DAC-58143

J. Downs

ORBITAL ASTRONOMY SUPPORT FACILITY (OASF) STUDY

(NASA-CR-123902) ORBITAL ASTRONOMY SUPPORT FACILITY (OASF) STUDY. VOLUME 3: TASK B, INSTRUMENTS FOR ORBITAL ASTRONOMY, BOOK 1 J.W. Wechsler, et al (McDonnell-Douglas Co.) 28 Jun. 1968 401 p

N72-75710

Unclas

00/99 39068

VOLUME III
TASK B INSTRUMENTS FOR ORBITAL ASTRONOMY
BOOK 1 OF 2

DOUGLAS MISSILE & SPACE SYSTEMS DIVISION

28 JUNE 1968

MCDONNELL DOUGLAS CORPORATION

ORBITAL ASTRONOMY SUPPORT FACILITY (OASF) STUDY

VOLUME III
TASK B - INSTRUMENTS FOR ORBITAL ASTRONOMY
BOOK 1 OF 2

28 JUNE 1968

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PREPARED BY
J.W. WECHSLER
DEPUTY PROGRAM MANAGER
ADVANCE SPACE AND LAUNCH SYSTEMS
DOUGLAS AIRCRAFT COMPANY
J.J. TROCCHIA
PROGRAM MANAGER
ELECTRO-OPTICS DIVISION
KOLLSMAN INSTRUMENT CORP.

APPROVED BY
H.L. WOLBERS
PROGRAM MANAGER
ADVANCE SPACE AND LAUNCH SYSTEMS
T.J. GORDON
DIRECTOR
ADVANCE SPACE AND LAUNCH SYSTEMS

DOUGLAS
MISSILE & SPACE SYSTEMS DIVISION
SANTA MONICA, CALIFORNIA

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PREFACE

This report is submitted by the Douglas Aircraft Company, Missile and Space Systems Division, to the National Aeronautics and Space Administration Marshall Space Flight Center (NASA-MSFC). It has been prepared under Contract No. NAS8-21023 and describes results of the Orbital Astronomy Support Facility (OASF) Study. The study began on 12 December 1966 and ended on 28 June 1968.

This volume is the third of five and reports on the selection and conceptual design of astronomy instruments for manned Earth orbital missions (Task B). The other four volumes present a technical summary (DAC-58141), detailed results of Tasks A and C (DAC-58142 and DAC-58144), and a discussion of the research and technology implications for orbital astronomy (DAC-58145).

Comments or requests for information concerning this report will be welcomed by the following individuals:

- H. L. Wolbers, Program Manager
  Douglas Aircraft Company
  Missile and Space Systems Division
  5301 Bolsa Avenue
  Huntington Beach, California 92647
  Telephone: 714-897-0311, Extension 4754

- J. R. Olivier, R-AS-VO
  National Aeronautics and Space Administration
  George C. Marshall Space Flight Center
  Marshall Space Flight Center, Alabama 35812
  Telephone: 205-876-2234

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FOREWORD

The unparalleled research opportunities offered by manned space flight are perhaps nowhere more evident than in astronomy and astrophysics. The ability to overcome atmospheric interference is, in itself, a major breakthrough, and this, when coupled with the astronaut's ability to select and process data and to calibrate, modify, and repair instruments, will yield unprecedented and invaluable insights into many fundamental questions.

While the opportunities for important astronomical research from a manned platform in Earth orbit are clear, significant planning questions remain for NASA. For example, the space station and its scientific instrumentation and crew participation may be greatly dependent on the research program. What is their sensitivity to research objectives? What are acceptable strategies in reaching these objectives? Considering the real-life constraints of limited fiscal and intellectual resources, is there a systematic approach to planning for the accomplishment of these objectives?

In a sense, the ultimate objective of this study was to reduce the uncertainty in the planning of astronomical research and the design of the space facilities which the research demands.

The specific purpose of this study was to identify and analyze elements of a long-range evolutionary plan for the 1974-to-1990 time period that will fulfill the needs of the scientific community to as large an extent as possible, with flexibility for change as new data about the universe stimulate new objectives, and to assess the requirements which such a long-range space astronomy program would place on manned orbital facilities. The sequence followed by the study team was as follows:

1. Deriving--with the aid of contributing members of the scientific community--a set of significant astronomical research objectives.
2. Identifying those objectives which are particularly appropriate for a manned orbital observatory.
3. Translating those objectives into observation and measurement requirements.
4. Deriving a set of conceptual instrument designs.
5. Deriving a series of orbital facilities which can accommodate these instruments and perform the desired research.
6. Formulating an evolutionary plan that is based on the objectives, instruments, and facilities.

In developing the approach to this plan, the study team was faced with several significant challenges. First, it was important to recognize that long-range programs of national scope require considerable time for the development of necessary systems and equipment. Long-range planning is therefore desirable because it offers the promise that necessary long-term fiscal commitments can be made and that the systems and equipment required will be available by the time they are scheduled for use. Yet the team recognized that in scientific disciplines, unexpected rather than planned events sometimes contribute most significantly to scientific insight, and such unexpected discoveries could well influence subsequent planning. Furthermore, while rigid research plans may facilitate the design of the space instruments, they may stifle innovative research. Recognizing these aspects, the study team sought to develop an approach that would provide concepts structured well enough for initial planning and for the derivation of instrument and space station designs but flexible enough to permit change and individaul contributions and participation.

