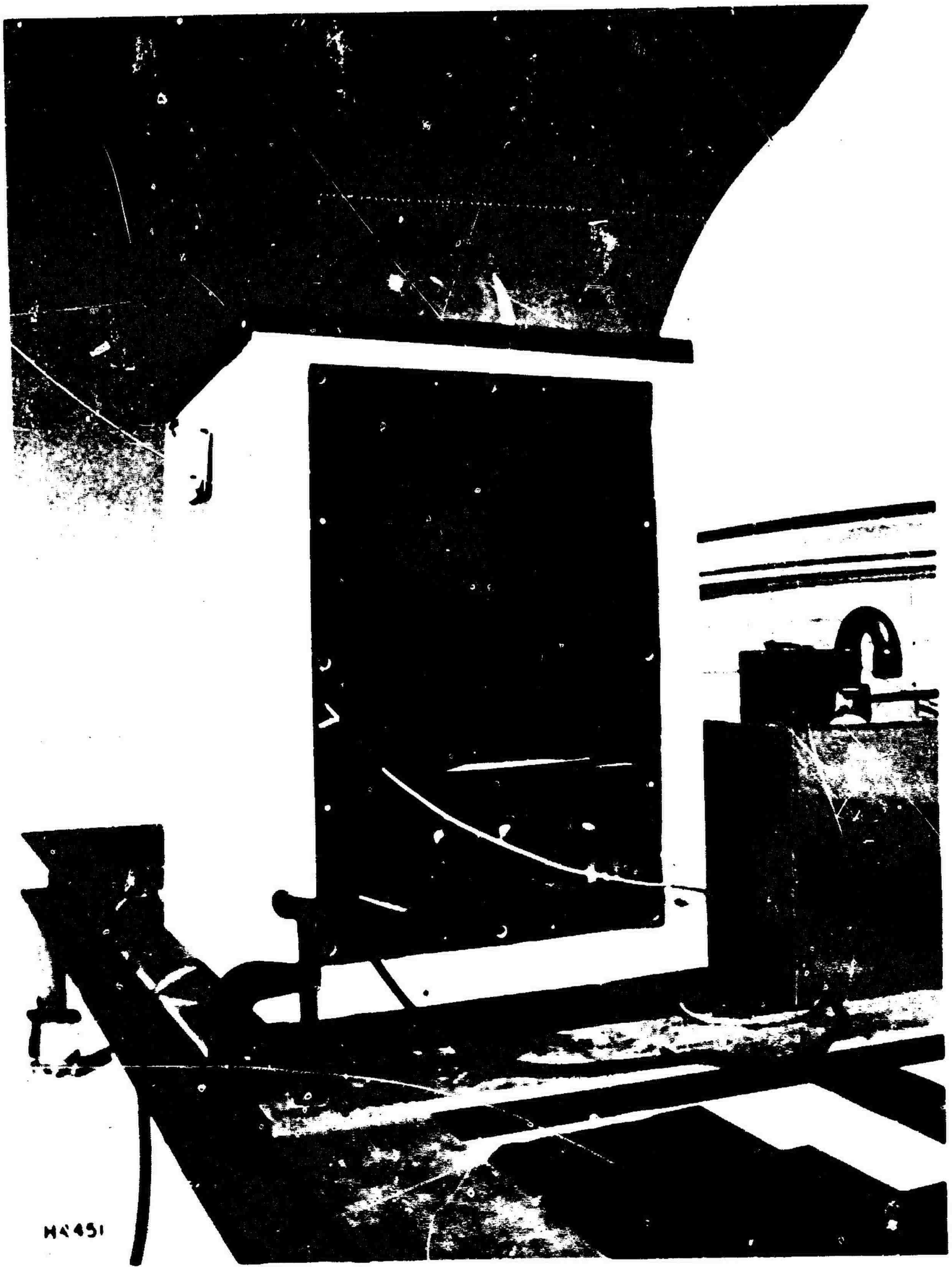
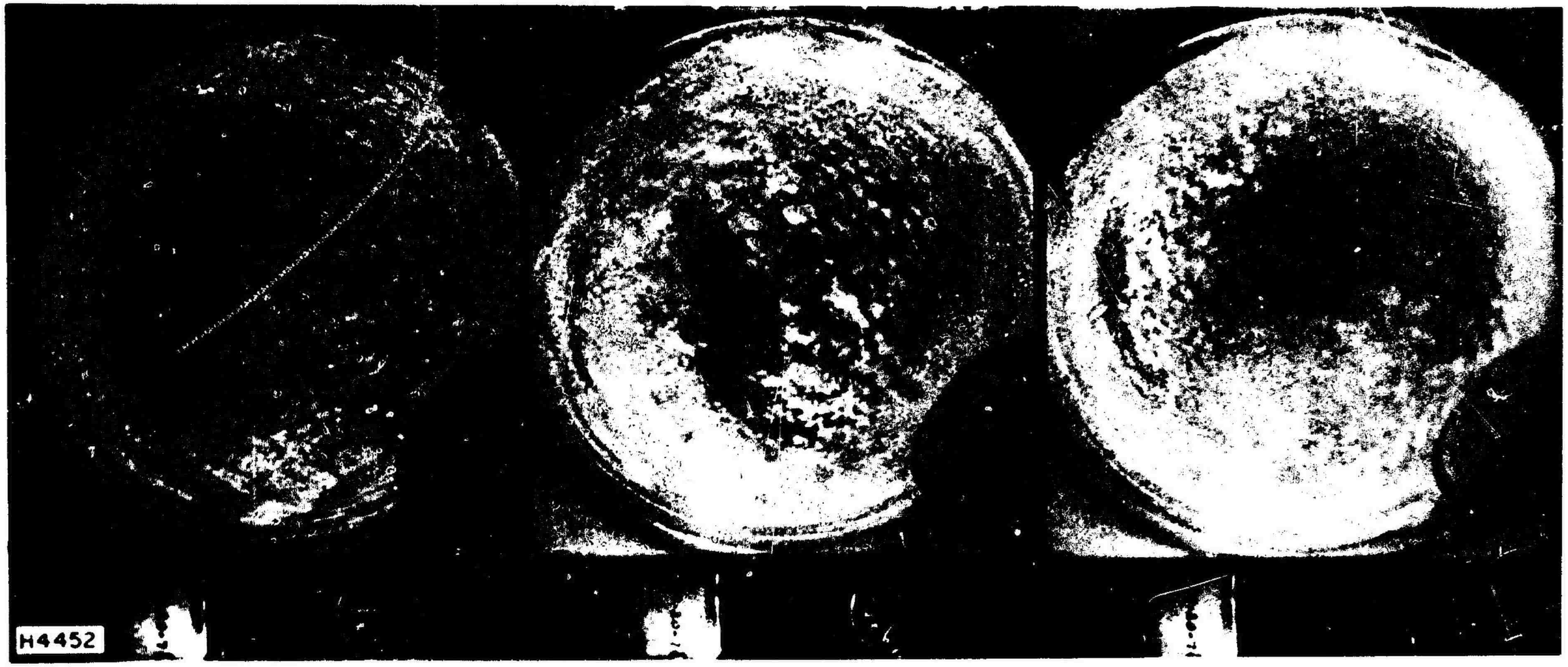


Figure 43   All-Sky/CLOS System in Housing Stop AMOS Observatory

The All-Sky/CLOS System is presently operational at AMOS. Minor modifications are planned as time and priorities permit. An intermittent problem with the nighttime shutter dwell has occurred on several occasions and may necessitate some rework.

Data reduction from the All-Sky films is performed at AMOS using an analyst stop frame projector. Figure 44 shows a series of data frames taken by the system. The required information from the film is recorded on Air Force form 185h as provided by ETAC/RADC. The data film is retained in the AMOS data library and the completed data forms are provided to RADC.



Figurc 44 Consecutive Data Frames from All-Sky/CLOS System Showing High Cirrus Condition. Ten minute exposure intervals.

3.0 MEASUREMENT PROGRAM

The AMOS measurement program is comprised of subprograms each containing objectives and requirements as specified by the agencies utilizing the AMOS data. The composite measurements program is coordinated so the various subprogram data requirements are satisfied in an orderly, logical and timely sequence of observations. The majority of satellite operations during this reporting period has been in support of signature characterization data, while the missile operations have been supported to provide metric (angle) data relative to specific objects in the target complex.

Special system testing is also included as a part of the measurement program. The system testing includes AMOS support of FPQ-14 remote radar calibration and activities related to improving and qualifying AMOS systems for support of new programs.

It should be noted that the measurement program plan for Phase III was to concentrate measurement activities in the first 18 months of the contract allowing resources to be scheduled for the Transistion Program in the final 18 months.

3.1 SUMMARY

3.1.1 Objectives

The objective of the AMOS measurement program is to provide state-of-the-art measurement support to the USAF and DoD SOI communities and to other government users as requested. The measurement support includes mission planning, direction and execution of observations, and data reporting. The measurement program must be capable of responding to a broad spectrum of needs as specified by the various requesting sources. Configuration of the AMOS facility must be maintained with the flexibility required to respond to measurements of both routine and unique characteristics making optimum use of personnel and facilities both on Maui and at the Everett Laboratory.

3.1.2 Accomplishments

AMOS successfully supported all measurement program requirements specified suring the Phase III contract period. Program requirements varied from a single requirement such as metric (angle) data, to complex measurement requirements such as simultaneous metric, photometric, and infrared measurements. Observations were also conducted simultaneously with other sites including Haystack radar, FPS-80 radar at Shemya Island, Alaska, and FPQ-14 radar on Oahu, Hawaii. A brief "handoff" exercise was also performed with the Experimental Test Site (ETS) at White Sands, N. M. Many of the measurement programs successfully supported were for purposes of Space

Object Identification (SOI) in which determing object physical characteristics was the prime purpose. The SAMSO Photometric Signature Measurement program was an SOI program which also required coordination with several radar sites.

Another type of measurement program is in support of operational requirements. The support AMOS has provided to ADCOM in acquiring deep space objects and reporting their position is an example of this type program.

There were a total of 17 missile operations and 3 sounding rocket tests supported during the Phase III period. AMOS met or exceeded the minimum data requirements on all the operations that were successfully launched.

3.2 MISSION PLANNING

Effective support to the AMOS program required extensive mission planning prior to measurement observations. The mission planning function for most programs follows a similar procedure. Initial tasking of AMOS to support a program or a series of measurements is directed by RADC with DARPA approval. Communications between AMOS and program personnel via interface meetings, telephone, and memoranda are accomplished to define the program objectives and measurement requirements. Using the information obtained through the preliminary planning cycle, an AMOS Mission Instruction and Operation Plan (MIOP) is written. The Mission Instruction and Operation Plan is the document which is both an interface document between AMOS and data users, and an operation plan for the collection of data. The MIOP is forwarded through RADC for concurrence by the appropriate agencies, and, when finalized, becomes the governing document at AMOS for program support. Table 17 enumerates the MIOP's prepared and performed during Phase III. A time frame in which measurements are to be recorded, consistent with program schedules and objectives, is selected and integrated into the AMOS target measurement schedule.

Prior to initial measurement activities, a premeasurement briefing is conducted at AMOS in which all program objectives and requirements are reviewed with pertinent personnel.

Satellite pass predictions are reviewed with a view toward selecting observation passes with most favorable geometry and lighting conditions to satisfy data requirements. A weekly schedule meeting is held in which all measurement observations and significant mount configuration changes are planned. Support from external sites, such as radar, is also scheduled at this time. At the beginning of each measurement observation shift, a final crew briefing is conducted to review data objectives, requirements, and procedures. Figure 45 is a flow diagram outlining AMOS tasks for support of a typical mission.

3.3 COMMUNICATION SYSTEM

The means by which the AMOS site communicates with off site support agencies is via (1) teletype, (2) data circuits to remote radar, and (3) voice communication.

TABLE 17

MISSION INSTRUCTION AND OPERATION PLANS

(1975 - 1977)

MIOP Number	Subject
01A	SAC Minuteman Test
02	Seeing Monitor
03	Photometer Baseline Calibration
04A	Target Signature Photometer Measurement
05	Have Lent III
06	b = 29 Photometer Measurements
07	Lunar Ranging Experiment (LURE)
08	Thermal Balance Studies
09	Teal Blue Testing
10	AMOS/Sandia Experiment
11	Atmospheric Characterization
12	High Gain Intensified Video Experiment
13	Position Photometric Observation for ADC
14	Baseline Performance Testing of AMTA Modifications for Deep Space Observations
15	Measurement of Atmospheric IR Spectral Radiance and Extinction at AMOS
16	Sky Radiance Data
17	ITEK Speckle
18	Wavelength Dependence of Atmospheric Refraction Structure
19A	SAMSO Evaluation Program
20	RTAM Familiarization
20-01A	RTAM/Seeing Monitor Measurements
21	Teal Onyx Measurement
22	Speckle Experiment (ITEK)
23	SAMSO Evaluation Program (Phase 2)
24	All Sky Camera
25	Laser Beam Director Experiment

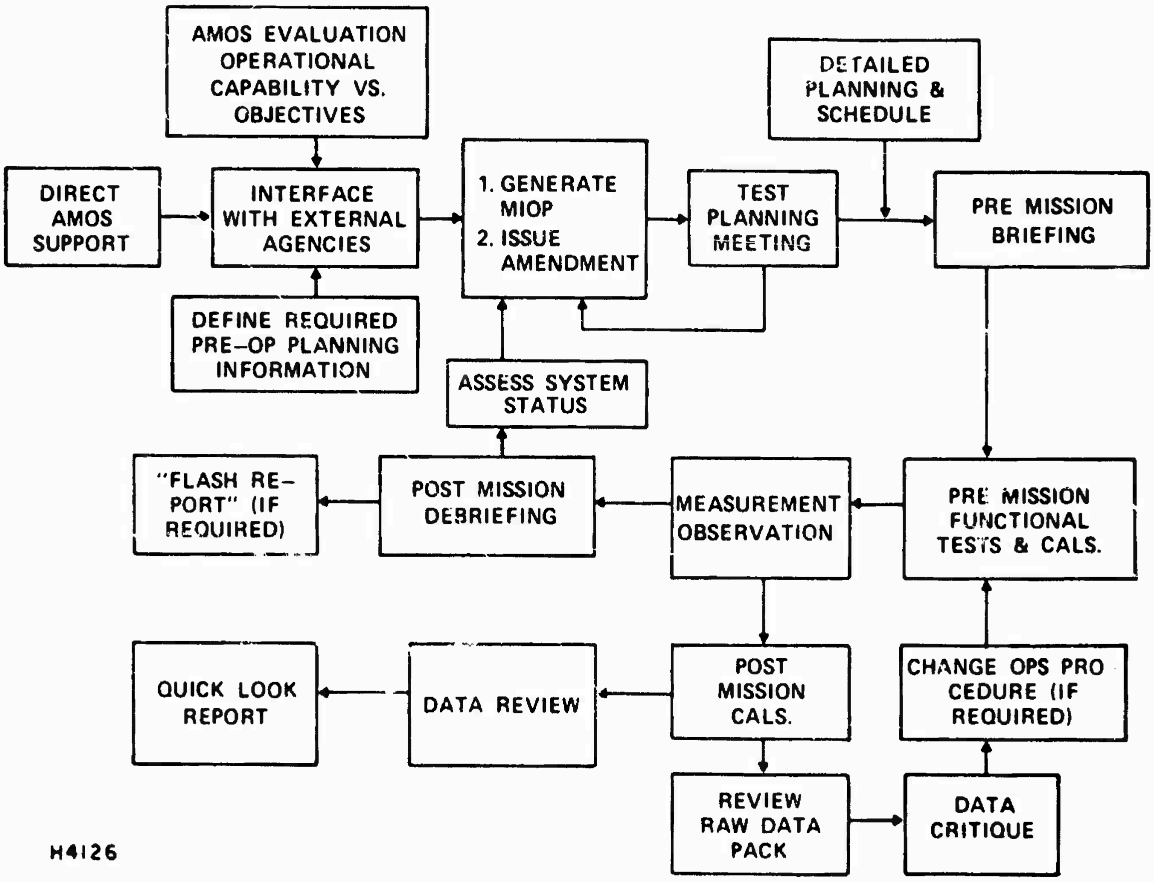


Figure 45 Typical AMOS Mission Support

There are two separate sets of terminal teletype equipment at AMOS. Set one is comprised of a Teletype Corp. Model 28 ASR, a Model 28 receive-only printer, and a Model 28 receive-only tape reperforator unit. This set is located within the classified vault and is used for classified communication only. Set two consists of a Teletype Corp. Model 28 ASR, a Model 28 receive-only printer, and two Model 28 receive-only tape reperforator units. This set is located within the communications room and is used primarily for updating satellite elements and in support of launch operations. Both sets of equipment operate at 100 wpm (75 baud). The vault operation will handle classifications from "unclassified" up to and including "secret", while the other set is strictly "unclassified". The teletype equipment previously leased from Hawaiian Telephone Company was recently replaced by GFE equipment. The SAMTEC Range Communications Control Center (RCCC) provided and installed the equipment with assistance from AMOS personnel.

The teletype circuit consists of a four-wire duplex circuit terminating at the RCCC at Wheeler AFB, Oahu, Hawaii. The circuit is normally input to an automatic relay system computer called "Teletype Data Multiplexer Addresser System" (TDMAS). Direct communications with other stations that have circuits terminating at Wheeler RCCC can be accomplished via circuit patching. Communications with stations outside the SAMTEC network can be accomplished using NASCOM and AUTODIN interface facilities at the TDMAS switching center at Vandenberg AFB, California.

AMOS has four four-wire full duplex data/voice circuits terminating at the RCCC. Pointing data can be received at AMOS from several selected Hawaiian radar sites; FPQ-14 Kaena Point, Oahu, FPS-16 Kokee Park, Kauai, and MPS-25 Barking Sands, Kauai. AMOS can also transmit telescope pointing data to the FPQ-14 radar. The site presently has the hardware, but not the software, to transmit data to the FPS-16 radar; neither hardware nor software are available on site to transmit data to the MPS-25. Figure 46 shows the AMOS data line capability.

Through the use of the four data-voice circuits identified above, voice communications can be conducted with other stations having circuits that terminate at the RCCC and Vandenberg AFB. Access to the AUTOVON network is available through interface facilities at the Vandenberg and Kaena Point switchboards.