The result of the OASF Study, then, is a plan that is of sufficient breadth to permit definition of (1) the effort required to realize the projected objectives of astronomy, (2) the future performance requirements for orbital facilities with reasonable expectation that they will avoid obsolescence in the near-term, and (3) a time-phased implementation plan.

The final report of this study is contained in five volumes, of which this document is one. These five volumes are:

Volume I — The Orbital Astronomy Support Facility Study Final Report: Technical Summary

This volume compactly summarizes the material contained in Volumes II through V.

Volume II — OASF Study Final Report: Task A--Orbital Astronomy Research Requirements

Part 1: The Baseline Astronomy Research Program

This portion, in describing the baseline research program used in Tasks B and C, discusses the participation of scientific contributors, the systematic derivation and evaluation of the program, and the potential of space astronomy.

Part 2: A Methodology for Systematic Identification of Candidate Space Astronomy Observations

This portion discusses the development of a methodology for use in follow-on research planning as applied to space astronomy.

Volume III — OASF Study Final Report: Task B--Instruments for Orbital Astronomy

This volume describes a set of instruments--radio telescopes, optical telescopes, and radiation counters--for accomplishing the observation requirements derived in Task A. It also discusses the procedure used in selecting the instruments, the requirements for developing the instruments, and the characteristics of the instruments which will affect their operation in orbit.

Volume IV — OASF Study Final Report: Task C--Orbital Astronomy Support Facility Concepts

This volume discusses the evolution of manned OASF concepts that accommodate and support astronomy instruments and respond to demands of the observation program. It contains a logical, evolutionary plan for developing the instruments and orbital facilities and for utilizing them in a series of missions that will accomplish the baseline research program.

Volume V — OASF Study Final Report: Research and Technology Implications for Orbital Astronomy

This volume discusses the research and technology requirements related to astronomy instruments and orbital observatory facilities which appear to warrant further effort.

ACKNOWLEDGMENTS

The Orbital Astronomy Support Facility (OASF) study was conducted under the program management of Jean R. Olivier, Contracting Officer's Representative for the Advanced Systems Office of the NASA Marshall Space Flight Center. The OASF study reflects the combined contributions of many persons both within and outside the Douglas Aircraft Company. Special appreciation is extended to Maurice J. Raffensperger and Charles A. Huebner of the NASA Office of Advanced Space Flight for their continuing help and guidance during the course of the study.

In addition to the efforts of these individuals, valuable contributions to the Task B portion of the study were provided by the scientific contributors listed in Table 1. The list includes astronomers and other scientific and technical personnel affiliated with major astronomical observatories, universities, NASA centers, and industrial research organizations. In most cases, participation was in the form of consultation regarding preliminary conceptual layouts of astronomy instruments. Several of the contributors who devoted considerable time and effort are also identified in Table 1 as consultants to Douglas.

Preliminary reports on the selection and conceptual design of astronomy instruments were presented for review to members of the NASA Subcommittee for Astronomy (Dr. Nancy G. Roman, Chairman, and Mr. Ernest J. Ott, Secretary) in September and December 1967. Members of the subcommittee provided many useful recommendations for revision and augmentation of the instrument conceptual designs.

Task B of the OASF study was performed under subcontract to Douglas by the Kollsman Instrument Corporation of Syosset, New York. Kollsman in turn was assisted by Airborne Instruments Laboratory, Deer Park, New York,

in the derivation of radio astronomy instruments, and by Barnes Engineering Company, Stamford, Connecticut, in the derivation of infrared astronomy instruments. Although the results reported here are the product of the efforts of Kollsman and its second-tier subcontractors, credit for the merits of the instruments is shared with the scientific contributors identified in Table 1. However, identification of these persons in Table 1 does not necessarily imply that each scientific contributor concurs in all respects with the OASF study results.

Members of the Douglas, Kollsman, AIL, and Barnes study teams who participated in Task B are listed in Table 2.

Table 1 (page 1 of 2)

OASF TASK B SCIENTIFIC CONTRIBUTORS

Scientific Contributor	Affiliation
Gordon C. Augason	NASA Ames Research Center
Albert Boggess, III	NASA Goddard Space Flight Center
Elihu A. Boldt	NASA Goddard Space Flight Center
*Ira S. Bowen	Mount Wilson and Palomar Observatories
*Arthur D. Code	University of Wisconsin
*Armin J. Deutsch	Mount Wilson and Palomar Observatories
Carl E. Fichtel	NASA Goddard Space Flight Center
Kenneth J. Frost	NASA Goddard Space Flight Center
Kenneth L. Hallam	NASA Goddard Space Flight Center
John H. Hill	Douglas Missile and Space Systems Division
*Frank J. Low	University of Arizona/Rice University
John D. Mangus	NASA Goddard Space Flight Center
James E. Milligan	NASA Goddard Space Flight Center
Gordon A. Newkirk, Jr.	High Altitude Observatory
William H. Parkinson	Harvard College Observatory
*Laurence E. Peterson	University of California, San Diego
E. M. Reeves	Harvard College Observatory