3.4 RADAR SUPPORT

The present data circuits (see Figure 46) allow AMOS to accept radar pointing data from three remote radars. The radar required for pointing data most often is the AN/FPQ-14 which is a modified MIPIR class, "C" band monopulse tracking radar, incorporating the ON-AXIS predictive pointing technique. The data provided to AMOS from this radar can be used unfiltered, with the mounts slaved to the radar, or filtered via the Kalman filter for improved trajectory estimation. Since this radar has the capability to skin track most objects in near earth orbit, AMOS utilizes its support for acquisition of satellites in earth shadow or during

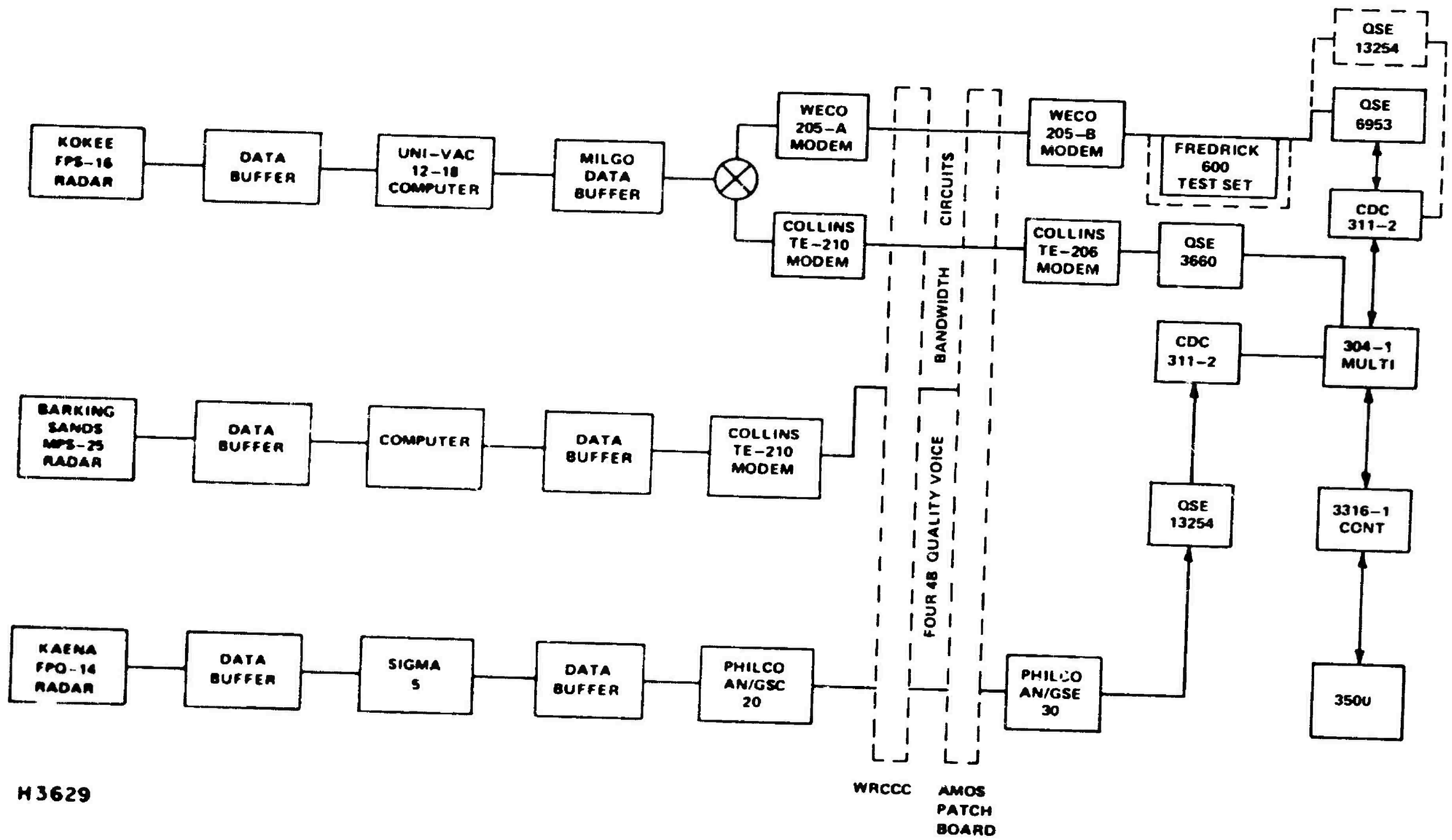


Figure 46 AMOS Radar Support Capability

daylight observations. This radar is also used in support of missile operations as designated for AMOS targets.

The FPS-16 radar is used by AMOS primarily as backup support during missile operations, since it operates chiefly in the beacon track mode. During missile operations it is usually requested as designate for a secondary target. It has performed in the past as acquisition aid on GEOS and other satellites which carry a "C" band beacon.

The MPS-25 radar did not provide direct pointing information to AMOS during the Phase III period. However, the MPS-25 radar did provide indirect pointing assistance for the first OBLSS test which AMOS supported. The MPS-25 radar was the only radar in the Hawaiian area capable of interrogating the beacon on the Mark 11 C Mod 6 reentry vehicle. Therefore the FPS-16 was slaved to the MPS-25, the FPS-16 shaft encoder data being transmitted to AMOS in a normal fashion. Offsets to the target using this unique acquisition link were measured during the mission and found to be within an acceptable circle of error for AMOS acquisition.

3.5 MISSILE OPERATIONS

There were a total of 17 missile operations supported by AMOS during the Phase III contract period. (See Table 18) The tests were sponsored by SAC and were operational training for SAC personnel. The AMOS objective in all the missile operations was to obtain metric (angle) data relative to the reentry vehicle. The recorded and reduced data is compared to a Best Estimate of Trajectory (BET) as derived from multiple radar sources at the Western Test Range. The missile configuration included seven Minuteman III, one Titan II, with the balance being Minuteman II.

Two of the operations proceeded into the countdown but were not launched, and two were anomalous flights which precluded AMOS data. The thirteen successful launches were supported by AMOS with all data requirements being met. Improvements in AMOS procedures, hardware and software during Phase III have resulted in metric data which is now reported as having the lowest residuals of all sensors used in the BET reconstruction for MM II tests.

3.6 SATELLITE OPERATIONS

(This Section appears in Volume II.)

3.7 SMITHSONIAN ASTROPHYSICAL OBSERVATORY

The Smithsonian Astrophysical Observatory (SAO) facility at Mt. Haleakala was operated under subcontract to AERL, Inc. The facility contains a Baker-Nunn camera mounted on a triaxial mount, and related support equipment. The camera has a field-of-view of $5^{\circ} \times 30^{\circ}$ and is capable of detecting objects of $M_v + 15.3$.

The facility was used in conjunction with AMOS sensors to support missile operations where the camera wide field-of-view permits reduction

TABLE 18

SAC SUPPORT - PHASE III

Operation	Type	Date	Remarks
(3375) GT-48GM	MM III	29 Jan 75	All objectives satisfied
(4526) GT-29GM	MM III	5 Feb 75	Anomalous
(4227) GT-30GM	MM III	11 Jun 75	All objectives satisfied
(7173) GT-31GM	MM III	20 Jun 75	All objectives satisfied
(2371) GT-49GB	MM III	29 Aug 75	All objectives satisfied
(2239) GT-123M	MM II	17 Sep 75	All objectives satisfied
(6017) GT-50GM	MM III	14 Nov 75	HELD - out of AMOS window
(5678) BMDTP DG-4	Titan II	5 Dec 75	All objectives satisfied
(8522) GT-51GB	MM III	17 Dec 75	Technical Problem, Limited Data
(3030) GT-125M	MM II	30 Jan 76	All objectives satisfied
(6306) GT-124M	MM II	25 Feb 76	All objectives satisfied
(5683) GT-127M	MM II	9 Jun 76	All objectives satisfied
(8230) GT-128M	MM II	23 Jun 76	Anomalous
(8446) GT-129M	MM II	27 Aug 76	All objectives satisfied
(7269) GT-132M	MM II	2 Feb 77	All objectives satisfied
(2180) GT-134M	MM II	29 Jun 77	All objectives satisfied
(3544) GT-133M	MM II	16 Nov 77	All objectives satisfied

of position of all objects in the target complex using the star field background. The facility was also used for satellite position determination and visual magnitude estimation for synchronous and quasi-synchronous objects, and tumble rate determination for nearer earth objects. Support was also provided in photographic coverage of a Los Alamos Sandia Laboratory Barium cloud experiment.

The subcontract with Smithsonian Astrophysical Observatory for support to AMOS was terminated on June 30, 1976.

4.0 DATA SYSTEMS

This section deals with the variety of functions related to the AMOS data product. Data systems includes data control, data validation and data reduction as major subjects. The data control function consists of data cataloging, access and retrieval, inventory and transmittal procedures. The validation function includes configuration verification, information collection and a level of data reduction sufficient to qualify the AMOS data product. The data reduction function is comprised of calibration and reduction techniques, procedures and equipments as required to generate the data product in units or in terms that convey the most information to the AMOS user.

4.1 SUMMARY

Early in the Phase III program, routine data gathering activities increased to the point where the old data storage area was overflowing with data. In addition, the data handling and control procedures were unable to cope with the large quantities of material being generated on a daily basis. Space was therefore provided at the Puunene office building, and custom bins, cabinets and shelving were built. To manage this facility modification, reorganization of the old area and the normal data handling activities, the position of data librarian was established. In addition, procedures were written to facilitate the retrieval of data items and formalized validation and control techniques were established.

The last two years of the Phase III contract saw a reduction in routine data gathering activity. This led to a proportionate reduction in data handling and validation requirements. Data handling at the lower rate continued under the guidelines that had been established and proven effective. These same guidelines and procedures proved to be a valuable base of information for the data planning required under the MOTIF transition.

4.2 DATA HANDLING

The AMOS Data Acquisition, Handling and Analysis (DAHA) Plan[7] served as a basis for many aspects of data handling throughout the Phase III program. This document is primarily concerned with data transmittal and reduction techniques while the subject of data handling must encompass other areas as well.

Basically, data handling starts before the data is collected. It starts with check lists that ensure that the system is calibrated and ready to collect data and the report forms which operators use to record the parameters that will be necessary for proper understanding of the data. Data handling includes the assembly and labelling of all items associated with a given mission, including history listings which are run on a different shift and film data which usually is processed the next day. It includes the logging in of data items in such a manner that they can be readily retrieved. It entails having the proper procedures for transmitting data to other facilities and for keeping track of such disposition. Data handling also includes review of the data and qualification (i.e., validation) that the data is (or is not) suitable for reduction. Finally, it includes the reduction and reporting mechanisms which have been established for the dissemination of the final data product.

4.2.1 Data Control

One of the prime objectives of the DAHA plan was to provide for the accountability of all individual data items. This requirement was satisfied by the implementation of a signature release system combined with periodic inventory summary reports. Transmittal memoranda and complete log books provided the desired control.

At the beginning of the Phase III program, most data going between AMOS and Everett had done so on an informal basis. To establish an orderly flow, several actions were taken. First, copies of all successful Operations Reports were routinely sent to Everett. Secondly, teletype messages were initiated to keep Everett informed of AMOS data collecting activity. Thirdly, data request forms were provided to data users. These request forms were channelled through the Everett data control function to avoid duplication of effort in requesting data. Finally, all data transmittals were documented by transmittal memos which follow a standard distribution list. As a result of these actions a complete data control inventory has been prepared, maintained and distributed as required.

4.2.2 Data Validation

The purpose of data validation is to ensure that the end product leaving AMOS (whether it be raw data destined for further reduction or fully reduced data) is good. When further reduction is going to be performed, validation at AMOS includes the flagging of potential reduction problems, checking sensor performance, noting changes to the sensor configuration or system changes which might affect a sensor, detecting operator errors or equipment malfunctions and seeing that the data package and report forms contain all the necessary information. When fully reduced data is sent out or included in a report, validation includes making every effort to ensure that the data and/or conclusions are correct. Wherever possible, cross checks are performed or supporting data is gathered as backup to the AMOS data or to independently reach the same conclusions. However, the nature of the AMOS site (i.e., as a unique R&D optical site) is such that supporting data is often not available.

During Phase III, data validation report forms were added to the Operations Report. These forms were completed for data that was sent to Everett for reduction and/or analysis. In addition to these general forms, specific report forms were established for photometric data and for AMTA data. These specific validation reports included calculations (performed by programmable pocket calculators) which checked the sensor performance for a given operation or set of operations. These specific forms in particular and validation in general has been highly successful in detecting problems before transmittal occurred.

The only contrary situation to the above concerned a time bias problem that affected metric data on three consecutive SAC launches. The magnitude of the bias problem was such that stellar pointing data and metric data for synchronous or semisynchronous objects was virtually unaffected. This made detection almost impossible using the validation techniques being employed at the time. The problem of detection was even further compounded by the nonavailability of Baker-Nunn metric data due to the closure of the SAO station. Finally, the problem was allowed to persist because of the slow feedback and conflicting information from the agencies involved in trajectory estimation. Once the nature of the problem (as discussed in Section 2.5.6) was recognized, letters acknowledging the existence of a timing bias problem were sent to all who received the AMOS data. In addition, the validation procedure for metric data was revised to make detection of this type of problem more probable.

4.3 DATA REDUCTION

Reduction of AMOS data during Phase III was primarily handled by the Data Base Implementation (DBI) effort at AERL/Everett. On-site data processing consisted of generation of SAC metric data, data validation, a specific SDC request for metric data on object #83555 and a Metric Objectives Task. The latter two items were discussed in Reference 1.

4.3.1 On-Site Data Processing

As reported in Section 3.5, AMOS supported 17 SAC metric missions during the Phase III program. Metric position data, derived from telescope pointing angles, were reduced on-site and provided to organizations responsible for evaluating missile performance. Table 20 shows the Quick Look Data Reports generated from the missile support missions. An accuracy review meeting held at Vandenberg on 26 October 1977 compared all sensors on OP7269, the GT-132M flight. AMOS data was held in high regard, as it had the lowest residuals of all the sensors compared for this operation.

Also shown in the Table is the Quick Look Report generated by AMOS on the Have Lent III mission, which is discussed in Section 5.8.4.

4.3.2 Data Base Implementation (DBI)

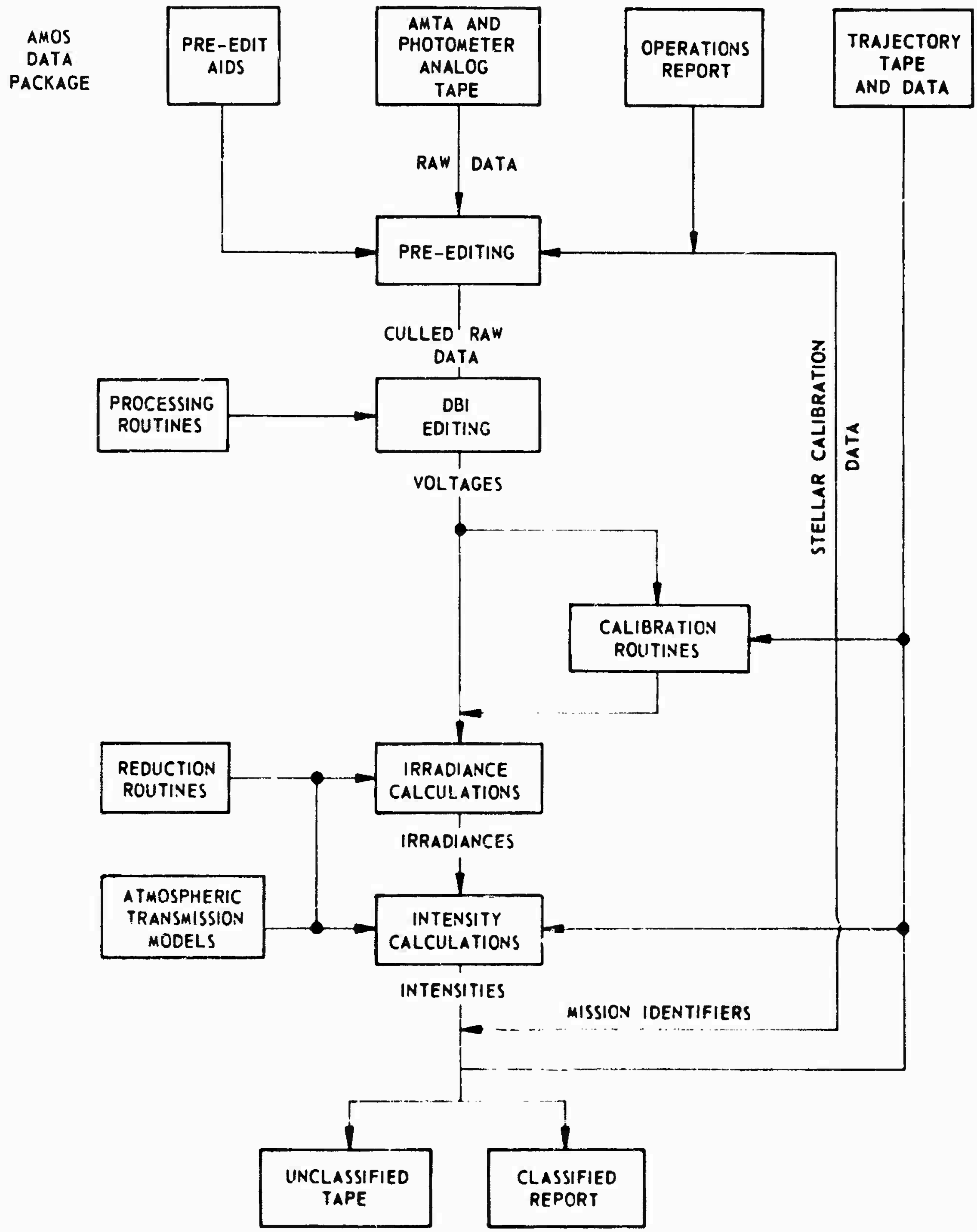
Data Base Implementation is the name given to the Everett activity of providing a system to handle a high rate of data flow from AMOS. This semiautomated system routinely accomplishes the reduction of photometric and infrared data obtained with AMOS sensors. Figure 47 shows the DBI reduction procedure. The DBI Final Technical Report[8] gives a detailed overview of the hardware and software comprising the system. The DBI reduction activity for the years 1975 and 1976 is covered in the Annual Reports for those years.[1,2] During 1977, the DBI system completed reduction of SEP data (which was started in 1976). Following this, effort was directed to the reduction of IR Atmospheric Data (Hartmann).

TABLE 20

QUICK LOOK DATA REPORTS

1975-1977

WTR Operation	Document No.	Date
OP 3375	M-1036	24 Feb 1975
OP 4227	M-1218	4 Aug 1975
OP 4227 (Addendum)	M-1224	18 Aug 1975
OP 7173	M-1255	27 Aug 1975
OP 2371	M-1283	10 Sep 1975
OP 2239	M-1353	14 Oct 1975
OP 5678	M-1529	22 Jan 1976
OP 3030	M-1682	30 March 1976
OP 6306	M-1708	April 1976
OP 5683	M-1840	June 1976
OP 8446	M-2025	Sep 1976
OP 7269	M-2227	February 1977
OP 2180	M-2423	July 1977
OP 3544		November 1977
Have Lent III	M-1631	March 1976



F8?.6

Figure 47 DBI Reduction Procedures

Reduction of IR atmospheric data focused on a 30-sec interval of Venus data, filter 6, for digital reduction. Cross spectral densities and cross correlations were calculated and plotted for pairs of declination detectors and for pairs of polar detectors. Error signals were used to enable the differentiating between atmospheric induced detector signal and signals due to tracking error. Analog reduction of IR Hartmann data was also carried out. The analog data was processed for the entire tape containing Mercury and Venus data.

In addition to SEP and IR Hartmann data, one photometric mission (ATN 3576) was reduced under DBI, and nine photometric missions were rereduced with an expanded (50 Hz) low pass filter. For these rereduced missions, plots of the final reduced product, along with the original realtime chart records, were transmitted to RADC at Griffiss Air Force Base. Digital tapes of the data were also furnished to AVCO Systems Division, Wilmington. The rereduced missions were ATN's 3927, 3703, 3269, 3188, 3328, 3521, 3527, 3477 and 3329.

The only DBI malfunction during 1977 involved a Tidox analog recorder. This unit was subsequently repaired and gave no further difficulties.

One software development task was completed during 1977. SEP data reduction software was refined to allow differencing operations to be performed on selected one-second averages.

4.4 AMOS INTERNAL DATA STORAGE (AIDS) SYSTEM

The AIDS system consists of a subject organized document file, a chronological inventory of submitted material. The system provides a centrally located, rapid access area for data that is of interest to AMOS personnel. Since this is primarily an internal file, all types of data are accepted, and emphasis is placed on getting the data filed quickly and simply as possible. Informal test data, handwritten notes, Xeroxed notebook pages, Polaroid pictures, etc., are entered into this file. Table 21 is the current subject index for inputs into the AIDS file. This index is open ended to accommodate new equipment and new programs as they are added to the AMOS effort.

TABLE 21

AIDS FILE

I. TELESCOPES

A. 1.2-m b = 30/37
B. 1.2-m b = 29
C. 1.6-m
D. 60"

II. SENSOR SYSTEMS

A. AMTA/Scanner
B. Photometer
C. Laser/LBD
D. Cine Video Systems
E. Photography
F. Baker Nunn
G. Speckle

III. SUPPORT SYSTEMS

A. Servo/Shaft Encoder/Pointing
B. Computer
C. Film Processing
D. Timing
E. Acquisition/Boresight
F-1. Video Systems/VTR
F-2. Video/Photorecorder
G. Densitometers
H. Tape Recorders
I. Chart Recorders
J. PFA
K. Dome: A 1.2-m
L. Dome: B 1.6-m

IV. FACILITY/SITE CHARACTERISTICS

A. Weather/Seeing
B. Vibration/Image Motion
C. Construction
D. General

V. SPECIAL PROGRAMS

A. Astronomy (General)
B. Comets
C. Special Tests (STD)
D. "MIKE"
E. Barium
F. LURE
G. Teal Onyx

VI. MISCELLANEOUS

A. DBI Material
B. Optical Tests
C. ATN Data/No #

5.0 SPECIAL PROGRAMS SUPPORT

AMOS, because of its state-of-the-art sensor and test bed capability, its unique location, its excellent average seeing, and its experienced staff, constitutes a national asset for support of classified and unclassified research and development in areas critical to DARPA and DoD. Its usefulness and utilization in this role have been demonstrated throughout the eight years of AMOS operations. In particular, over the three year duration of the Phase III contract, the value of this asset in providing broad scoped support is typified by the categories covered in this Section.

Support of long term measurement programs, large scale system developments by other DARPA contractors, special analyses or experiments, interfaces with major concurrent programs, and for visiting experiment(or)s are all considered in this Special Programs Support Section. Specifically, the Atmospheric Characterization measurement program, Compensated Imaging and Teal Amber system developments, Thermal Balance analyses, the AERL Speckle and DARPA laser ranging experiments, the MOTIF interface and a host of visiting experiments are discussed herein as the efforts which were undertaken during Phase III in Special Programs Support.

5.1 ATMOSPHERIC (TURBULENCE ENVIRONMENT) CHARACTERIZATION PROGRAM

A major influence on the operation of large optical systems arises from random phase and amplitude perturbations introduced into a propagating optical field by atmospheric turbulence. The origin of these effects are local, small scale, temperature fluctuations which, in turn, produce variations in the index of refraction. These random perturbations in the received field are very significant in imaging systems because they limit resolution to the order of one or more arcsec. In order to measure these effects a set of atmospheric turbulence characterizing experiments have been developed and implemented at the AMOS site. Although directed under separate contractual funding, the program was conducted as an integrated component of the total AMOS program and measurements were supported by AMOS personnel.

5.1.1 Summary

5.1.1.1 Objectives

The objectives of this program fall into three general categories:

1. Installation and checkout of experimental systems,

2. Collection, reduction, and interpretation of data,

3. Determination of location and strength of regions of high turbulence.

Activity associated with category one consisted of instrumenting the site to allow the quantitative characterization of the turbulence environment. During the contract period five sensor systems were tested and four became permanent components of the "characterization system." These sensors, several of which were prototype instruments, were the Seeing Monitor, Star Sensor, Acoustic Sounder, and Microthermal Probe Systems and are described in detail in reference 9.

The second category of activity is the collection of data and its reduction and analysis. Objectives were to measure the correlation scale distance r_o, log-amplitude variance, $\sigma_\ell^{\ 2}$ and turbulence strength parameters C_T^2 and C_n^2. It was also a program objective to obtain these descriptors in such a manner as to build a statistical data base that could be used to characterize the seeing conditions at AMOS and be used to evaluate the performance of the Compensated Imaging System (CIS).

As a result of the collection of this data base and its interpretation, category three objectives led to the construction of turbulence profiles for use in the determination of regions of high turbulence.

5.1.1.2 Accomplishments

The program has accomplished the testing, acceptance and installation of sensor systems capable of measuring the r_o, σ_ℓ^2, C_T^2 and C_n^2 parameters. 270 data missions were completed with two periods of simultaneous data from all sensor systems (including climatology). The following special purpose tests were also conducted: small aperture photometry for Star Sensor validation; noise determination tests for both Seeing Monitor and Star Sensor; simultaneous Seeing Monitor and Realtime Atmospheric Measurement systems tests. An atmospheric data base has been collected consisting of approximately 30 Microthermal Probe data runs, 45 Star Sensor data runs, 30 Acoustic Sounder data runs, and 60 Seeing Monitor data runs. Other program accomplishments were the upgrading of acoustic Sounder software, replacement of fragile fine-wire microthermal probes with more weather resistant types, upgrading the Star Sensor with an advanced version (Model II) and improving data recording and playback capability.

5.1.2 Instrumentation

Five separate instrument systems were installed at the AMOS observatory starting mid-summer 1975. These were:

1. Routine Meteorological (climatology) sensors consisting of two 20-m towers, instrumented with wind speed and wind direction sensors; ambient temperature and dewpoint sensors (north tower only).

2. Microthermal Probe systems consisting of three probes mounted as triads on top of each tower.

3. Seeing Monitor, located first on the side Blanchard of the 1.2-m, b = 37 telescope and then, from mid-1976, on the rear Blanchard of the 1.6-m telescope.

4. Star Sensor located on its own 36 cm aperture Schmidt-Cassegrain telescope operating in the Teal Amber dome.

5. Acoustic Sounder, an echosonde device located approximately 50-m west of the observatory.

Figure 48 shows the location of these sensor systems at the AMOS site. A more complete technical description of the sensor instrumentation is given in Reference 9. An additional sensor, the Realtime Atmospheric Measurement system, was tested at AMOS but its utility was limited due, primarily, to sensitivity problems. This instrument and its testing are more fully described in References 10 and 11.

In addition to sensor systems designed to measure the atmospheric turbulence descriptors, data handling and reduction systems were also implemented. The outputs of the Routine Meteorological sensors, Microthermal probes and Seeing Monitor (analog seeing angle data) are processed in realtime using an a/d converter, a PDP-8I computer and a teletype. This data system produces the means, variances and covariances of the input data and is used directly in the computation of r_0, C_T^2 and C_n^2. Raw acoustic sounder data is also processed by this data system in post-mission time using special software (MK 5.0 Sounder Program) that reduces echo returns and computes C_T^2 or C_n^2.

The Star Sensor system has a dedicated Nova 2/10 computer with analog to digital conversion electronics which processes raw Star Sensor data and computes C_n^2 altitude profiles. The associated teletypewriter peripheral also produces a small plot of C_n^2 vs altitude. Other data handling capability is comprised of a multichannel data recorder for use with the Acoustic Sounder and for collateral data (see Reference 2 for additional description of system).

5.1.3 Measurements

It has been a goal of the program since its inception to place the Turbulence Characterization measurement activity on as regular a data gathering schedule as possible. Within the constraints of higher priority observatory activity, weather, and special systems tests, a semioperational status was achieved during 1977. Table 22 shows the mission breakdown for data acquired during Phase III.

Figure 49 shows typical r_0 data as produced by the Seeing Monitor. The values are in cm and represent a 10 min average as computed by the means and variance program. Figure 50 displays five nightly averaged

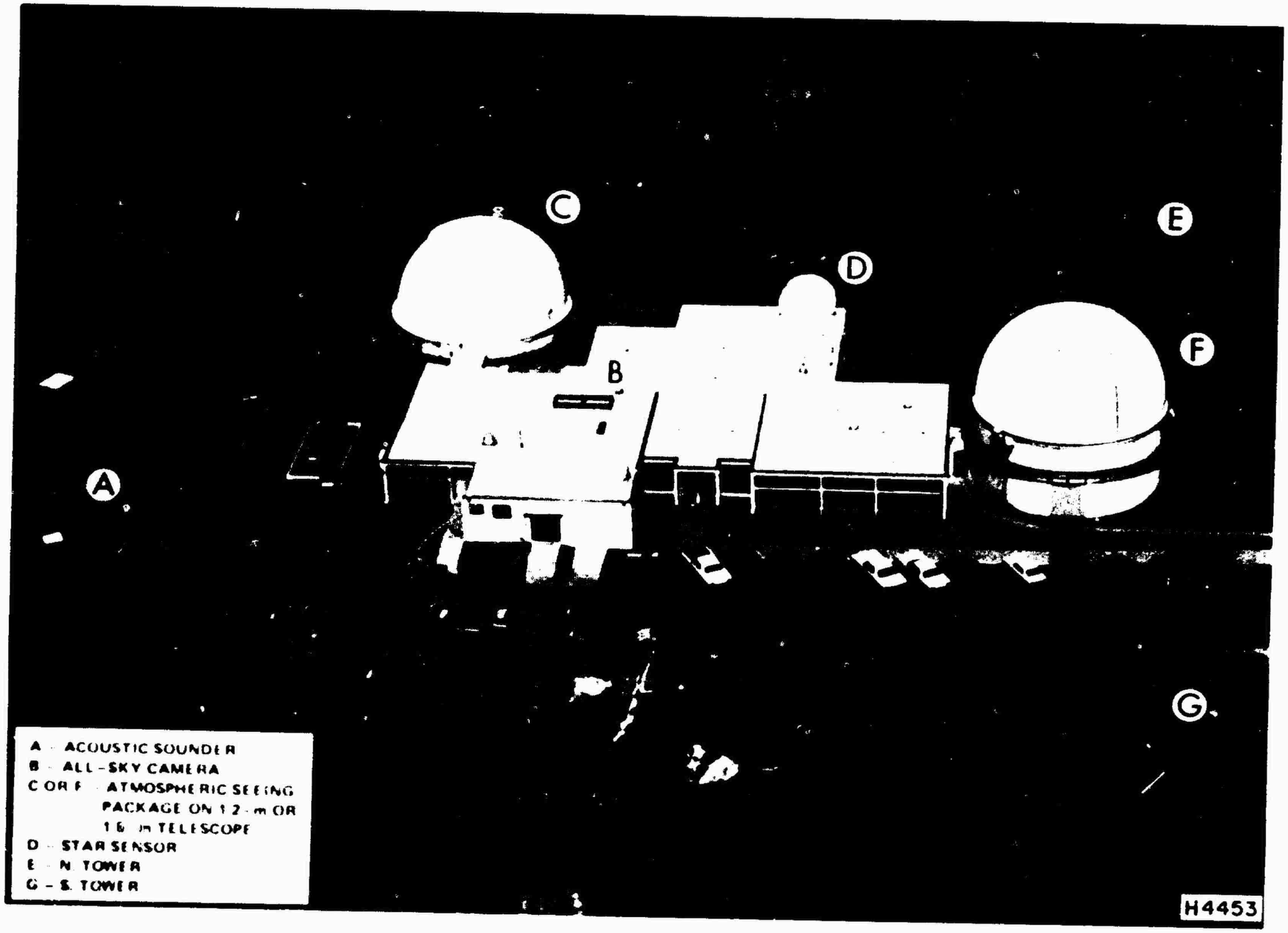


Figure 48 Atmospheric Characterization Instrumentation

TABLE 22

AMOS ATMOSPHERICS MEASUREMENTS SUMMARY

DATA- / DATE	RMET	μT	SAP	AS	SS	SM	ARN
11 NOV 75	X	X	X	X*	X	X	751111
12	X	X	X	X*	X	X	751112
14	X	X	X	X*	X	X	751114
17	X	X	X	X*	X	X	751117
18	X	X	X	X*	X	X	751118
19	X	X	X	X*	X	X	751119
21	X	X	X	X*	X	X	751121
06 DEC 75	X	X	X	X*	X	X	751206
08	X	X	X	X*	X	X	751208
16 APR 76			X				760416
23			X				760423
29			X		X	X	760429
05 MAY 76	X		X		X		760505
06	X		X		X		760506
12	X		X		X	X	760512
13	X		X		X	X	760513
26			X		X		760526
27	X		X		X	X	760527
09 JUN 76			X		X		760609
10	X		X		X	X	760610
18	X				X	X	760618
21	X				X	X	760621
24	X				X	X	760624
29	X				X	X	760629
30	X				X	X	760630
06 JUL 76	X				X	X	760706
08	X				X	X	760708
09	X				X	X	760709
12	X				X	X	760712
13	X				X	X	760713
22 SEP 76	X				X	X	760922
24	X				X	X	760924
27 OCT 76	X				X	X	761027
28	X				X	X	761028
29	X				X	X	761029
09 DEC 76						X	761209
10				X	X	X	761210
12 JAN 77				X	X	X	770112
13				X	X	X	770113
14 FEB 77						X	770214
16						X	770216
17						X[1]	770217 A,B, C,D,E,F,G
23 MAR 77						X	770323
31	X	X				X	770331
07 APR 77	X	X				X	770407
08	X	X				X	770408
12	X	X		X		X	770412
13	X	X		X		X	770413
08 JUN 77	X	X		X			770608
09	X	X		X			770609
14	X	X				X[2]	770614
15	X	X		X		X[2]	770615
14 JUL 77						X[2]	770714
21	X	X		X	X	X	770721
22	X			X	X	X	770722
25	X			X	X	X	770725
26	X			X	X	X	770726
02 AUG 77	X	X		X	X	X	770802 A,B
03 AUG	X	X		X	X	X	770803 A,B
12	X	X		X		X	770812 A,B
18	X	X		X		X	770818 A,B,C
19	X	X		X		X	770819 A,B
26	X	X		X	X	X	770826 A,B
01 SEP 77	X	X		X	X		770901
02	X	X		X			770902
08	X	X		X	X	X	770908 A,B
09	X	X		X	X	X	770909 A,B
15	X	X		X	X	X	770915 A,B
16	X	X		X	X	X	770916 A,B
22	X	X		X	X	X	770922 A,B
23	X	X		X		X	770923

RMET - Routine Met
μT - Microthermal Probe
SAP - Small Aperture Photometer
AS - Acoustic Sounder
SS - Star Sensor
SM - Seeing Monitor
ARN - Atmospheric Run No.
* Facsimile Record only, no Mag Tape
[1] Simultaneous SM/RTAM Test
[2] Special CI Test

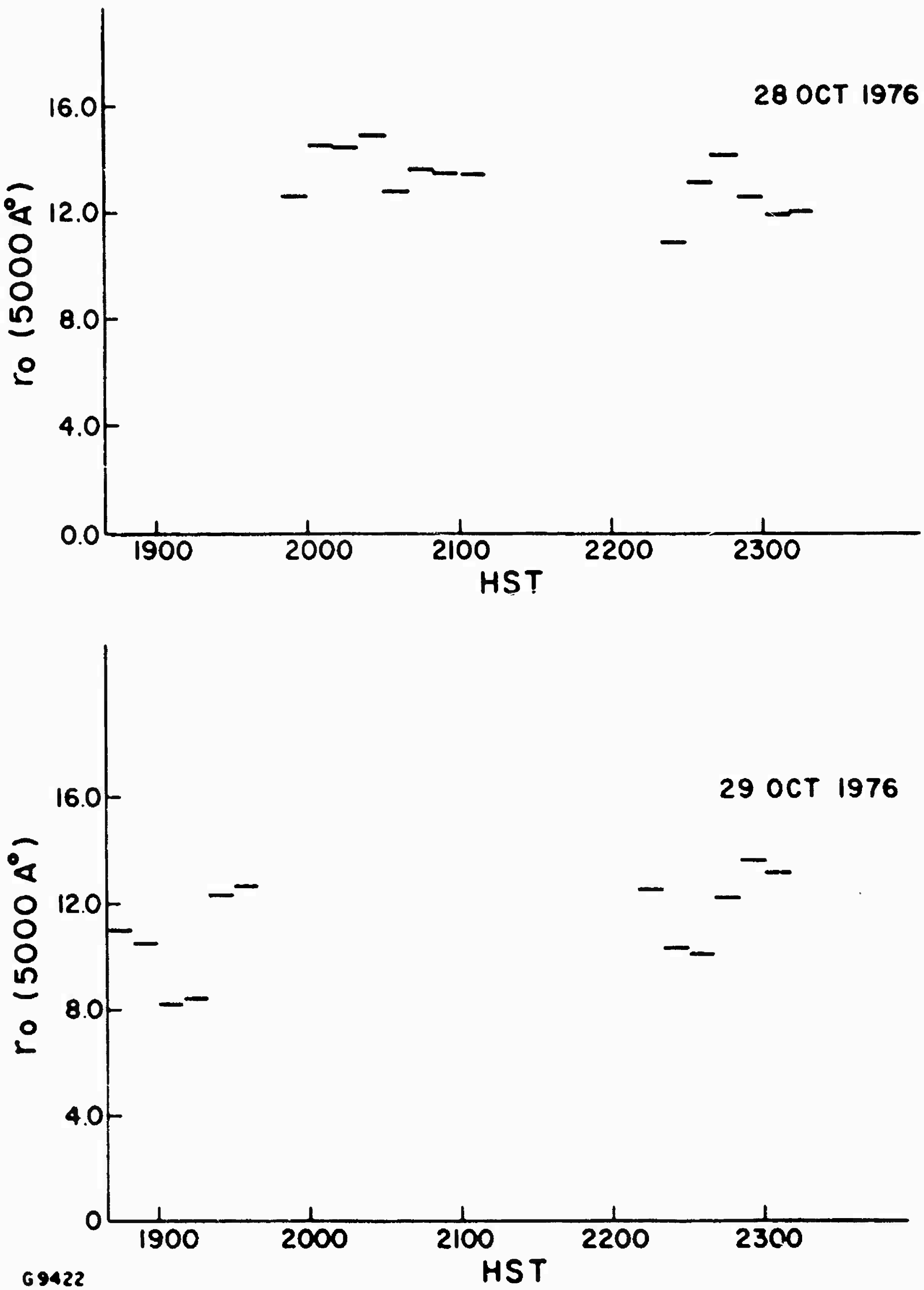


Figure 49 Seeing Monitor Data of 28 and 29 October 1976. The horizontal bars indicate the averaging period.