*Douglas Aircraft Company Consultant

Table 1 (page 2 of 2)

Scientific Contributor	Affiliation
Nancy G. Roman	NASA Headquarters
Bruce W. Shore	Harvard College Observatory
Philip C. Steffey	Douglas Missile and Space Systems Division
Robert G. Stone	NASA Goddard Space Flight Center
*Harold Zirin	California Institute of Technology

*Douglas Aircraft Company Consultant

Table 2

OASF TASK B STUDY TEAM

Douglas Aircraft Company

John H. Hill	Philip C. Steffey
Kenneth L. Parker	Joseph W. Wechsler

Kollsman Instrument Corporation

Charles Blaut	Norman Goldman
Boleslaus S. Chojnowski	Edwin Hudson
William P. Devereux	Robert J. Kraushaar
Stanley Drake	Lee M. Lieberman
Maxwell R. Eichenwald	Irving A. Simon
Seymour Feldon	Joseph J. Trocchia
Albert Fink	Bernard Zivotofsky

Airborne Instruments Laboratory

Stanley Becker

Barnes Engineering Company

A. Pierson

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CONTENTS

*Instruments listed by OASF Instrument No. are shown on page xvi

BOOK 2

OSAF INSTRUMENTS (page 1 of 2)
(Listed by OSAF Instrument Number)

OSAF Instrument No.	Instrument Name	Section in Text	Page No.
04	0. 2-m UV off-axis telescope (solar)	3. 2. 11	235
05	0. 5-m UV off-axis telescope (solar)	3. 2. 16	325
06	0. 25-m XUV spectroheliograph	3. 2. 12	251
07	0. 125-m XUV high-dispersion-spectroheliograph	3. 2. 17	341
08	0. 25-m XUV grazing-incidence telescope (solar)	3. 2. 18	355
09	0. 5-m XUV grazing-incidence telescope (solar)	3. 2. 22	411
11	0. 225-m spectrographic X-ray grazing incidence telescope (solar)	3. 2. 20	384
13	1-m UV Schmidt telescope	3. 2. 14	287
14	1-m IR telescope	3. 2. 4	109
19	1-m X-ray grazing-incidence telescope	3. 2. 21	395
20	0. 7 keV to 20 keV proportional counter array	3. 2. 23	425
22	10 keV to 300 keV scintillation counter	3. 2. 24	443
23	300 keV to 1 MeV scintillation counter	3. 2. 25	445
25	10 keV to 20 MeV solid state counter	3. 2. 28	491
27	20 MeV to 100 GeV gas Cerenkov counter	3. 2. 29	503
30	Terminated-loop tethered interferometer	3. 2. 2	63
32	Crossed-H tethered interferometer	3. 2. 1	45
33	0. 3-m UV Schmidt telescope	3. 2. 7	173
34	1-m diffraction-limited UV-visible-IR telescope	3. 2. 6	151
35	3-m diffraction-limited UV-visible-IR telescope	3. 2. 13	189
36	1- to 6-solar-radii coronagraph	3. 2. 8	265
37	5- to 30-solar-radii coronagraph	3. 2. 9	203
39	0. 25-m imaging X-ray grazing-incidence telescope (solar)	3. 2. 19	369
41	Kilometer wave orbiting telescope	3. 2. 3	85

OSAF INSTRUMENTS (page 2 of 2)

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FIGURES

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BOOK 1

BOOK 2

Section 1
INTRODUCTION AND SUMMARY

1.1 PURPOSE OF TASK B

The purpose of the Orbital Astronomy Support Facility (OASF) Study was to identify and analyze the requirements for manned orbital facilities that will support orbital missions during the 1974 to 1990 time period, and to develop a series of mission concepts that are responsive to astronomy research objectives.

The major objective of Task B was to (1) select a set of instruments for accomplishing the observation requirements derived in Task A, (2) estimate their development requirements, including time, cost and supporting research and technology, and (3) identify characteristics of the instruments that affect their operation in orbit. This volume documents the activity of Task B.

Under subcontract to Douglas Aircraft Company, Task B was performed by the Electro-Optics Division of the Kollsman Instrument Corporation, Syosset, New York, Kollsman was assisted by Airborne Instrument Laboratories, Deer Park, New York, and by Barnes Engineering Company, Stamford, Connecticut.

1.2 SPECIFIC OBJECTIVES OF TASK B

A principal guideline in the selection of astronomy instruments was to satisfy the observation requirements to the greatest extent possible. Observation requirements were documented in 91 Observation Requirement Data Sheets (ORDS) during Task A. The ORDS cover the electromagnetic spectrum from radio frequencies (50 kHz) to gamma rays (100 GeV) and appear in full in Volume II of this report. A typical ORDS is shown in Figure 1-1.