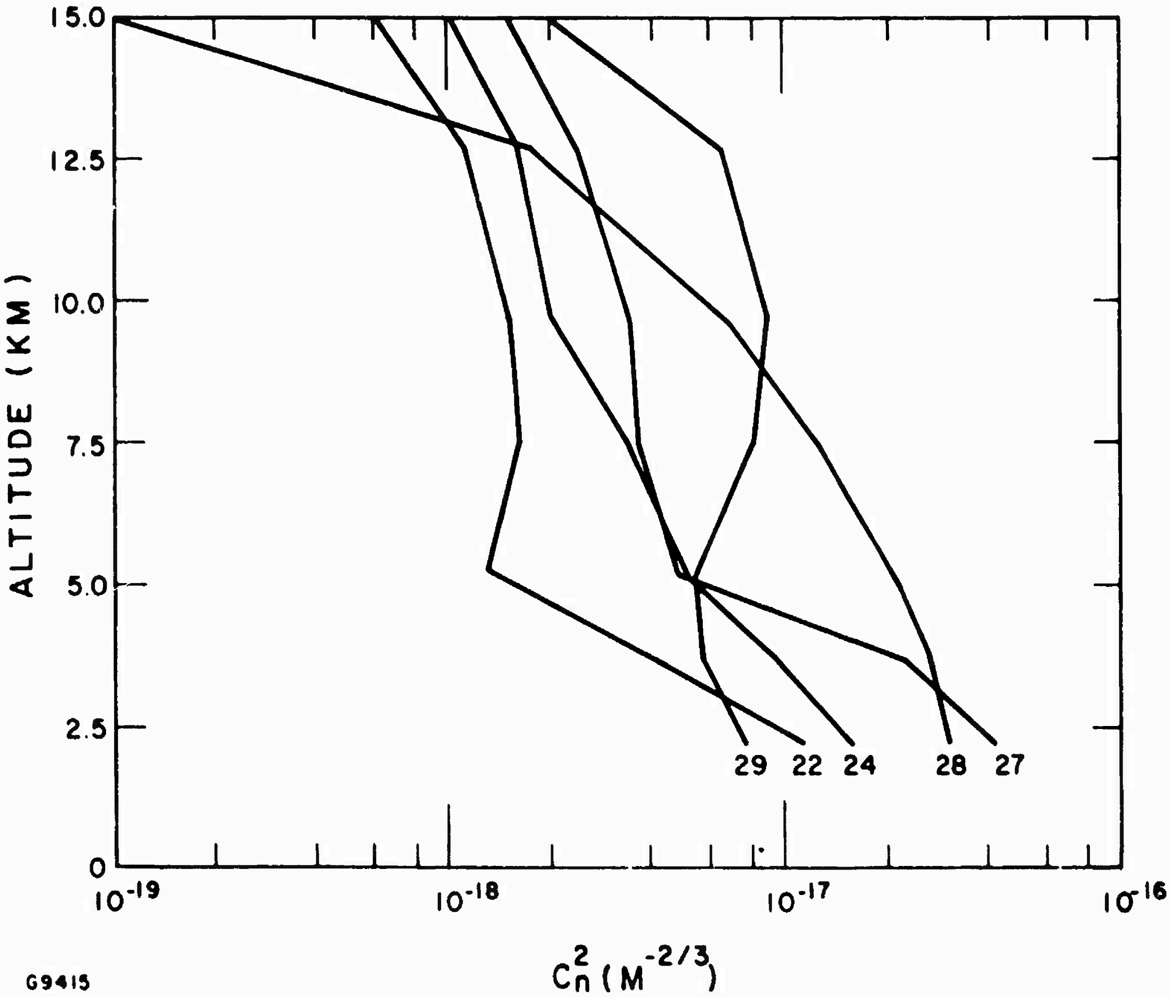


Figure 50 Star Sensor Nightly Averaged Profiles for 22 and 24 September and 27, 28 and 29 October 1976. Altitude is in height above the observatory. Each profile is an average of all valid data collected on a specific night. The widths of the weighting functions are not shown.

profiles of C_n^2 as produced by the Star Sensor. These data are taken using the Model I Star Sensor. Representative examples of C_n^2 as measured by the Microthermal Probe systems are shown in Figure 51. A reduced plot of C_n^2 vs altitude based on Acoustic Sounder returns is shown in Figure 52. The noise line is the background limiting noise expressed in terms of C_n^2. The three lines of varying slopes represent from left to right, a previous empirical fit, a theoretical fit for unstable conditions, and a theoretical fit for the neutral limit (cloudy conditions), respectively. A more complete compendium and discussion of the data acquired during the Phase III program is given in References 10, 11 and 12.

5.2 COMPENSATED IMAGING SYSTEM (CIS)

CIS represents an ongoing DARPA program of major importance to DoD and to the scientific community in general. AERL involvement in the CIS, which has spanned essentially the entire Phase III AMOS program, encompasses several critical areas of the activity. Under a separate contract, the Everett Laboratory is providing essential subsystems for the CIS. This hardware (the Data Recording System, the Short Exposure Video System and the Solid State Imaging System), when combined with the basic precompensating device which is being developed by ITEK, will provide a technological breakthrough in the general area of imaging through a turbulent medium. AMOS Phase III support to the program, although not specifically concerned with the development of CIS hardware, is nevertheless of basic importance to the successful accomplishment of CIS program goals. This section describes activities and accomplishments provided by AERL under the Phase III contract.

5.2.1 Summary

5.2.1.1 Objectives

Basic objectives of AMOS Phase III support to the CIS program can be summarized as follows:

a. Assure that all relevant state-of-the-art capabilities currently existing at AMOS are fully exploited in support of the program.

b. Identify critical interface issues, and - after defining and conducting special tests, evaluation, analyses, etc. - recommend and/or implement modifications to CIS hardware systems and/or AMOS systems.

c. Provide expertise in various technical areas to aid in optimizing CIS design and, thereby ultimate performance.

In brief, the AMOS mandate is to assure successful integration of the CIS into the Observatory and to participate in the development and exploitation of this new capability.

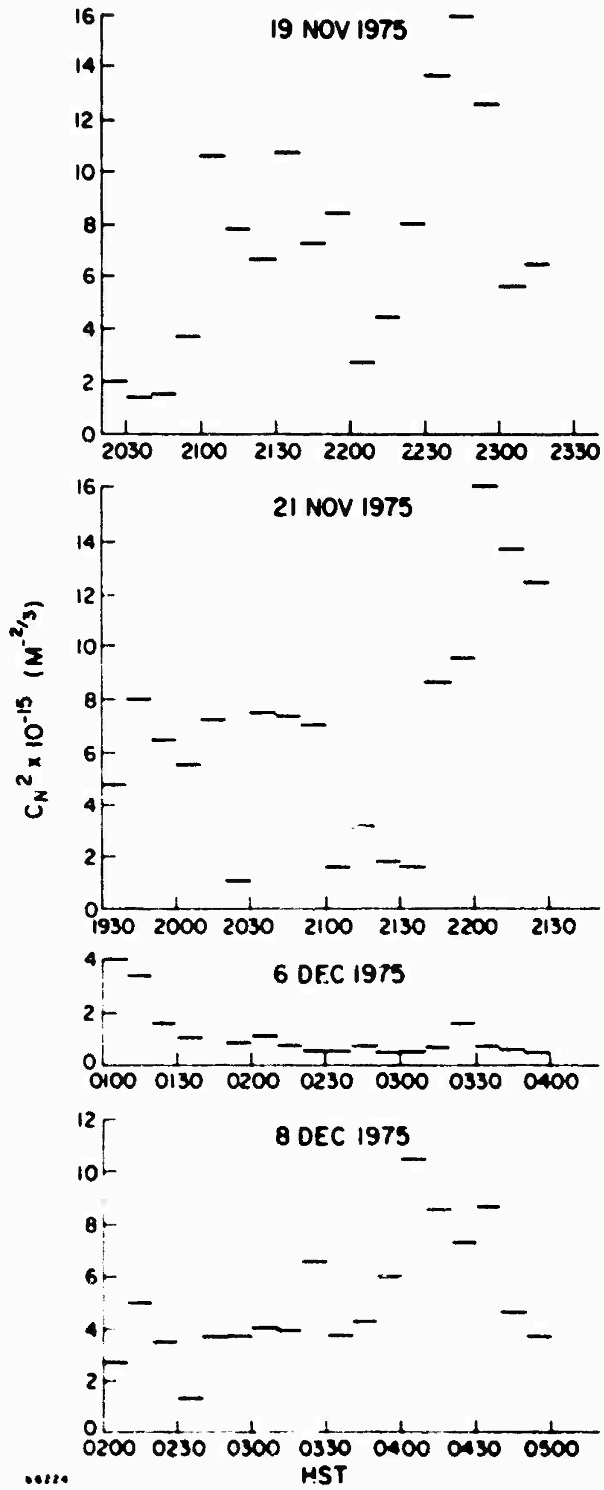


Figure 51 Microthermal Data - 19 and 21 November and 6 and 8 December 1975.

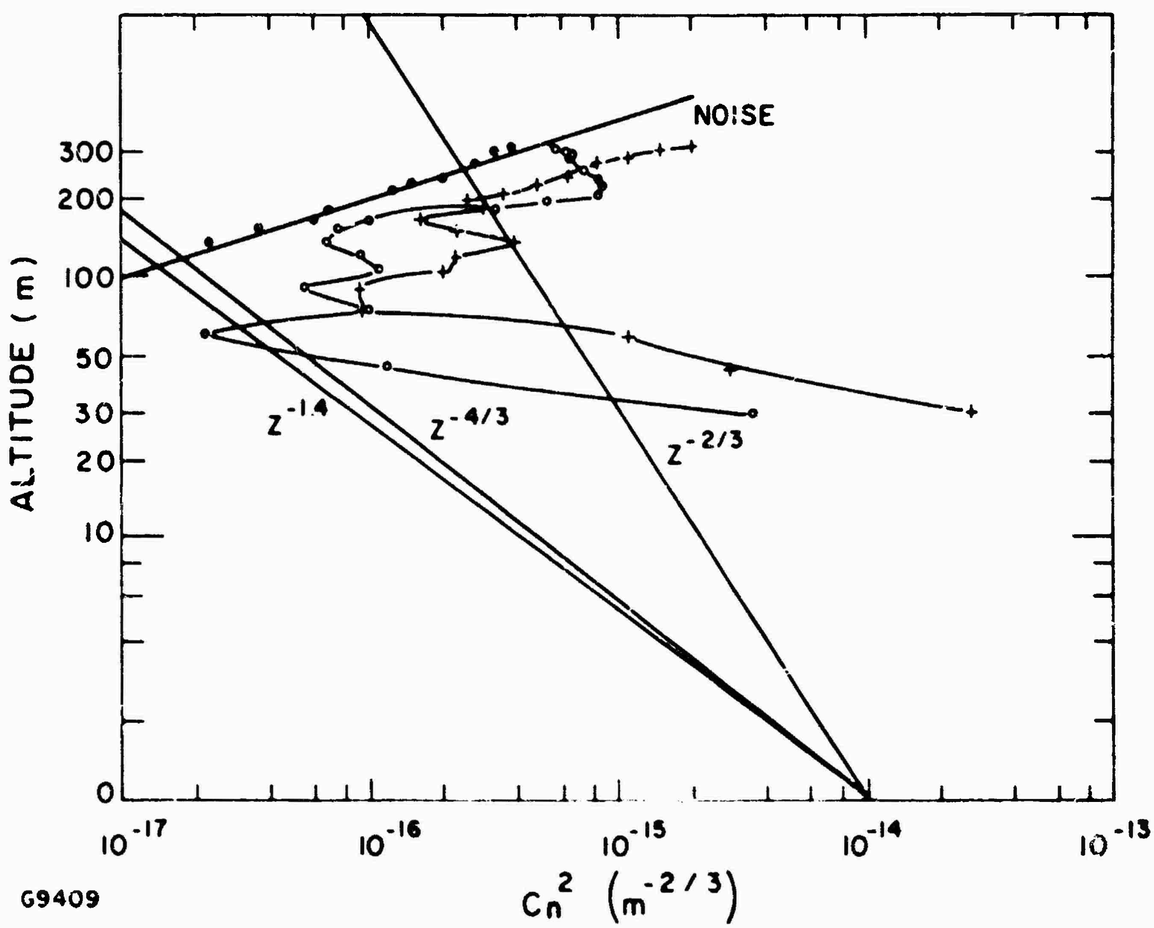


Figure 52 Acoustic Sounder C_n^2 Profile of 10 December 1976

5.2.1.2 Accomplishments

Design and implementation of special tests related to the CIS was one of the most significant accomplishments during Phase III. Information obtained during these tests was used both by ITEK and by AMOS personnel to optimize CIS design parameters and to recommend and/or implement modifications to AMOS subsystems.

Under the Atmospheric Characterization Program (see Section 5.1) an extensive data base began to be accumulated during Phase III. These data - which provide information on the environment that the CIS will be operating in - were used to make critical design decisions on precompensator subsystems and processing algorithms. In addition, this information is of great value in determining mission operating scenarios for the on-site test and evaluation phase of the CIS program.

A large amount of data was obtained on existing AMOS hardware to aid in development of the CIS. For example, wind buffet data (i.e. servo response) were obtained to determine dynamic range requirements of the precompensator tilt mirror. Observatory power line fluctuations were monitored for several weeks to determine the level of complexity required for precompensator electronics subsystems.

A major effort, of course, consisted of ongoing interface activities between AMOS and all of the other organizations involved in the program. This involved transmittal of data on existing AMOS systems, review of all CIS designs for compatibility with AMOS capabilities, participation in CIS design review meetings, etc.

5.2.2 Interfaces

Control of all interfaces between the participating organizations is accomplished by means of Interface Information Documents (IID's). Several dozen of the IID's - prepared by the appropriate organizations - were issued during Phase III. The IID's define hardware and software interfaces, document agreements, define operation scenarios, etc. to assure that integration of the CIS at AMOS will proceed smoothly.

Frequently, an IID will initiate modifications. For example, and ITEK IID which defined CIS control room hardware initiated an AMOS study to define required facility modifications. The result was a detailed Facility Modification Plan which was submitted to the government for approval.

5.2.3 Special Testing

Numerous special tests in support of the CIS were conducted at AMOS during Phase III. The most important ones are described here.

To allow the 1.6-m telescope to achieve required look angles for target tracking and system tests, certain envelope restrictions exist for any hardware system that is mounted on the telescope. Since the CIS is an extremely large and complex system this constraint was of special concern. Over a period of several months during Phase III AMOS personnel installed models (provided by ITEK) of the CIS telescope mounted hardware and performed mount clearance tests. Results of these tests required, in several instances, that ITEK modify their design. Figure 53 shows the model of the rear Blanchard mounted hardware being tested on the 1.6-m telescope.

Another area of concern is thermal degradation of the environment. AMOS objections of initial CIS designs - which allowed approximately 250 W to escape into the atmosphere at the rear Blanchard surface - resulted in design modifications by ITEK that decreased the heat loss to 60 W. At the same time, AMOS personnel looked carefully at the overall problem of local seeing degradation due to thermal sources. Location of thermal sources such as air conditioning exhausts, the CIS heat exchanger, etc. with respect to the direction of the prevailing winds was of particular interest. A series of tests was conducted in which the Seeing Monitor was mounted on the 1.6-m telescope and used to determine possible degradation in seeing (e.g. decrease in r_o) caused by these sources. Figure 54 shows a test being conducted on an existing air conditioning system. A smoke bomb was used to locate the turbulent volume and investigate the effects of winds with respect to Observatory buildings. Initial conclusions from these tests suggest that seeing degradations to be expected for typical CIS missions do not warrant costly relocation of the heat exchangers.

Differential flexure tests between the rear Blanchard and the East Blanchard surfaces were conducted to aid in the design of ITEK's beam bending optics for the CCD imaging camera system. Test results showed that the flexures are within tolerance limits allowed by the ITEK optical/mechanical design and that no stiffening of the relevant 1.6-m telescope mounting surfaces will be required.

A major area of concern has been the tremendous increase in 1.6-m telescope inertia that will be produced by the CIS and its counterbalance system. Several iterations in ITEK's design were accomplished, but the inertia will still be about ten percent over the telescope manufacturer's design limit. Mount performance (i.e. acceleration) is, therefore, of concern. Tests are currently scheduled for January 1978 to determine 1.6-m mount performance under conditions to be expected when the CIS is installed.

5.2.4 Conclusion

The AMOS role in the CIS program continually expanded during Phase III. Although there are still many questions to be answered, tests to be conducted and modifications to be implemented, the period was one of continual progress towards assuring successful integration of the CIS into the AMOS complex. AMOS will continue to become more involved in this program during Phase IV, culminating in the installation and evaluation of the CIS.