In addition to being responsive to the observation requirements of the baseline research program, it was required that the selected instruments (1) utilize when feasible known instrument concepts and designs, (2) be

OBSERVATION REQUIREMENT DATA SHEET NO. *ORDS-002*

COMPILATION DATE *8 February 1967; revised 21 November 1967*

1. OBSERVATION TITLE *Wideband ultraviolet photometry of stars*
2. OBSERVATION TYPE (ENCIRCLE 1 OR MORE): IMAGERY (PHOTOMETRY) POLARIMETRY RADIOMETRY SPECTROSCOPY OTHER
3. RADIATION (ENCIRCLE 1 OR MORE): COSMIC VLF MICROWAVE IR VISIBLE (UV) X-RAY GAMMA GRAVITATIONAL
4. ASTRONOMICAL SOURCE(S) OR OBJECT(S) OBSERVED *Stars, especially early type stars*
5. SPECIFIC RESEARCH OBJECTIVE TITLE *Stellar energy distribution; interstellar extinction*
6. RELATED OR CONCURRENT OBSERVATIONS *See item 53*
7. RELATED OR CONCURRENT THEORETICAL WORK *Theory of stellar atmospheres; stellar evolution; studies of interstellar grains.*
8. OBSERVATION PERIOD OR EPOCH SPAN *1970-1971 and beyond (based on instrument feasibility estimate).*

MEASUREMENT REQUIREMENTS (INCLUDE UNITS)

DETECTOR (ITEMS 9-12)

9. TYPE *See item 53*
10. SENSITIVE AREA
11. SENSITIVE SOLID ANGLE
12. WAVELENGTH FOR MAXIMUM RESPONSE λ

WAVELENGTH (ENERGY) λ (ITEMS 13-16)

13. SHORT λ *900A*
14. PRINCIPAL/CALIBRATION λ *1200 to 2800A*
15. LONG λ *4000A*
16. RESOLUTION *~200A* AT λ *2000A*

ENERGY OR PARTICLE FLUX AT COLLECTOR, STELLAR MAGNITUDE, ETC. (ITEMS 17-19)

17. MINIMUM (THRESHOLD) *$\sim 1 \times 10^{-21}$ watt $cm^{-2}A^{-1}$ at 2000A*
18. MAXIMUM (SATURATION) *5×10^{-16} watt $cm^{-2}A^{-1}$ at 2000A*
19. RESOLUTION ± *1 per cent* AT λ *2000A*
20. COUNTING RATE
21. BITS PER EVENT *See item 53*
22. BIT RATE *See item 53*
23. TIMING RESOLUTION ±

PRIMARY COLLECTOR (ITEMS 24-27)

24. TYPE *Optical telescope*
25. APERTURE (DIAMETER) *1 meter*
26. FOCAL LENGTH *5 to 15 meters*
27. OTHER DATA *Instrumentation simpler if f ratio is f/10 or slower*
28. ANGULAR FIELD OF VIEW (DIAMETER) *2 arc minutes*
29. IMAGE SIZE *N.A.*
30. ANGULAR RESOLUTION *5 arc seconds* AT λ *2000A*
31. DISPERSION ELEMENT *Filters*
32. WAVELENGTH DISPERSION *N.A.* (λ/LENGTH) AT λ
33. RECORDING MEDIUM *Storage of binary bits*
34. RECORDING SCALE (ANGLE) PER (LENGTH)
35. SCALE ACCURACY ± %
36. DATA RECOVERY MODE *Telemetry or retrieval of magnetic tape*
37. ONBOARD DATA PROCESSING *See item 53*
38. GROUND DATA PROCESSING
39. TELEMETRY
40. TIME PER OBSERVATION *10^{-1} to 10^2 seconds*
41. NUMBER OF OBSERVATIONS *Up to 10,000*
42. FREQUENCY OF OBSERVATIONS *See item 53*
43. SIDEREAL (REF) TIMING ACCURACY *1 second*
44. INSTRUMENT USAGE TIME *100 per cent* PER *600 hours*
45. NUMBER OF PHOTOGRAPHS, ETC.
46. ORBITAL INCLINATION *See item 49* ±
47. PERIGEE ALTITUDE *450 kilometers* ± *100 kilometers*
48. APOGEE ALTITUDE *450 kilometers* ± *100 kilometers*
49. OTHER ORBITAL *Orbital inclination as low as possible; not critical*
50. POINTING ACCURACY (ACQUISITION) ± *0.5 arc minute*
51. GUIDANCE STABILITY ± *0.5 arc sec** FOR *120 seconds* (TIME)
**Pitch and yaw*
52. SCAN SIZE, RATE, INCREMENT, ETC. *N.A.*

53. MISCELLANEOUS *Item 6: Ultraviolet photometry of stars from ground observations, sounding rockets, and unmanned satellites (OAO); ultraviolet stellar spectroscopy. Required study areas for supporting ground based photometric observations: (1) absolute energy calibration techniques; (2) reflecting and transmitting materials for UV; (3) filters shortwards of 1800A; (4) study of effect of scattered sunlight and earthlight and of trapped radiation belts; (5) radiofrequency interference problems.*

Item 9: Photomultipliers (CsSb and CsI) with filters; possibly ion detectors.

Items 21, 22: Total number of bits for program on 2,000 stars is approximately 5×10^5 bits including status data.

Item 37: Analog-digital converters, prescalers, formatting electronics, 10^5 bit core memory or magnetic tape.

Item 42: In groups of 5, 2 minutes apart.

ORDS-002

Figure 1-1. Typical Observation Requirement Data Sheet (ORDS) divided into two time periods, "intermediate" (late 1970's) and "late" (the 1980's), and (3) fit collectively within development funding limitations anticipated by NASA.

Another important objective of Task B was to provide supporting data for Task C on each selected instrument. Instrument characteristics, space-station interface requirements, mass properties, power requirements, data processing, and maintenance are examples of the type of information required by Task C in order to include the instruments in the orbital facility concepts. It was also desirable to select instrument characteristics that tend to minimize mission and operational constraints.

Other objectives of Task B included estimating development schedules and costs for each selected instrument; identifying critical areas of supporting research and technology; and investigating man's usefulness in assembly, alignment, calibration, operation, and maintenance of the instruments in space.

1.3 TASK B INFORMATION SOURCES

Task B used three principal sources of information: (1) the 91 ORDS derived in Task A, which represented the Baseline Astronomy Program, (2) information on known astronomy instrument concepts and designs supplied by NASA, and (3) consultation with the scientific community, an extension of the consultation conducted in Task A.

The ORDS were used as the interface between Tasks A and B, since they defined in specific terms a representative set of observation requirements specified by the scientific community for the astronomy program. The ORDS also contained recommendations on the basic characteristics of relevant instrument designs. These data sheets provided the basis for new conceptual designs and for modifications to existing instrument designs.

Information was supplied by NASA on concepts and designs for instruments already identified with such current items as (1) the Apollo telescope mount (ATM), (2) the electromagnetic radiation (EMR) instrument package for ATM, (3) the advanced Princeton satellite (APS), (4) the manned orbital telescope (MOT), and (5) the Goddar experimental package (GEP). These and other instruments and instrument concepts were used wherever possible, "as is" or modified, to satisfy the observation requirements.

Consultations were held with members of the scientific community to review instrument concepts under consideration. The consultants included many of the astronomers who generated the ORDS in Task A and other astronomers and physicists who are prominent in the development of some of the instrument types involved (see Acknowledgements).

1.4 ASTRONOMY INSTRUMENT TERMINOLOGY

A self-consistent terminology for describing astronomy instruments was adopted in Task B and is adhered to in this report. In this terminology, which is explained in the following sections, an attempt was made to concur, inasofar as possible, with current scientific and technical usage. However, multiple uses of many terms in current usage inevitably made such an effort imperfect in its results. Therefore, the terminology explained below should not be construed to suggest any general usage outside of this study.

Astronomical observations involve electromagnetic radiation and cosmic-ray fluxes. Both electromagnetic radiation and cosmic-ray particles have energy, momentum, and wavelength. However, wave properties are apparent only if the energy and momentum are sufficiently large to permit the detection of individual quanta.

The terminology adopted in Task B refers to all observational apparatus as "instruments" and subdivides instruments into two categories, (1) telescopes, for observations involving radiation whose wave properties predominate and (2) counters, for which particle properties predominate. These two categories are explained in the following sections.

1.4.1 Instruments

The term, "instrument," as used in this report, refers to the specific item(s) of hardware that provide a complete capability for making some type of astronomical observation. "Complete capability" refers to the fact that an observation can sometimes be divided into separate functions such as (1) collecting the incident radiation and (2) dispersing, filtering, magnifying, and measuring this radiation (among other tasks) to extract information.

1.4.1.1 Telescopes

As utilized in this study, the term, "telescope," refers to any instrument concerned with the detection of fluxes where wavelength is detectable and the design of the instrument is strongly influenced by that branch of physical sciences called "wave mechanics." The region over which telescopes (as defined here) may be employed extends longward from a wavelength of about 1 Å; thus, it embraces X-ray, UV, visible, IR, microwave, and radio radiation. In general, electromagnetic radiation in any of these regions can be reflected, refracted, diffracted, and polarized.

It is generally convenient to subdivide telescopes into two categories according to their method of collection, for example, electrical methods for microwave and radio, and optical methods for X-ray, UV, visible, and IR.

1.4.1.2 Counters

Counters, unlike telescopes, do not cause any meaningful deviation in the path of the intercepted radiation. They employ various means of identifying (for example, counting) radiation pulses (photons or particles) coming from a specified direction and falling in a specified range of energy; and they reject (for counting purposes) those coming from other directions or falling outside the specified range of energy.

(The term, "counters," provides an example of the multiple use of a term in various circumstances. Besides the use of this word as a basic category of instrument, as explained here, it is sometimes used to denote a component of an optical instrument. Thus, a small counting device, such as a Geiger counter or a proportional counter, may be used as the sensing element of an optical telescope by placing it in the path of the focused radiation.)