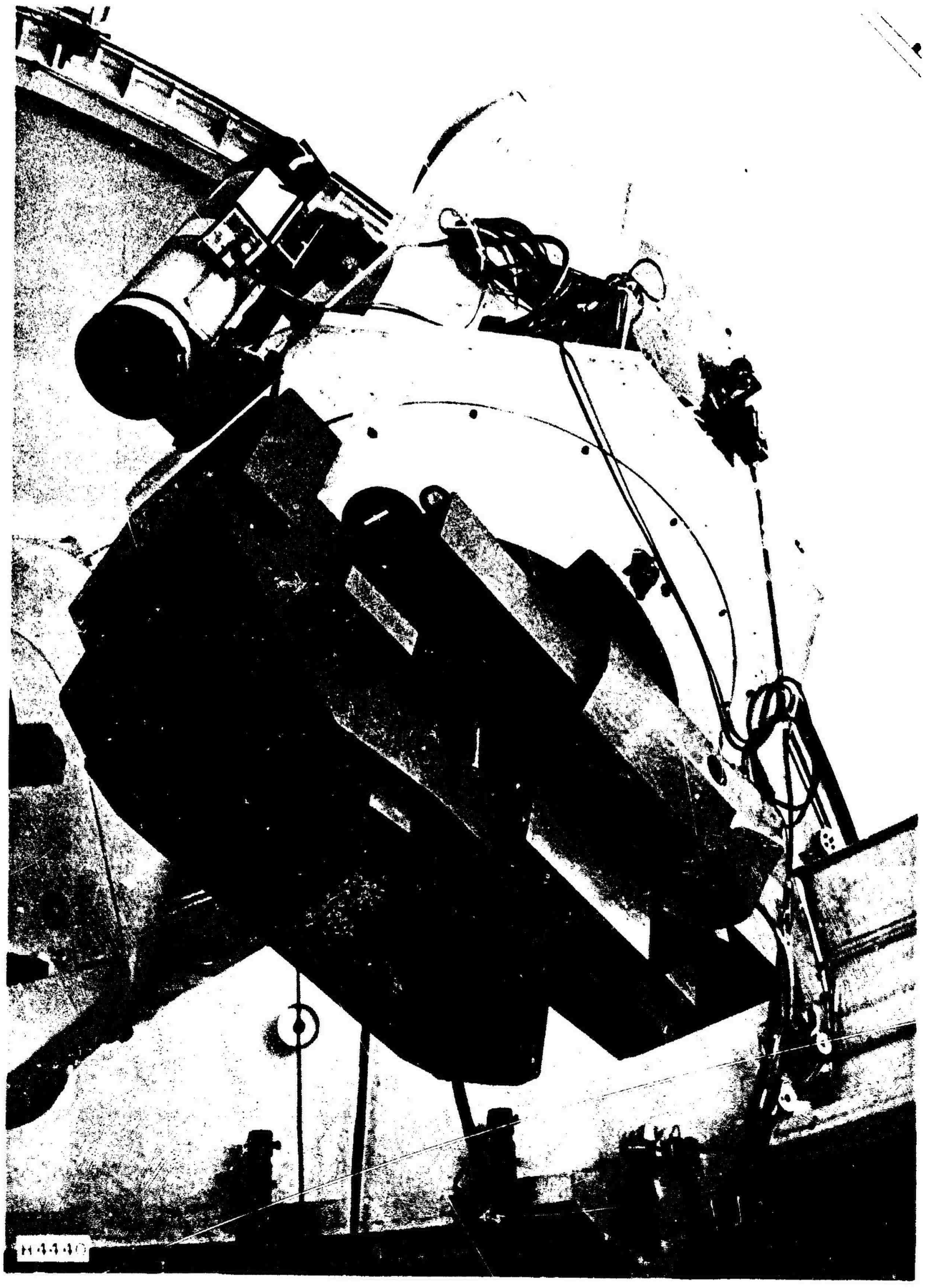


Figure 53 CI Module on 1.6-m Telescope

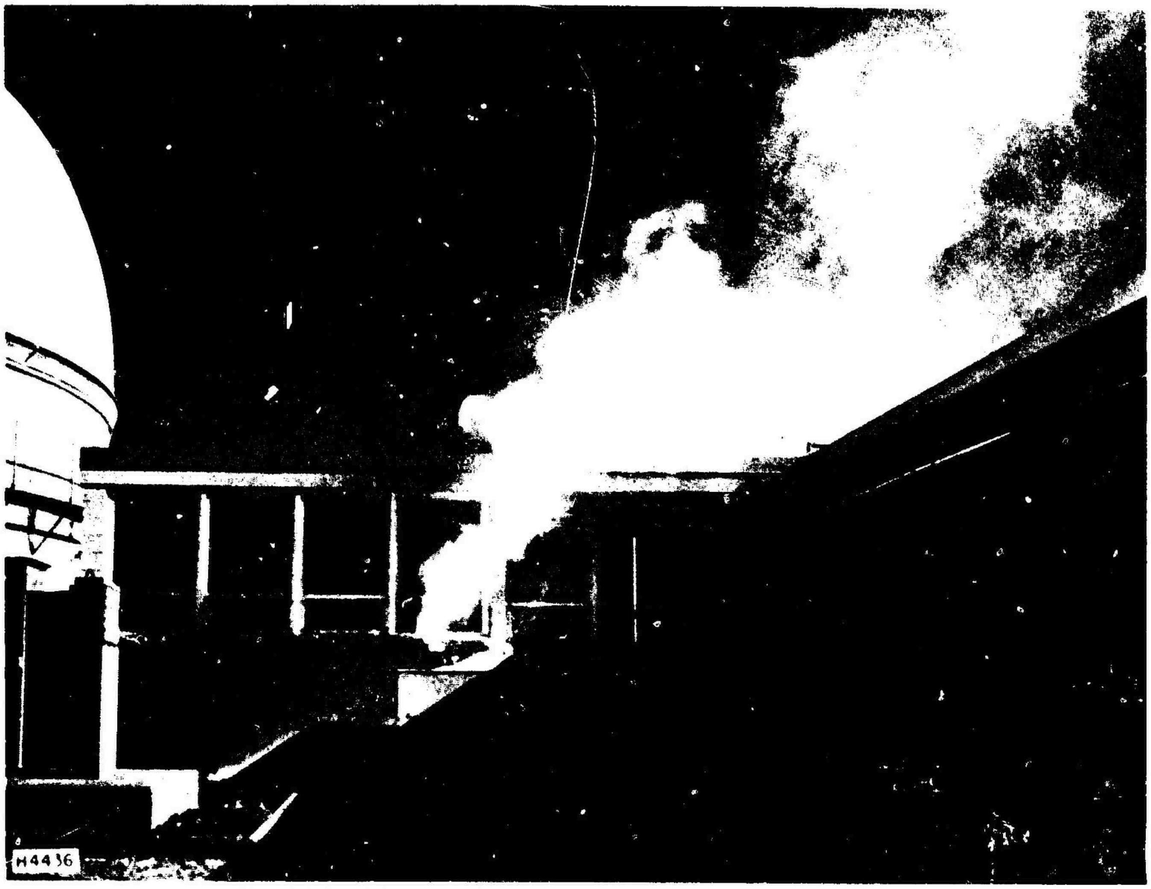


Figure 54 Thermal Degradation Testing for CIS

5.3 TEAL AMBER SYSTEM

Teal Amber is a concept for a groundbased surveillance and detection system utilizing an advanced monolithic CCD detector array. This system has three major goals:

1. Altonomous detection of high altitude satellites
2. Generation of pointing commands for an associated tracking telescope, and
3. Generation of ephemerides on all satellites detected, to update their orbital elements, and to confirm or deny their presence.

The system was conceived as being comprised of three subsystems; Surveillance and Detection (SDS), Operational Logic (OLS), and Acquisition and Tracking (ATS). The Surveillance and Detection subsystem was considered as including focal plane sensor and processing electronics, telescope, gimbal, sensor, control and display console, and the Teal Amber facility. The Operational Logic subsystem was to include data processing hardware and software and timing equipment. The Acquisition and Tracking subsystem was to utilize the AMOS 1.6-m telescope system (for test purposes) together with associated computer equipment, control and display equipment, and appropriate software.

The AMOS Observatory had been selected as the site for the evaulation of Teal Amber. Preliminary interface efforts were undertaken but, in mid-1977, the plans for the AMOS proof-of-concept demonstration and evaluation were deleted from the program.

5.3.1 Summary

During Phase III a Teal Amber facility was constructed from plans and architectural drawings prepared under Phase II. The facility was designed to provide environmental protection for the Teal Amber sensor, gimbal and telescope. Construction of the facility began in August 1975 and work was completed in October 1975.

From October 1975 until July 1977, AMOS personnel provided interface information and prepared plans for the installation of Teal Amber.

In July 1977 a decision was made to reduce the scope of the program due to funding limitations. Part of this reduction in scope deleted the planned installation of Teal Amber at AMOS.

5.3.2 Facility

A new dome facility was constructed at AMOS to house the Teal Amber telescope, gimbal, and sensor. The facility as designed by the architectural firm of Creegan and D'Angelo. Facility design criteria were supplied to the firm of Bolt, Beranek and Newman, Inc. who were engaged to perform a vibration analysis. The results of the analysis showed that the maximum dynamic pitch angle of the telescope/gimbal, due to reaction torques of the telescope/gimbal, was only 4.6% of the maximum allowable value of 0.50 arcsec. The maximum dynamic pitch angle of the telescope/gimbal due to ground vibration would be 53.6% of the maximum allowable value of 0.50 arcsec, and the damping time constant for the facility was estimated to be 0.123 sec, less than the maximum allowable value of 0.30 sec. The facility was constructed by Fuku Construction, Inc., of Maui.

The new facility is located at the northeast corner of the Observatory. The facility is 16 ft square and is capped by a 16 ft diameter Parabam fibre glass dome (see Figure 55). The pedestal, designed to support the gimbal/telescope measures 8 x 10 ft. It is 14 ft high and is located on a vibration isolating 12' x 12' x 3' concrete seismic slab.

The electronic equipment was programmed to be housed in room 43 of the Observatory adjacent to the Teal Amber Facility.

The facility presently houses a 14 in. diameter Celstron telescope equipped with a NOAA sensor to make scintillation measurements as part of the Atmospheric Characterization program.

5.3.3 Interfaces

During the period from October 1975 to July 1977 numerous pieces of interface documentation were prepared and forwarded from AERL/AMOS to AERL/Everett. This information was documented in Integration and Installation Drawings (IID's). The technical data requirements were documented in an Integration and Installation Data Requirements List (IIDRL).

AMOS supplied data on the quality of commercial power available, assessed the amount required and determined its source and distribution. Data was supplied on cable routing from the TA gimbal to the electronic equipment located in room 43 of the Observatory. The excess capacity of the existing air conditioning system was measured and found to be inadequate. A supplementary system was investigated and proposed.

Early in 1977 work had progressed on the gimbal to the point where accurate information on the interior envelope of the Teal Amber dome was required. Preliminary studies indicated that there would be a tight fit between the gimbal/telescope and the already existing 16-ft diameter fibre glass dome. An extensive measurement program was undertaken to accurately define the dome and to validate existing drawings.

During the period when the Teal Amber system was being developed by AERL and Rockwell International AMOS supported the technical review and interface working group meetings and provided responses to action items.

5.4 THERMAL BALANCE

(This section appears in Volume II.)

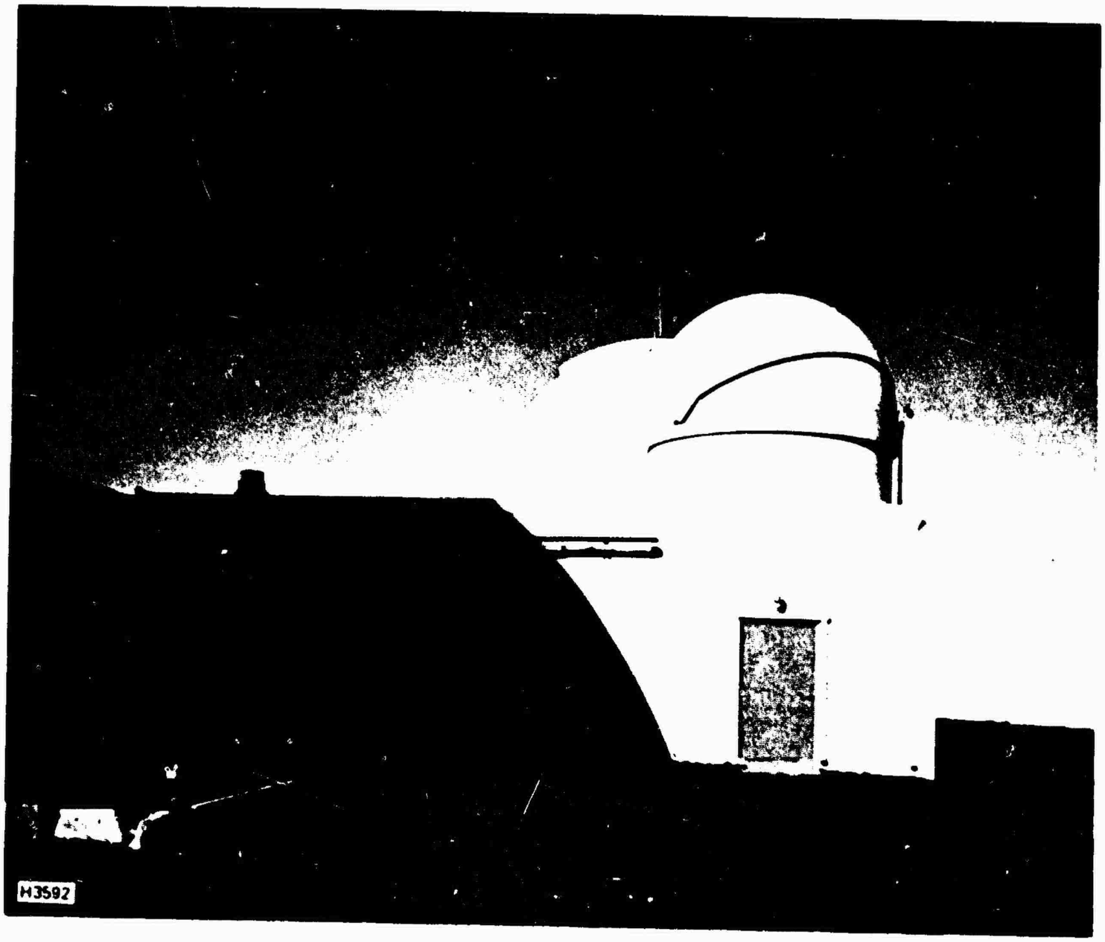


Figure 55 Photograph of the Teal Amber Dome Facility

5.5 MOTIF TRANSITION PROGRAM

Following the decision by the Aerospace Defense Command to utilize the AMOS 1.2-m Telescope System as a prime sensor in the SPACETRACK system, efforts were undertaken to prepare the system for transition to ADCOM.

The Transition Program was divided into two phases, definition and implementation. The Definition Phase took place during the period from July, 1976, through July, 1977, and was performed under AMOS Phase III. The Implementation Phase started on 1 August 1977 with AF issuance of a separate contract to AERL continuing through July, 1979.

Only the work performed under the Definition Phase is described herein.

5.5.1 Summary

The objective of the MOTIF Definition Phase was to define the tasks that would be required to transform AMOS systems, that had been designed to accomplish a wide range of research and development tasks, into an operational SPACETRACK sensor.

Certain tasks, as specified in the statement of work, were to be accomplished during the Definition Phase as necessary presursors to the Implementation Phase. These tasks were System Definition, Periodic Maintenance, ACONS Modification, Reliability and Maintainability Studies, and Data Transmission System Preliminary Design. A report covering each of these tasks has been issued.

5.5.2 Program Definition Phase

5.5.2.1 System Definition

The System Definition task in the statement of work specified that the existing equipment, software, and components at AMOS which are to be part of MOTIF be identified. Also, any systems or subsystems which are not an integral part of the 1.2-m telescope system but required for MOTIF operation were to be identified separately. In addition to performing the specific work outlined above, it was apparent that it would be necessary for the systems engineers working on other Definition Phase tasks to have an intimate knowledge of system operation. Hence, the System Definition task was expanded to include the purpose, function and general theory of operation of each system, subsystem and equipment item. Performance data on each subsystem were also collected under this task to create the System Specification document.

The output of the task was the System Specification/Definition for Maui Optical Tracking and Identification Facility, dated 1 June 1977. This document established the performance, design and functional characteristics for the MOTIF.

5.5.2.2 Periodic Maintenance

Under this task, a Maintenance Plan for the Maui Optical Tracking and Identification Facility was prepared and published on July 31, 1977. The objective of the plan was to document the maintenance, calibration, and performance verification tasks required to achieve a high percentage operational availability, assure data quality and minimize the maintenance cost of the MOTIF.

The plan specifies: required periodic maintenance, calibration, and performance verification tasks and their schedules; corrective maintenance to be performed at each maintenance level; how maintenance schedules and records will be maintained; how material will be processed and maintained. Technical skill levels are identified in the plan to indicate the degree of expertise required to perform the various maintenance, calibration and verification tasks.

Corrective maintenance guidelines are provided in the plan. These guidelines delineate the maintenance to be performed on each item of equipment at each of the three maintenance levels: organizational or operator, intermediate, and factory or depot.

The plan identifies the three types of periodic maintenance functions pertinent to operational effectiveness, i.e., preventive maintenance, performance verification and calibration. The heart of the plan is the table listing the periodic items to be performed for each function. Each system maintenance table has a breakdown into assembly, subassembly and component. The item number column enumerates each equipment item maintained and the Maui Engineering Documentation List (MEDL) number which is used to locate technical documentation.

5.5.2.3 ACONS Modification

ACONS stands for AMOS Control Software. It was originally written as a general program to provide management visibility and status of the following information:

1. Equipment inventory
2. Preventive maintenance scheduling
3. Preventive maintenance performed during previous month
4. Discrepancy report status
5. Engineering documentation by equipment number and by drawing number sequence
6. Maintenance listing information
7. Government tag number/MEDL number

At the present time, the ACONS file contains ~ 3000 items of documentation. The most important feature of the computerized printout is a listing of all the drawings and documentation associated with a particular piece of hardware. This allows rapid location of relevent information on any equipment by a member of the engineering staff involved in hardware maintenance or modification.

Under the definition phase task ACONS was modified to enable seperate retrieval of 48-in. Telescope System data. Additionally the data base was expanded to include all of the MOTIF technical (operation and maintenance) manuals.

A report entitled Maui Optical Tracking and Identification Facility Controls Software, dated August 22, 1977 gives a detailed description of the information contained in the various computer listings as well as sample printouts.

5.5.2.4 Reliability and Maintainability

The objective of this task was to obtain a measure of reliability, maintainability, operability, and availability of the MOTIF.

The data accumulated and the results of its analysis are contained in the MOTIF Transition Program Definition Phase Reliability/Maintainability Study, dated June 1977.

Analysis of the data gave an estimated percent availability for MOTIF of 91%. It further showed that only minor modifications to hardware and preventive maintenance procedures are required to upgrade this to the desired 95%.

5.5.2.5 Data Transmission System (DTS)

One of the tasks under the MOTIF Definition Phase was to undertake the preliminary design of a system for recording, processing and transmitting photometric and positional data.

The Data Transmission System was designed and is documented in the Data Transmission System Design Report dated March, 1977. The basic requirements for this system were obtained from the Program Introduction and Concept of Operations prepared by ADCOM.