Counters are generally applicable in the X-ray and gamma-ray regions of the specgrum. In terms of wavelength, their region of applicability may be identified as less than 20 Å. However, it is common practice to express points in this region in terms of the energy associated with the photons (discrete pulses) of electromagnetic radiation. The relationship, established by Planck's constant, is such that the energy is inversely proportional to the wavelength, the energy associated with a photon whose wavelength is 1 Å being approximately 12.4 keV. The region of applicability of counter type instruments, which starts at about 0.6 keV and embraces all higher energies (shorter wavelengths), is referred to in this report as the region of high-energy radiation.

1.4.2 Telescope Components (Collectors and Instrumentation Devices or Sections)

A telescope may generally be considered as a combination of two basic componets: (1) a collector which intercepts and focuses the electromagnetic radiation of interest and (2) an instrumentation device, into which the focused energy is directed, and whose function is to sense, analyze, record or otherwise process this energy to extract information. Instrumentation devices may include detectors, image recorders, spectrometers, filters, polarimeters, magnetometers, or other special purpose items. Since a single collector may be fitted with more than one instrumentation device, the complement of instrumentation devices associated with a given collector is referred to as the "instrumentation section." Generally speaking, the collector is identified with the "front-end" of the telescope, and the instrumentation devices, or section, are identified with the "back-end" of the telescope.

In the case of the high-energy radiation counters, because of the increased difficulty in focusing or concentrating energy as the energy level increases, the "front-end" and "back-end" terminology associated with optical telescopes loses its significance. Each basic function of an optical telescope has its counterpart in a high-energy radiation counter: a collimator corresponds, insofar as possible, to the optical (reflective) elements; shielding (possibly augmented by active elements such as photomultiplier tubes) corresponds to the telescope tube; and a detector suitable for the energy levels involved corresponds to any of the types of instrumentation devices mentioned in the preceding paragraph. Nevertheless, the requirements of the design are usually such that these elements are intimately associated with each other, both physically and functionally, and moreover are usually designed as an integrated whole. Therefore, the physical distinction between "front-ends" and "back-ends" generally becomes indistinct and the single term "counter" is usually used to refer to the entire instrument.

1.5 TASK B PROCEDURE

The flow of Task B events is shown in Figure 1-2. Starting with the observation requirements from Task A, an analysis and sorting of the observation requirements and recommended instrument parameters was carried out. The sorted instrument parameters were then expressed in generic instrument concepts arranged in time-phased groups. These concepts were reviewed with consultants and revised to take advantage of the information gained. The generic concepts were then compared with known instrument concepts and designs, and known designs were substituted for generic concepts wherever feasible. The output of this process was a set of selected instruments in time-phased groups that could satisfy the requirements of the baseline astronomy program. These instruments include (1) existing concepts and designs suitably modified to satisfy observation requirements associated with the baseline astronomy program and (2) new conceptual instrument designs which fill the voids in cases where no suitable instruments were known. Supporting data were developed for each of the selected instruments and provided as a major input to Task C. The supporting data include the pertinent physical characteristics and space station subsystem requirements of each instrument, estimates of development schedules and costs, assessments of the utilization of man in the operation of the instruments, and identification of required supporting research and technology.

1.6 SUMMARY OF ASTRONOMY INSTRUMENTS AND THEIR REQUIREMENTS

A summary of the instrument classes developed during Task B appears in Figure 1-3, which is arranged to show the time-phased groups and the groupings according to instrument category. Within the optical telescope category, further subdivision is made into the categories of normal incidence