In designing the DTS, the first step was to determine the system requirements, including both operational performance capabilities and hardware interfaces. Certain aspects of the requirements definition, however, were indeterminate without detailed knowledge of both the communications subsystem and the facility computer subsystem. Although definition of these subsystems had not been included as tasks for this first phase of the MOTIF program, it became clear that the approach to the DTS design would be more efficient if it considered an integrated system which included the communications and computer functions along with the DTS.

The DTS is required to operate in both realtime and near realtime modes simultaneously. The realtime mode includes sensor and tracking data input, preprocessing and recording. The near realtime mode includes editing and processing prior to transmission to the Space Defense Center (SDC).

Photometer data will be transferred in realtime to the DTS and recorded on disc. These data are recalled and displayed to the operator on a graphics CRT display showing signal amplitude vs time. The operator will have the capability to selectively call up certain portions of the data for display, to change scales as desired to view the data with greater or less resolution, to edit the data by deleting bad or unusable data, and to achieve data integration by adding a selectable number of data samples.

Once the operator has determined what portions of the mission data file are useful and appropriate for transmission, he will instruct the DTS to reduce the selected data. This requires factoring in calibrated responsivities and atmospheric extinction, along with target range obtained from the metric recording, and then normalizing the data.

Metric tracking data is acquired, processed and stored by the CDC computer system and transfered to the DTS.

The DTS interfaces with the communications subsystem. This interface is bidirectional and permits the transfer of formatted and reduced photometric and metric data to the SDC, and the receipt of satellite element update messages and satellite tasking messages from the SDC. The DTS is capable of exercising this interface in either direction simultaneously with the normal realtime data acquisition mode.

The basic system configuration is shown in Figure 56. The two major components of the DTS - the computer and the graphics display terminal - are shown, as well as the communications subsystem. In addition, interfaces to the existing MOTIF equipment - the photometer sensor subsystem and the CDC-3500 computer subsystem - are shown.

5.5.3 MOTIF Interface

AMOS developments have resulted in a state-of-the-art 1.2-m measurement system capabile of routine data collecting operations. Following completion of this groundwork by DARPA, USAF began the transition of this capability to ADCOM. They are currently in the process of adding major systems improvements to satisfy ADCOM operational requirements. These system additions, as well as other major MOTIF tasks, are being performed under a separate USAF transition contract. Certain interface efforts were, however, conducted under the phase III contract.

These efforts included the evaluation of safety hazards and human engineering deficiencies in AMOS systems. Hardware modifications, i.e., modification of the dome crane and dome control console, were initiated to correct previously identified deficiencies. Documentation of systems that will be shared by the ADCOM MOTIF system and DARPA systems was

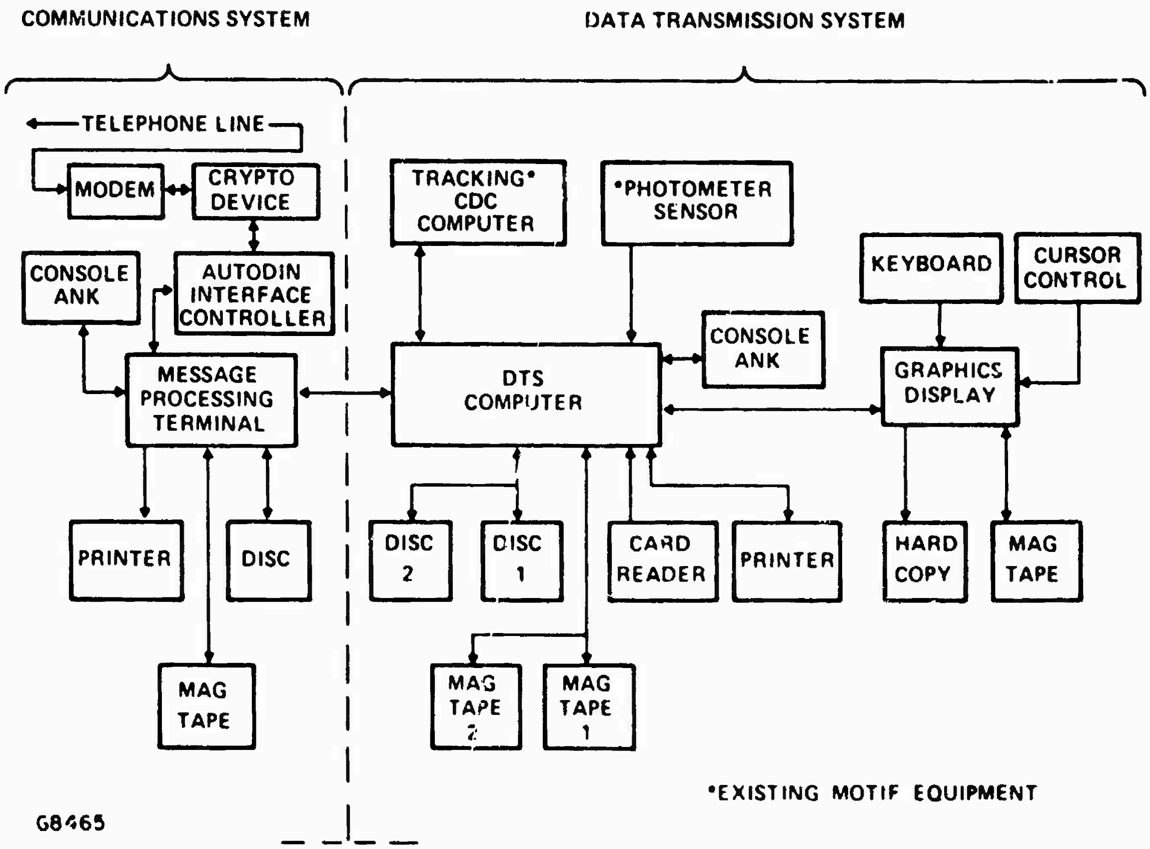


Figure 56 The MOTIF System - New Hardware Configuration

improved. Work was performed to interface the low light level television camera, procured by AMOS for the SEP program, with an optical package that will become an operational MOTIF sensor. The common computer system capabilities were improved through the purchase of additional magnetic tape, tape storage racks, a tape degaussing unit and a tape verifier. Maintenance of the 1.2-m telescope system was also performed during the initial phase of the transition program.

5.6 LASER RANGING PROGRAM

In July of 1977 a laser ranging program was initiated for DARPA. The primary objective is to provide sufficient data and analyses to show feasibility of accurate ballistic target tracking and state vector handoff to downrange sensors.

5.6.1 Summary

Specific tasks to be performed for the laser ranging program during the period 1 July to 31 December, 1977, were:

1. Reactivate the AMOS/LBD ruby laser system
2. Incorporate minor modifications to improve ranging precision and system versatility and reliability.
3. Completely calibrate the system
4. Perform tracking/ranging on GEOS C and targets of opportunity
5. Generate an error model to show accuracy requirements for propagating the state vector down-range.
6. Determine residual errors in range precision and accuracy for input to the error model
7. Determine/recommend necessary system improv ments
8. Define an on-going experimental program

5.6.2 System Description

Basic components of the AMOS laser ranging system are shown in Figure 57 and include the Laser Beam Director/Pulsed Ruby Laser complex (Section 2.3), the 1.6-m telescope (Section 2.2) and the CDC 3500/SC 1700 computer systems Section 2.4).

Operation of the system for ranging measurements can be briefly described as follows:

1. The laser pulse is aimed at the target with the LBD

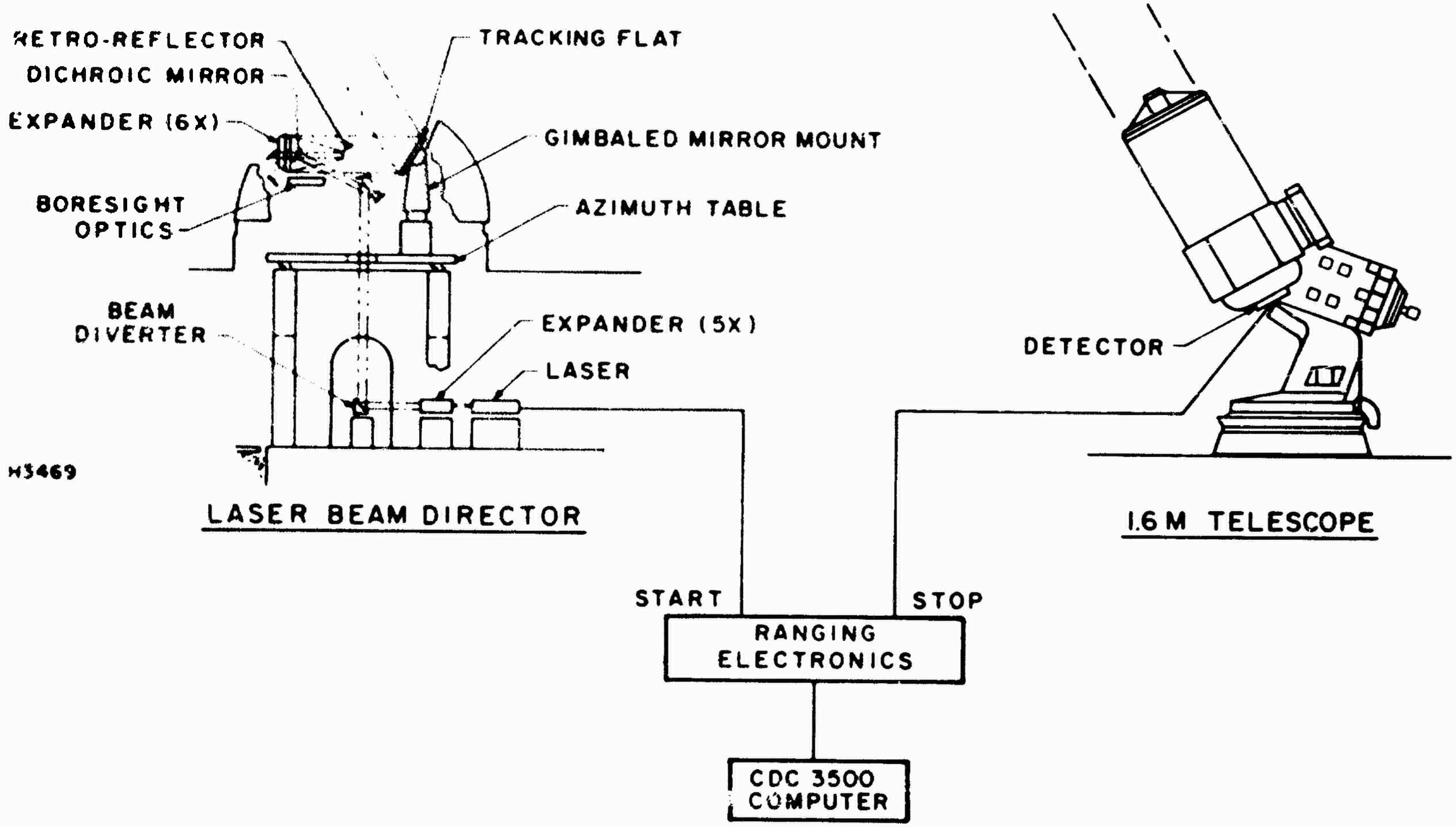


Figure 57 AMOS Laser Ranging System

2. Reflected laser radiation is collected by the 1.6-m telescope and focussed on a photomultiplier tube at the Cassegrain focus. Appropriate spectral and neutral density filters, variable field stops and high speed shutters are available in the receiver package.

3. The photomultiplier tube output is input to the ranging electronics system which consists, basically, of an oscillator and a pulse counter. Oscillator pulses are gated into the counter by the outgoing laser pulse. The oscillator pulses are gated off by the pulse from the photomultiplier. Other electronics tag the firing time.

4. Both the range word and the time-tag word are sent to the CDC 3500 computer for storage and later processing. Data reduction programs allow printing out of raw and processed range data, fitting of residuals with high order polynomials etc.

5.6.3 Predicted Performance

Table 23 shows the system performance expected for this Program.

5.6.4 Program Status

All of the tasks shown above were successfully accomplished by the end of the AMOS Phase III program.

The LBD/laser was reactivated as scheduled. Major modifications implemented during that period included: 1) a redesign and upgrade of the ranging receiver electronics to reduce ranging jitter to the theoretical system limit of $\pm$ 2-m for retroreflector satellites, and 2) the installation of a new platform encoding system for the LBD azimuth turntable to provide required repeatability in turntable repositioning.

Preliminary satellite ranging and system calibration began in October. During November and December, 7 successful ranging missions on the satellite GEOS C (the program's reference target) were conducted. Analyses have successfully identified all major sources of residual errors in the data and the error model has been exercised to show the handoff accuracies which can be achieved with the AMOS LBD system.

5.7 AERL SPECKLE EXPERIMENT

In early 1970, Antoine Labeyrie demonstrated a revolutionary technique for recovering near-diffraction limited information about objects imaged through turbulent media by large aperture instruments. His discovery of speckle interferometry suggested that large earth-bound telescopes could finally be used to resolve diffraction limited detail. The ability to observe meaningful object detail ten to one hundred times finer than conventional imaging techniques opened new research areas to the astronomical community.

TABLE 23

PREDICTED PERFORMANCE

Parameter	Value	Comments
Energy/pulse	10 J	Maximum
Pulse Width	≃ 20 nsec, FWHM	Minimum
Beam Divergence	≃ 2 arcsec, FWHM	Minimum
Pointing/Tracking	± 1 arcsec	Assumes accurate elements
Expected return	≃ 10^9 photoelectrons/ pulse	GEOS C (R ≃ 1 Mm)
	≃ 10^1 photoelectrons/ pulse	(ρ A ≃ 0.1 m^2, R = 1.6 Mm)
Ranging Precision	± 2 m (retroreflectors)	Set by 75 MHz oscillator
	≃ 10 m (few photo/ electrons)	Set by pulse width
Firing Time-Tag	± 10 μsec	$\|\Delta R\| < 0.1$ m

AERL, under the Phase III Program, conducted a series of efforts to explore the utility of the speckle technique in imaging objects of interest to DARPA. The initial work resulted in a second potential application of the technique, investigating atmospheric effects of interest to the development of techniques for imaging through the atmosphere. This second issue was explored under an AERL sponsored study, but involved AMOS support of measurements. Both efforts are described below.

5.7.1 Summary

Three complementary speckle program areas were explored under the Phase III contract: theory, laboratory simulation and study, and field demonstration.

Certain theoretical development was necessary to put the concept on a sound basis. Understanding the technique would enable its optimization for the areas of interest, as well as determine possible limitations.

Laboratory simulation was proposed as a necessary element in the practical development and implementation of the technique. Ideas could be quickly and efficiently tested at low cost on a realistic simulation facility. Equipment for a field demonstration of the technique could also be effectively developed in the laboratory, and data processing techniques could be generated.

The field demonstration program area was designed to show that a reliable field technique producing useful data on objects of interest could be developed.

Measurements were taken during mid-1975 at AMOS using the 1.2-m b = 30 telescope. Over 60,000 frames of data were taken. Several 100 frame sets were processed on-line while the remainder were stored on tape for later processing in the Everett Laboratory.

Data on single and binary star sources were taken to establish the capabilities of the sensor and data reduction equipment, to compare with the previously generated laboratory simulations and to generate a data base for understanding the requirements for image reconstruction, atmospheric effects evaluation and further potential applications of the technique.

In July of 1976, a more limited measurement period was supported by AMOS. The 1.6-m telescope was utilized for this series of tests. Results were obtained to characterize and quantify noniosplanatic effects in extended object imaging. Temporal nonstationarity in the atmospheric function was also confirmed. The results, and others, have been shown to be of interest to Compensated Imaging System development.

5.7.2 Theoretical Analyses

A relatively complete analysis of speckle interferometry was performed early in the program. Additional work was performed dealing with other interferometric techniques and in calculating nonisoplanatic effects. Limited theoretical efforts went toward more extensive S/N calculations and preliminary work on connections between speckle interferometry and compensated imaging, especially regarding nonisoplanatic limitations.

5.7.3 Laboratory Experiments

Speckle investigations had been initiated under a previous DARPA sponsored study. Although both laboratory and field experiments had been undertaken, all data were recorded on film, making the processing laborious and, often, imprecise if not inadequate to derive meaningful results. During this phase of the efforts, the simulator was modified to utilize a SIT sensor to record the speckle images. A digital output from the sensor was available for direct digital processing by a minicomputer. Various levels of atmospheric parameters were selectable, and target models could be observed through the resulting simulated atmosphere. Simulator results were used to evaluate the applicability of atmospheric models, to implement image reconstruction algorithms and to further evaluate nonisoplanatic effects.

5.7.4 Field Experiments

The primary effort under the Phase III sponsored speckle program went to the field demonstration. Components from the simulator facility were reconfigured and assembled for use on the 1.2-m b - 30 telescope. Electronics equipment for recording and processing the digital output of the SIT were also suitably mounted for in-dome use with the sensor system.

Several 100 frame averages of complete speckle lens-atmosphere modulation transfer functions were obtained using bright star sources. In addition, over 60,000 frames of data were recorded for later processing. These data were used to provide statistical information on seeing, image wander, and intensity variations as functions of exposure time, spatial bandwidth, telescope elevation angle, weather, etc. Results of the analyses conducted on the data appeared in Reference 13.

The data suggest the presence of significant levels of temporal nonstationarity in the atmospheric imaging transfer function on time scales of the order of seconds. At low (seeing limited) spatial frequencies the variance in the transfer function is above the level expected for constant seeing conditions. At higher frequencies out to the aperture diffraction limited frequency the variance in the transfer is above the level expected if the modulus of the instantaneous optical transfer function were Rayleigh distributed as predicted by the central limit theorem. These analyses were reported upon at the October, 1976, annual meeting of the Optical Society of America (Paper No. MF 14).

A second series of experimental measurements was performed in July, 1976. AMOS support was provided for the measurements, which were conducted as part of an AERL sponsored study. Nine nights of testing were accomplished with, again, some on-line digital processing to verify system performance and the major data base recorded for later processing.

The major objective was characterization and quantification of non-isoplanatic effects in extended object imaging. The technique employs the modulation of the fringes observed in the ensemble average squared modulus of the Fourier transform of binary star images to quantify the effects. The modulation is a function mainly of binary spacing, depending only weakly on spatial frequency. It was shown by the measurements taken that for a typical atmospheric turbulence profile nonisoplanaticity reduces the modulation by a factor of 4 for a 1 arcsec and a factor of 30 for a 2 arcsec binary under 1 arcsec seeing conditions. A more thorough treatment of these data was presented at the October, 1976, annual meeting of the Optical Society of America (Paper No. TuF 13).