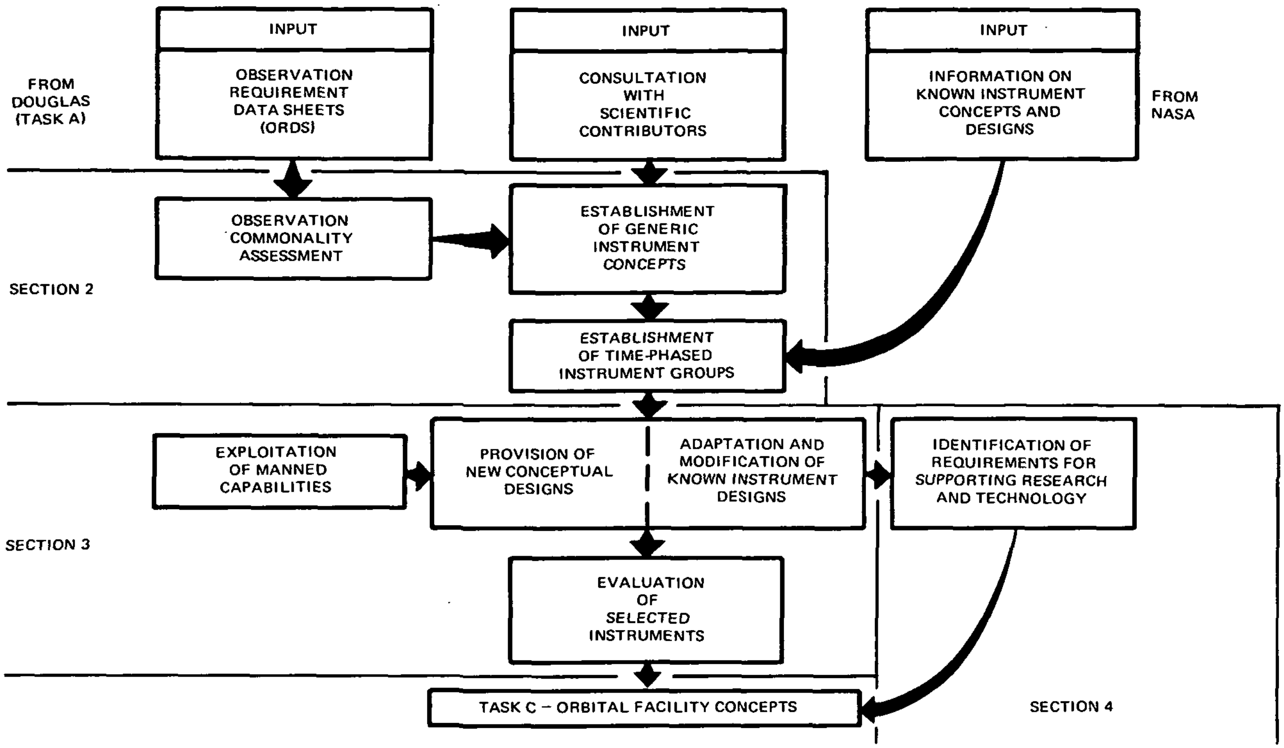

Figure 1-2. Task B – Identification and Evaluation of Astronomy Instruments

		INTERMEDIATE TIME PERIOD (POST-ATM)		LATE TIME PERIOD	
RADIO TELESCOPES		(32) CROSSED-H TETHERED INTERFEROMETER OR (30) TERMINATED-LOOP TETHERED INTERFEROMETER		(ADVANCED VERSION OF INSTR. 32) (41) KILOMETER WAVE ORBITING TELESCOPE (KWOT)	
OPTICAL TELESCOPES	NORMAL INCIDENCE	(14) 1-M INFRARED (45) 1-M NON-DIFF-LIM UV-VIS-IR (34) 1-M DIFF-LIM UV-VIS-IR (33) 0.3-M UV SCHMIDT	STELLAR USE	(ADVANCED VERSION OF INSTR. 14) (35) 3-M DIFF-LIM UV-VIS-IR (13) 1-M UV SCHMIDT	STELLAR USE
		(36) 1-TO 6-SOLAR-RADII CORONAGRAPH (37) 5-TO 30-SOLAR-RADII CORONAGRAPH (44) 0.8-M UV-VIS (04) 0.2-M UV (OFF-AXIS) (06) 0.25-M XUV SPECTROHELIOGRAPH	SOLAR USE	(46) 1.5-M DIFF-LIM UV-VIS (05) 0.5-M UV (OFF-AXIS) (07) 0.125-M XUV HIGH-DISPERSION SPECTROHELIOGRAPH	SOLAR USE
	GRAZING INCIDENCE	(08) 0.25-M XUV (39) 0.25-M IMAGING X-RAY (11) 0.225-M SPECTROGRAPHIC X-RAY	SOLAR USE	(09) 0.5-M XUV	SOLAR USE
				(19) 1-M X-RAY	STELLAR USE
RADIATION COUNTERS		(20) 0.7-keV TO 20-keV PROPORTIONAL COUNTER ARRAY (22) 10-keV TO 300-keV SCINTILLATION COUNTER (23) 300-keV TO 1-MeV SCINTILLATION COUNTER (42) 1-MeV TO 5-MeV SCINTILLATION COUNTER (43) 25-MeV TO 1-GeV DIGITIZED SPARK CHAMBER		(25) 10-KeV TO 20-MeV SOLID-STATE COUNTER (27) 20-MeV TO 100-GeV GAS CERENKOV COUNTER	

Figure 1-3. OASF Time-Phased Instrument Groups

and grazing incidence to emphasize the significant area of new technology represented by grazing-incidence optical instruments. A natural growth in most cases from the intermediate to the late time period is also in evidence. For example, most of the normal-incidence stellar instruments show a significant growth in aperture.

In the case of radio astronomy in the intermediate time period, alternative instrument concepts are shown for a single application. One concept, the crossed-H tethered interferometer (Instrument No. 32), was well-coordinated with the scientific community in the course of an earlier advance mission study (Reference 1-1); therefore, it constitutes the basic recommendation. However, the other concept, the terminated-loop tethered interferometer (Instrument No. 30), was generated in Task B in response to the specific requirements of Task A and, consequently, is somewhat better-suited to the requirements of the OASF Study, although the capabilities of the two instruments overlap considerably. Because the analysis in this study did not identify any decisive advantage for either type of instrument in terms of cost, development time, or technical feasibility, bith instruments are included here for future consideration.