5.8 VISITING EXPERIMENTS

The AMOS facility provides unique capabilities for the support of optical experiments which deviate from the routine AMOS operations. During the Phase III program, AMOS has supported experiments in speckle interferometry of stellar and planetary images; laser ranging to the moon (in conjunction with the University of Hawaii), photographic and infrared measurements of high altitude chemical release experiments, infrared atmospheric spectral radiance measurements, temperature determination of asteroids and planetary moon systems to develop and verify infrared integration measurement techniques, experiments with Low Light Level TV systems to explore the limits of detection and the measurement of the refractive structure of the atmosphere in the visual and LWIR spectral regions.

The majority of these programs have required special support which fall outside the normal mode of operation. Special fixtures are fabricated and special measurement techniques are developed to meet the objectives of the varied programs. For each program a detailed Mission Instruction and Operation Plan (MIOP) is prepared which defines the experiment and the data to be collected. During the course of the Phase III program 24 such MIOP's have been prepared; of these, 11 relate directly to the Visiting Experiments covered in this section or in Volume II, classified.

5.8.1 Summary

The nonclassified visiting experiments supported under the Phase III program are summarized as follows (classified summaries appear in Volume II):

LWIR Atmospherics - The upgrade modifications performed on AMTA provided an increased sensitivity capability which has been used to advantage to measure radiant intensities of deep space objects (asteroids and planetary moons), provide a direct measure of sky radiance noise, examine the angle-of-arrival fluctuation through the atmosphere and explore the possibility of determining the transmission of the atmosphere in realtime via a measure of atmospheric emission.

LURE Support - The AMOS 1.2-m telescope was used as a receiver to support the Lunar Ranging Experiment conducted by the University of Hawaii LURE Observatory. The support was requested by NASA as a result of a projected delayed arrival of the LURE receiving system. The AMOS support enabled early checkout of the LURE transmitter and data processing systems.

Have Lent III - AMOS has been active in the observations, both visual and infrared, of chemical release experiments. The Have Lent measurements performed in Phase III were the third in a series of sounding rocket tests performed in Hawaii. Infrared signature measurements were performed on six experimental aerosols.

5.8.2 LWIR Atmospherics

The modifications which were made to the AMTA signal conditioning and recording facilities (see Section 2.1.3.1) increased the system sensitivity sufficiently to permit observations of faint deep-space objects to be made routinely. This added capability led to a series of stellar and asteroids measurements designed to explore the limits of the integration technique. The limits are not directly related to available integration time, as was first suspected, but also depend on the magnitude of so-called "sky noise" present during the measurement. A separate investigation related specifically to sky noise determined that the noise is a function of telescope slewing rate. The noise produced while observing a portion of the sky with the telescope stationary is less than that produced when similar sky observations were made with the telescope moving. Wind-driven eddies were also observed on AMTA, even when tracking stars. If examination of the outputs is made at a number of detectors, it is possible to identify the wind direction very accurately.

The AMTA modifications which permit the dc recording of detectors were used to explore the possibility of obtaining a measure of atmospheric extinction in realtime. In effect, the dc resistance of a background limited IR detector is a function of the atmospheric emission at the wavelength of interest, and the emission can be related to transmission. The measurements were carried to a point sufficient to prove feasibility for the technique; however, further correlation with the normal mode of obtaining extinction measurements (through stellar observations) is required to refine the technique and obtain necessary constants.

Also covered under the LWIR Atmospherics program were experiments to investigate the wavelength scaling of angle-of-arrival fluctuations for radiant energy propagating in slant paths through the whole atmosphere. The overall object of this study is to provide information relative to defining physical limits imposed by turbulent atmosphere upon imaging and collimating systems, principally at LWIR wavelength. To perform these measurements, an IR Hartmann mask was fabricated and positioned within the AMTA housing.

Further details relating to the objectives, conduct and results of the LWIR Atmospherics program are documented in Reference 5.

5.8.3 LURE Support

As a result of a request from the NASA Lunar Programs Office and the University of Hawaii, AMOS provided measurement support to the LURE Observatory which is colocated with AMOS on Mt. Haleakala. The LURE Observatory was constructed to gather Lunar Laser Ranging data, to be used in conjunction with a similar site at the McDonald Observatory in a long term program to investigate the shape of the earth and measure horizontal distances along its surface. The optical receiver being constructed for LURE had been delayed far beyond the schedule for the other components which had reached operational status.

With concurrence of DARPA and SAMSO, the b = 30, 1.2-m telescope was fitted with a University of Hawaii photometer and an AMOS supplied boresight TV system. In addition to interfacing the hardware, a modified software program was developed for Lunar tracking. The receiver package was used periodically to detect reflected pulses generated by the LURE Neodymium YAG laser from the end of August 1975 until March of 1976.

Calculations performed by University of Hawaii personnel indicated the expected returns would be very low, on the order of 1/4 photon for every transmitted pulse. In addition, the photometric return from the sunlit moon would be high, on the order of 30,000 photoelectron counts per sec. These high background counts were observed even with a narrow spatial field-of-view of 4 arcsec and a narrow spectral filter with a 4 Å bandpass. Detection and background suppression were accomplished by the use of nsec time gating and via computer sorting.

The first positive returns were observed on August 27, 1975 when a total of 6,000 shots were fired. A total of 12 photoelectron events were observed which were grouped within a six nsec spread. The following night positive returns were observed on two sets of 1,000 shots. A time return spread of 8 nsec occured between these two sets which correlated with an expected range variation due to the libration motion of the moon.

AMOS support of the program continued until March of 1976. During this time, the AMOS observations enabled LURE to continue with the checkout and optimization of their transmitter and software data processing and provided McDonald with correlation data for the overall Lunar Ranging Program. AMOS support was terminated with delivery of the LURE optical receiver package.

5.8.4 Have Lent III

The Have Lent III experimental program was successfully supported in January and February of 1976. This program consisted of three sounding rocket tests launched from South Point, Hawaii. The primary AMOS objective was to obtain infrared signature measurements on each of six experimental aerosols, two of which were deployed during each launch.

Data collected during the test series was reduced, analyzed and a final report issued in April 1976.[14]

5.8.5 Itek Speckle

(This Section appears in Volume II.)

5.8.6 SAMSO Evaluation Program

(This Section appears in Volume II.)

5.8.7 Sandia Support

(This Section appears in Volume II.)

5.8.8 Teal Anyx Support

(This Section appears in Volume II.)

6.0 PROGRAM SUPPORT AND CONTROLS

Program Support and Controls form a key group of tasks in managing a nonroutine R&D program at a remote site such as AMOS. Immediate need for special requirements in personnel, equipment, supplies and information always need to be assessed against the time and distance from the sources. This dictated rather stringent scheduling, recordkeeping and personnel and property management techniques to assure a timely meaningful accomplishment of contract requirements. This following section discusses the techniques and vehicles used at AMOS to successfully support this unique situation during Phase III.

6.1 SUMMARY

Program Support and Control activities were delineated in the Phase III Program Plan and were required either specifically through the contract, or generally (particularly in Property Control, Security, Safety, and GSA Vehicles) by regulations of responsible government agencies. This support consisted principally of tasks in the following areas:

1. Scheduling - Manpower, Measurements Support and Development Activity
2. CDRL - Technical Data and Report Files
3. Program Costs - Control, Status and Analysis
4. Purchasing, Property Control and Inventory Management
5. Security - Classified Document and Personnel Clearance Control
6. Technical Interchange - Meeting Support, Visitors, Colloquia
7. Transportation - Management of GSA Vehicles
8. Maintenance - Preventive and Corrective, Failure Summary
9. Safety - Program, Plans and Reports
10. Quality Assuring - Receipt Inspection and Acceptance Testing of GFE, Instrument Calibration
11. Configuration Management - AMOS Controls Software (ACONS)

6.2 SCHEDULING

Scheduling activity during the AMOS Phase III contract fell into three broad categories:

- Manpower Scheduling - Accomplished formally at weekly scheduling meetings and documented by the Weekly Activity Schedule. All operations and Observatory maintenance personnel were work-assigned, for the short term, in this manner. Informal scheduling of all AERL-Maui personnel was accomplished at weekly staff meetings. In addition, periodic manning reviews defined long term (6 month) requirements and established personnel hiring and transfer policies.

- Measurements Support - Both long range and short term measurements scheduling was updated regularly, using as a base the AMOS Systems Schedule (CDRL Line Item #A004). First published in February, 1975, and revised and reissued approximately bimonthly thereafter, this schedule tracked both mandatory and target of opportunity measurements, visiting experiments, and significant system testing. All of these measurement activities were initiated by a Mission Instruction and Operations Plan (MIOP-CDRL Line Item #A00B), which described measurement objectives, system configuration and operational procedures. Figure 59, the Measurement Summary for the three-year contract period, shows external user or visiting experimenter support provided by AMOS during Phase III. The MIOP's not shown described internal test or evaluation efforts, such as AMTA evaluation or beamsteering testing; AERL/Everett experiments, such as IR atmospherics or sky granularity measurements; or additional testing tied to scheduled measurement support, such as Seeing Monitor or RTAM acceptance tests which were associated with Atmospheric Characterization. Further elaboration in this area may be found in Section 3.0, "Measurements Program."

The results of these two scheduling activities essentially dictated an Observatory Systems schedule, which controlled scheduled downtime, subsystem availability and required system configuration. The third category encompassed:

- Development Activity - The Development Program consisted of system modification and new technology integration, some carried over from Phase II (i.e., begun by LMSC, Inc., the AMOS Operations and Maintenance contractor prior to January 1, 1975) and others in the form of Work Requests, funded by Contract Change Notices to the Phase III contract. These also were tracked by the AMOS System Schedule, with progress detailed in the Quarterly Technical Progress Reports (CDRL Line Item #A00E), and summarized in the Design Change and Interface Specification Reports (DCISR-CDRL Line Item #A002).

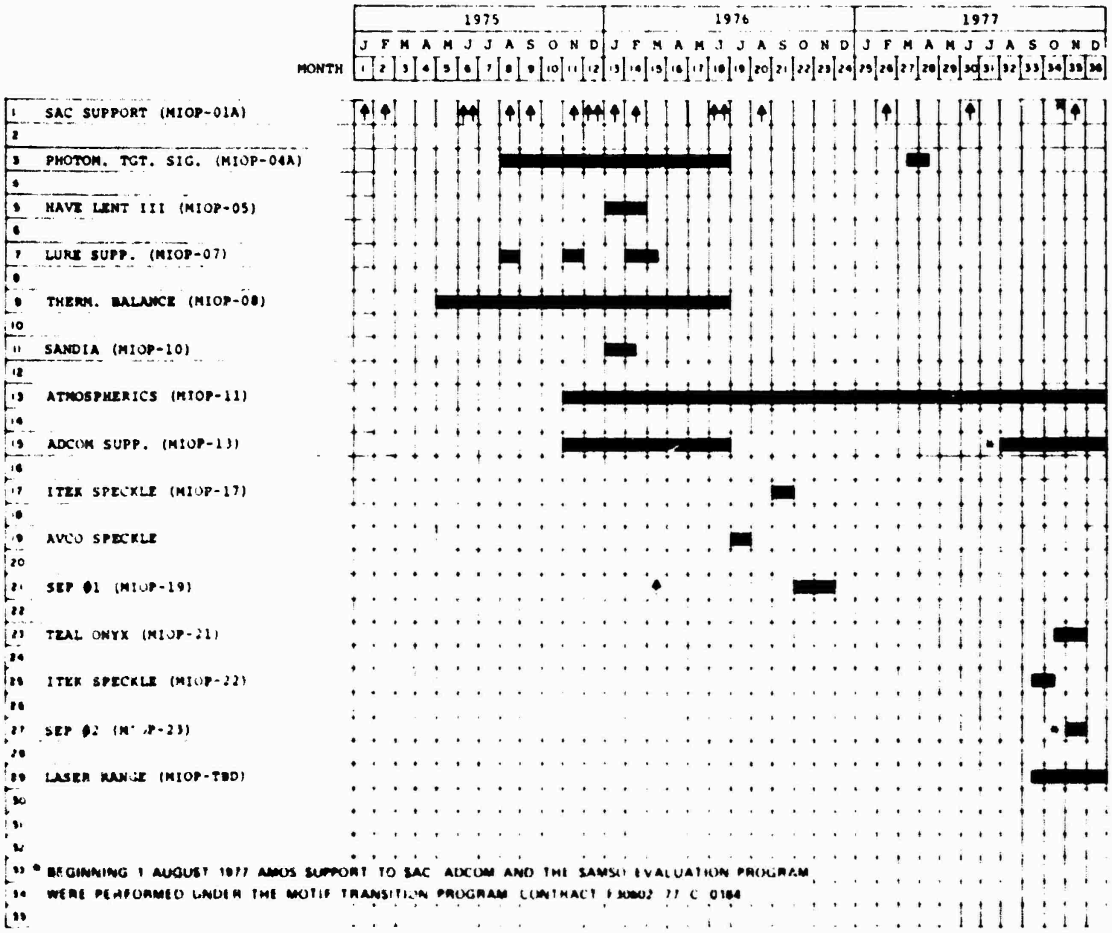


Figure 59 AMOS Measurement Support Phase III

Figure 60 displays this Development Activity Summary for the three-year contract period.

6.3 CONTRACT DATA REQUIREMENTS LIST (CDRL)

The CDRL, included in the Statement of Work for the AMOS Phase III contract, served as a means of keeping both DARPA and RADC informed of the technical and financial status of the Program. A summary of CDRL transmittals for the three-year period appears in Figure 61.

To facilitate the preparation of those CDRL items reporting technical status and progress on a periodic basis (e.g., AMOS System Schedules, Quarterly Technical Progress Reports, etc.), an AMOS System Schedule Item (ASSI) file was maintained. The file collected documentation on all Development Program activities (each is given a four-digit ASSI number) and all MIOP's. Included were memoranda, technical reports, specifications and acceptance test data for new hardware, which provided a permanent ready-reference and complete history for each item.

6.4 PROGRAM COSTS

Program costs were collected and controlled by means of a series of work order numbers which were established during the initial planning for Phase III and updated as necessary during the program. A series of weekly and monthly internal accounting reports made cost data available to the program management on the use of labor hours, purchase commitments, cost performance, and funding status. This sequence of collection and analysis made cost status available to program management on a timely basis. On a monthly basis throughout the Phase III program, a Contract Funds Status Report and a Monthly Cost Analysis Report were submitted to the government to provide timely information.

6.5 PURCHASING, PROPERTY CONTROL AND INVENTORY MANAGEMENT

Purchasing throughout the Phase III contract conformed to AERL, Inc. buying practices. All purchases were initiated by a Purchase Requisition, ordered via a Purchase Order and okayed for payment with a Payment Authorization, each of these documents requiring different signatory responsibility. A full time Purchasing Agent (Buyer), with corporate commitment authority, was assigned to AMOS throughout the contract period. Costs of both accountable (tagged) property and expendables were carefully segregated between AERL-owned (overhead) and GFE (direct) by use of the Work Order # system discussed in Section 6.4. A close working relationship was established with several key vendors affording AMOS more timely and attentive service than might normally be expected for Hawaii.

The contract authorized the use of GSA supply sources under ASPR paragraph 7-204.28, and these sources, as well as the advantageous GSA pricing available from certain commercial vendors, were used whenever practical. Government Bills of Lading (GBL's) were used frequently to reduce transportation costs on these shipments which were not time critical.

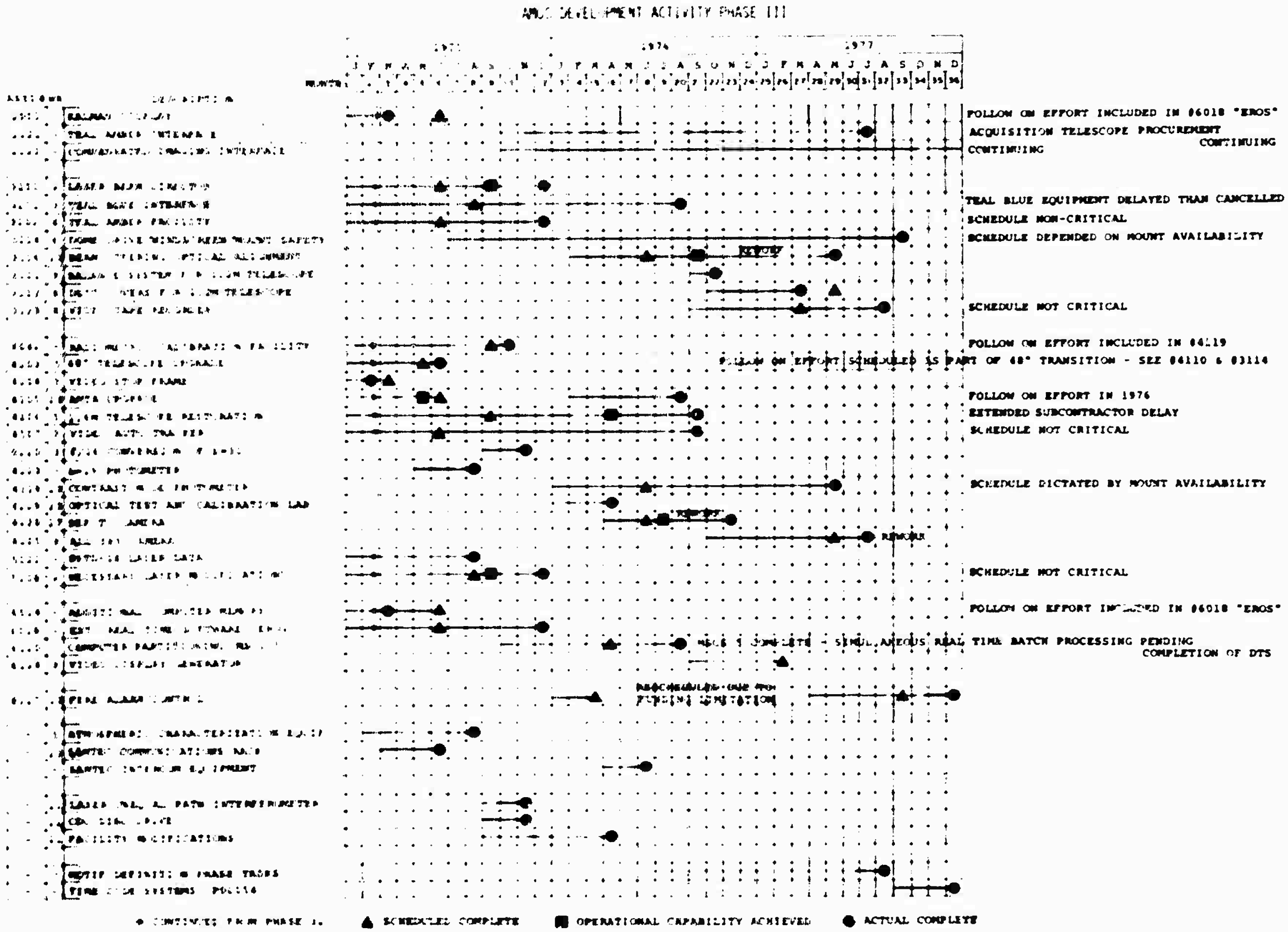


Figure 60 AMOS Development Activity Phase III

CDRL		1975												1976												1977											
SEQ #	TITLE	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D
A001	CONTRACT FUNDS STATUS REPORT		21 24	24	28		9			30	1 3	6 6 7	22	23	13	10	13	12	10	12	9	9	7	10		11/20	22	17	28		6/10		15/19		18/19	Δ	Δ
A002	DESIGN CHANGE & INTERFACE SPEC																												29							Δ	Δ
A003	FINAL REPORT																																			Δ	
A004	AMOS SYSTEMS SCHEDULE		14		2		11			15		24		19		16		14	28				7		15			4	21		23			9		Δ	
A005	AMOS USER'S MANUAL								1																			27 (D)		20							Δ
A006	ABSTRACT OF NEW TECHNOLOGY	A/R →																																			
A007	FLASH REPORT	A/R →																																			
A008	QUICK LOOK DATA REPORT	X							X	X	X			X		X	X		X				X				X					X					
A009	DATA ANALYSIS REPORT				29												22												5								
A00A	QUALIFIED DATA PACKAGE								X	X	X	X	X		X	X	X	X	X		X		X					X									
A00B	MISSION INST & OP PLAN MIOP		X					X	X	X	X	X	X	X					X	X	X	X			X	X											
A00C	OPERATIONS & MAINTENANCE PROCEDURES	A/R →																																			
A00D	FAILURE SUMMARY REPORT			20	4	7	12	2	5	4	3	6	3	5	2	3	2	12	24	12	9	17	27	16	15	31	14	18	11	16	10	20	19	16	28	Δ	Δ
A00E	QUARTERLY REPORT					2				18	31				11		22				10			15				7	26			29					
A00F	ANNUAL REPORT											26 (D)			15 (D)													16 (D)									
A00G	CONTRACT MANPOWER REPORT	14	6 11	13	24	30	4		7/8			6 6 7	24	15	6	8	11	10	19	12	9	8	6	10	16	13	9	16	14	4	8		15/19	9	3/	Δ	
A00H	DATA PLAN		26																																		
A00J	TECHNICAL STUDY REPORT (MOTIF)																												X		X		X				
A00K	SYSTEM SPECIFICATION FOR MOTIF																														15						

Δ DUE
A/R AS REQUIRED
X SUBMISSION THIS MONTH
(D) DRAFT

NUMBERS INDICATE DAY OF MONTH SUBMITTAL OCCURED

H4460

Figure 61 AMOS Phase III - CDRL Submittals

The control of tagged GFE and the management of direct spares and supplies for the observatory was accomplished according to DCASR requirements. A master property list was maintained at Everett and was reviewed by DCASMA - Boston. This list was used as the base for an Annual DCAS Property Audit on site. These audits generally lasted in excess of one week and never reported any discrepancies other than minor ones, correctable during the audit. This audit also reviewed AMOS purchasing procedures as well as expendables inventory practices on all records. Certain Special Test Equipment, often calibratible and controlled by IPEC, were inventoried separately. DCAS also regulated our surplussing of no longer required, obsolete or unusable property and authorized its disposition method. No particular problems were encountered in this overall property area during this contract period.

6.6 SECURITY

Classified document and personnel clearance control were supervised by an AMOS Security Officer, assisted by two Associate Security Officers, one at the Observatory and one at the Puunene office facility. Each site had classified document storage facilities at one central location only. AMOS maintained an inventory of ~ 1000 active classified documents throughout the contract period. The preparation, transfer storage and dissemination of classified material was accomplished strictly in accordance with the "Industrial Security Manual for Safeguard of Classified Information" (DoD 5220. 22-M), and the Communications Security (COMSEC) supplement.

In the case of COMSEC, the special regulations of USAF Cryptologic Depot, San Antonio, Texas were also followed.

Onsite inspection by DCAS - Honolulu Security Personnel occured semiannualy, supported by semiannual self-inspections in the intermediate quarters. In addition there were one or two unannounced COMSEC inspections. In all instances the only discrepancies found were minor and were corrected on the spot.

Although there was no classified hardware or area requiring special access at the observatory, (except, of course, the vault containing COMSEC equipment) the level of document storage required 24 hour surveillance. This was accomplished by a subcontract with Freeman Guards, Inc. This arrangement afforded AMOS with added control over property and facilities at the observatory as well as additional fire and equipment safety protection.

All permanent employees and subcontractors assigned to AMOS were required to have security clearance at the "Secret" level. A visitor control system assured that all cleared visitors submitted classified visit requests in advance of their arrival and uncleared visitors were required to be escorted at all times when within the observatory. The guard service helped immeasurably in managing and enforcing the necessary regulations in this area. Despite the high level of casual visitors at the adjacent National Park property, there were no significant security incidents involving visitors or the general public during Phase III.

6.7 TECHNICAL INTERCHANGE

Technical interchange continued to be a key activity during Phase III. It served both the purposes of short range planning for specific programs and those of long range planning. For the latter, this activity consisted of acquainting the user community with the capabilities of AMOS and providing senior members of the AMOS staff with opportunities to keep current with the state-of-the-art in their respective fields. Technical interchanges were accomplished both onsite and by attendance at meetings, conferences and symposia on the mainland.

Over the Phase III program, the AMOS staff attended more than 75 meetings related to specific programs. These fell into three general categories. First, support was provided for program review, technical and administrative meetings with DARPA and RADC relating to the AMOS program. Second, support was provided at meetings concerning new programs or systems coming to AMOS, for example, the Compensated Imaging System. Third, the AMOS staff supported technical meetings with major subcontractors during the development of new systems for AMOS. An example of this was the development and testing of the 1.6-m telescope.

In the area of long range planning, AMOS supported technical interchange meetings and capabilities briefings with a broad spectrum of the user community representing both the military services and other government agencies and their contractors. The AMOS staff attended professional meetings such as the conference of the Optical Society of America (OSA), the OSA Optical Propagation Conference, and the American Astronomical Society. In addition, technical symposia were conducted at AMOS both by the AMOS staff and by visiting scientists. Topics ranged from realtime computer programming to LWIR twinkle experiments.

6.8 TRANSPORTATION

A fleet of GSA vehicles was assigned to AMOS, primarily to transport personnel from the sea level program office facilities to the Observatory atop 10,000-ft Mount Haleakala. Over the contract period, the number of passenger cars varied from 18 to 24, in addition to two small trucks.

The vehicles were supervised and assigned to specific car pools by AERL administration, and maintained by several commercial garages on Maui, there being no government motor pool facility on this island.

The 70-mile round trip to the Observatory was undertaken each day by 35-40 individuals in 10-15 cars. The upper half of the journey traverses a narrow, winding mountain road through Haleakala National Park, frequented by tour buses and rental cars. At night, the road was often wet and, in winter, even ice covered. Throughout 1977, the Park portion of the road was under construction, compounding the difficult driving conditions.

The use of these vehicles was the major safety consideration during the AMOS Phase III program. There were several minor accidents, but no major ones and no injuries resulting in lost time.

The AMOS Safety Engineer emphasized this particular hazard in his prevention program and spent a significant portion of his time on vehicle-related activity.

There were certain other unusual aspects to management of this fleet (e.g., negotiating replacement of worn-out vehicles with the GSA in San Francisco via Honolulu; scheduling for monthly brake servicing; complete tire replacement every 4,000 miles; and having an average of 25% of the vehicles undergoing some form of maintenance at any given time), but there were no major incidents, and contractually required activity never had to be delayed or postponed because of inadequate transportation.

6.9 MAINTENANCE

AMOS maintenance was divided into two broad categories - preventive (PM) and corrective. Preventive maintenance involves cleaning, lubricating, recharging, aligning, adjusting and calibrating equipment to prolong its useful life, reduce corrective maintenance costs, and insure proper operation. Preventive maintenance tasks were added during this contract period to provide for major new observatory systems, particularly the refurbished 1.6-m telescope system and the Laser Beam Director. In addition, certain PM tasks were reviewed and modified to be compatible with changes in other subsystems (e.g., Dome Drive and Windscreen Modifications, 1.2-m Telescope Upgrades and Beamsteering/Optical Alignment) as well as sensors such as AMTA, Contrast Mode Photometer and the LLL TV Camera System.

Preventive maintenance requirements for each month were derived from the AMOS automated data recording and reporting system (see discussion of ACONS under Section 6.12 "Configuration Management").

Inputs to the system contained items such as manhours to repair, material costs and date completed.

A new AMOS Maintenance Report (MR) was developed specifically to meet the needs of the program. All corrective maintenance was documented on this form. This document was then used as a source of information for the automated maintenance data base. (In the first 33 months of the Phase III contract, 629 MR's were completed.) The automated system issues periodic status reports of all outstanding maintenance tasks, which were used as inputs for evaluation of overall system status, manpower scheduling and reliability.

Maintenance analysis was keyed primarily by preparation of the "Failure Summary Report" (CDRL Line Item #A00D), published monthly. This report itemized equipment failures, and outlined MR's remaining open from previous months, reported during the current month and closed during the current month. Additionally it discussed specifically those items which exhibited six (6) or more failures during the contract period and/or had been opened in excess of 3 months. This report served as a management tool for visibility and planning in problem maintenance areas.

6.10 SAFETY

An active safety program was in operation at the AMOS site throughout the contract period. The AMOS System Safety Committee met regularly to identify potential safety hazards, to assign appropriate corrective action and to assign individual responsibility for disposition of such corrective action.

Safety committee surveillance was supplemented by comprehensive System Safety and Ground Safety Plans.

A "safety profile" was constructed by the commitee for each new system installed at AMOS. When such a profile indicated potential hazards involved with system operation, a procedure was drafted relating specifically to these hazards. Such is the case with the Laser Safety Procedure, which addresses the safe operation of the ruby laser system installed in 1975.

Program effectiveness can only be measured by examination of the accident record at AMOS. During the three year tenure of this contract, there were only two accidents involving lost time, a minor laceration at the observatory and a cinder lodged in an eye enroute to work. Each of these incidents accounted for only one days' lost time and were not considered extraordinary.

This safety record takes on additional significance in light of the following unique conditions under which AMOS operations were conducted:

1. A majority of routine operations are performed at night with only moon or star light in the domes where many mission critical tasks are performed.

2. All work performed at the site is at the reduced oxygen levels of 10, 000 ft elevation.

3. Employees are required to travel by automobile daily to and from the site over a narrow, winding road. The trip one way requires ~70 min and adds an additional stress factor to the normal work load of personnel.

4. The site is remote from rescue and treatment facilities in the event of an emergency.

5. Much of the work performed was of an R&D nature; working with state-of-the-art systems and components with no demonstrated safety reliability.

Since the daily commuting of personnel to and from the observatory was considered the major safety risk at AMOS, vehicular safety was given special emphasis by the committee.

A number of projects were completed to reduce this unique hazard. For example, after considerable prompting by AERL, the State of Hawaii repainted the roadway center line at its most dangerous point (highest frequency of low visibility); emergency equipment, flares, chains and first aid supplies were added to each vehicle; and seat belt use and windshield cleanliness for visibility were stressed.

Program activity beyond routine meetings and inspections can best be summarized by a listing of projects accomplished during the tenure of this contract:

1. Successful completion by twenty AMOS employees of the Red Cross Standard First Aid course. This represents 40% of the work force. In addition, three employees completed cardio pulmonary resuscitation (CPR) training.

2. Drafting of a Comprehensive Laser Safety Procedure as an addendum to the Ground Safety Plan. This procudure is in current use.

3. Development of Comprehensive Critical Operating Procedures for the handling of system-critical components such as primary mirrors and associated equipment.

4. Design and installation of a sophisticated fire detection suppression system throughout the observatory. Description of this system can be found in Section 2.5.4 of this report.

5. Demonstration of fire extinguisher operation and initiation and development of a fire drill procedure.

6. Application of abrasive flooring strips in areas posing serious hazards during wet weather.

7. Procurement of safety glasses for personnel.

8. Procurement and installation of electrically insulated rubber matting.

9. Procurement and installation of an exterior type plexiglass mirror at a dangerous corner of the Puunene parking lot.

10. The administration of annual eye examination for all personnel associated with laser work.

11. The completion of an exhaustive Operational Hazard Analysis for systems and operations involved with the two 1.2-m telescopes currently being transitioned to the Air Force. Although this analysis was directed by another contract, many of the systems under study are common to both the 1.2-m and 1.6-m mounts. In addition, many of the items evaluated that are not

common to both systems are identical in function and operation. Consequently, a large spinoff safety benefit for remaining AMOS systems and operations has been realized.

12. Drafting of a comprehensive safety brochure delineating safety risks unique to the AMOS operating environment. The brochure was designed to acquaint visitors and new employees with these hazards.

6.11 QUALITY ASSURANCE AND CONTROL

The Quality Assurance Plan was revised during the initial year of the contract period to reflect the AMOS Phase III single contractor operation.

AMOS Phase III Quality Assurance is applicable to the acquisition of new hardware and to the maintenance and modification work done to existing government-furnished property. The revised plan also provides for management visibility of hardware condition/configuration when that hardware is in an operational mode.

The plan places primary emphasis on enforcing requirements imposed by MIL-I-45208A to include:

- Receiving inspection
- Review of maintenance records
- Surveillance of configuration records
- Quality of material derived from subcontractors and vendors.

Because of the specialized technical nature of the equipment purchased and fabricated at AMOS, the plan calls for quality acceptance specifications and testing to be implemented by the designated responsible engineer in conjunction with the resident quality assurance representative. Adequate controls were provided to assure that the Quality Assurance functions of responsible individuals are appropriately identified and recorded.

The revised plan, having received appropriate approval, is currently being utilized. Supporting AMOS Procedures, C-651 through C-658, that amplify and detail Quality Assurance responsibilities have also been revised and are in effect.

The revised plan provided procedures in these key areas: discrepancy reporting, equipment maintenance, receiving inspection of vendor furnished materials, receiving inspection of government furnished materials, calibration system and inspection of equipment modification.

During the contract period, quality assurance audits of the discrepancy reporting system, the equipment calibration system, and the preventive maintenance system were conducted annually. In addition, a special study of the large optics handling procedure resulted in major revisions to that instruction. This was accomplished prior to the installation of the 1.6-m primary mirror in March of 1975.

Certain secondary standards are maintained at AMOS, primarily to assure that the accuracy of calibratible electronic test equipment and instruments exhibited an accuracy within prescribed limits. Calibration of such equipment was controlled by regular scheduling and the standards themselves were periodically sent to the Precision Measurements Equipment Laboratory (PMEL) at Hickam AFB, Oahu, for calibration against primary standards.

6.12 CONFIGURATION MANAGEMENT

During AMOS Phase III, configuration management practices assured that no change was made to observatory systems under configuration control without proper authorization and that changes when implemented, were properly documented. Efforts under this task included maintaining a system for entering technical information into the AMOS data base and retrieving it.

The AMOS Controls Software (ACONS) computer program is used to maintain an index of engineering drawings and technical manuals. In addition, information from periodic and corrective maintenance is condensed and input to the ACONS data base. Periodic maintenance requirements and hardware data (manufacturer, model number, etc.) are also input to and stored by ACONS.

Each month the following listings are prepared:

1. Equipment inventory
2. Drawing and Manual list (by drawing number)
3. Drawing list (by the Maui Equipment Data List (MEDL) number)
4. Discrepancy Report (corrective maintenance) status
5. Discrepancy Report History
6. Preventive Maintenance Schedule
7. Preventive Maintenance Completed During Previous Month
8. Preventive Maintenance History
9. Government Tag Number vs MEDL Number
10. Maintenance Accounting Information

These lists are used by management to assess the status of preventive and corrective maintenance, by technical personnel to locate drawings and manuals, by maintenance supervisors for scheduling and by engineering to assess equipment performance.

Cognizance of AMOS upgrade and modification programs was maintained to assure that during procurement of new equipment and subsystem, provisions were made for the delivery of adequate documentation.

Numerous engineering drawings were completed and entered into the documentation system. These drawings were prepared to document the work performed under the various system development programs. In addition, drawings provided by subcontractors were also input to the system.

REFERENCES

1. "AMOS Annual Report - 1 January 1975 - 31 December 1975," Avco Everett Research Laboratory, Inc., RADC-TR-77-329, September 1977.

2. "AMOS Annual Report - 1 January 1976 - 31 December 1976," Avco Everett Research Laboratory, Inc., AERL 78-073, RADC-TR-77-330, September 1977. SECRET.

3. "AMOS Annual Report - 1973," Avco Everett Research Laboratory, Inc., AERL 73-1311, December 1973, SECRET.

4. "Advanced Multi-color Tracker for AMOS (AMTA)," Hughes Aircraft Co., p. 74-187, May 1974, SECRET.

5. "IR Atmospheric Measurements, Final Technical Report, June 29, 1975 - May 31, 1977," Avco Everett Research Laboratory, Inc., July 1977.

6. "AMOS 1.6-m Telescope Optical System," LMSC Detail Specification #1421750, Rev. C., Lockheed Missiles and Space Co., Inc., 8 March 1974.

7. "AMOS Data Acquisition, Handling and Analysis Plan," J. Beckman and G. Daniels, Avco Everett Research Laboratory, Inc., February 1975.

8. "Data Base Implementation - Final Technical Report," G.M. Daniels, et. al., Avco Everett Research Laboratory, Inc., July 1975.

9. "Turbulence Characterization and Control - Final Technical Report," RADC-TR-76-189, June 1976.

10. "Turbulence Environment Characterization - Technical Report," RADC-TR-77-70, March 1977.

11. "Turbulence Environment Characterization - Technical Report," RADC-TR-77-232, July 1977.

12. "Turbulence Environment Characterization - Interim Technical Report," RADC-TR- (to be published).

13. "Speckle Interferometry," A. Schneiderman and D. Karo, Journal of the Optical Society of America, 66-1252-1976.

14. "Have Lent III Quick Look Data Report," Avco Everett Research Laboratory, Inc., AERL M-1731, 23 April 1976, SECRET.

APPENDIX A

AMOS MISSION SUMMARY 1977

(This Appendix appears in Volume II)

MISSION
of
Rome Air Development Center

RADC plans and conducts research, exploratory and advanced development programs in command, control, and communications (C^3) activities, and in the C^3 areas of information sciences and intelligence. The principal technical mission areas are communications, electromagnetic guidance and control, surveillance of ground and aerospace objects, intelligence data collection and handling, information system technology, ionospheric propagation, solid state sciences, microwave physics and electronic reliability, maintainability and compatibility.

AMERICAN REVOLUTION BICENTENNIAL 1776 1976