The details on how the instruments were selected, descriptions for each of the instruments and associated instrumentation sections, as well as the supporting data, occupy the remainder of this volume. Section 2, as indicated in Figure 1-2, describes the rationale for the establishment of generic instrument classifications and the specific selections made after consultation with the scientific contributors. Section 3 provides a detailed description of each instrument on an instrument-by-instrument basis. The general characteristics, the criteria to which they were designed, specific characteristics required for space station integration analysis in Task C, the utilization of man, and an engineering drawing of the conceptual design are presented for each instrument. Brief identification of the supporting research and technology requirements are also given in Section 3.

Section 4 is devoted solely to supporting research and technology requirements and includes the summary relationships of each requirement to the various instruments, the predecessor-successor relationships of the various requirements to each other, and the program requirements in terms of cost and time for accomplishment of the supporting research and technology items.

From the analysis conducted during this phase of the study, the following conclusions can be offered relevant to the overall astronomy program:

- A feasible approach to providing the instruments for a manned orbital astronomy program has been demonstrated. The development costs of these instruments, in terms of both single instruments and the entire group, are within realistic budget levels.
- Current activities devoted to the development of astronomical instruments in this country can provide the starting point for 22 of the 29 instruments selected in Task B. These activities range from initial hardware development to flight testing of initial designs.
- Present technology (or reasonable extensions thereof) can provide enough of the required instruments to assure program success. Several areas have been identified where realistic technology advancements can give real benefits in astronomy program effectiveness.
- Man in orbit has a vital role in the setup, operation, and maintenance of many of the instruments identified for the astronomy program.
- A comprehensive astronomy program can be initiated with the instruments that can be available for 1-year-mission space stations (intermediate time period). Instruments available for 5-year-mission space stations (late time period) can provide a mature observational capability for the foreseeable requirements of astronomy in orbit.
- A more comprehensive exploitation of man's capability, through providing design characteristics that achieve a more effective man/machine interface, and a more effective interface between the instruments and the orbital facilities, can be accomplished with an iteration of Tasks B and C.

Section 2
INSTRUMENT SELECTION PROCEDURE

One of the principal objectives of Task B was to identify and describe a set of conceptual instruments (as small in number as possible) capable of performing the astronomical observations called for in the baseline astronomy program, derived in Task A. Information describing these conceptual instruments constituted the major input to Task C for use in the analysis of in-orbit facilities to carry out the astronomy program. The rationale for selecting these instruments is described in this section.

2.1 INFORMATION FOR MAKING INSTRUMENT SELECTION

The selection of instruments was based primarily on the interpretation of the observation requirements identified in the baseline astronomy program. These requirements are embodied in the series of Observation Requirement Data Sheets (ORDS) that were derived in Task A. The set of 91 ORDS appears in full in Volume II of this report, and a typical ORDS has been shown in Figure 1-1 of this volume. These ORDS provided definitive information on the observations required as a representative portion of the astronomy program. They also contained recommendations of instrument types to accomplish the required observations, as well as recommendations of specific design parameters for these instruments. Because the ORDS were developed with the aid of leading members of the astronomy community, these instrument recommendations were given considerable weight in the selection process described in this section.

Another major information source in the selection of instruments was the knowledge of a number of ongoing NASA-sponsored activities directed toward the development of astronomy instruments for orbit. After the types of instruments needed to accomplish the baseline astronomy program were generically identified, instruments associated with these activities were compared with the set of generic instruments and, in cases where it was deemed most practical, they were substituted for the generic types. In some cases, minor modifications to these designs were required to satisfy the observation requirements as fully as possible.

The third major information source in the selection of instruments was the opportunity for consultation with many of the astronomers whose contributions provided the basis for many of the ORDS in Task A, as well as with additional scientists who are prominent in the development of some of the instrument concepts involved. Preliminary conceptual layouts of many of the instruments under consideration were discussed. These discussions made possible the development of more practical design approaches and facilitated the inclusion of many design criteria derived from the collective experience of these consultants.

2.2 INSTRUMENT-ORIENTED CATEGORIZATION OF OBSERVATION REQUIREMENTS

As a preparatory step in the analysis of the instrument data and parameters developed from the baseline astronomy program, consideration was given to the categorization of the observation requirements from the point of view of instrument technology. The level of detail in categorization of the observation requirements that had been found advantageous in Task A is shown in Figure 2-1. This categorization distinguishes nine types of astronomical objects and eight regions of electromagnetic radiation. However, for the instrument selection, it was deemed preferable to distinguish fewer types of astronomical objects and fewer regions of electromagnetic radiation. The categories derived for instrument selection are explained below.

With regard to astronomical objects, the only categories considered significant for instrument selection reflect a distinction between the sun and all other celestial sources. This distinction derives from the fact that, near the Earth, the sun is many orders of magnitude more powerful, in terms of observed radiant-energy flux, than any other celestial source. Thus, except in cases where very high resolution is required, instruments observing the sun generally do not require the large collecting apertures of stellar-oriented

SENSING MEDIUM OR RADIATION REGIME SEE COSMO GRAPHIC SOURCE OR OBJECT SEE	a COSMIC	b VLF RAD	INFRARED	d VISIBLE	e ULTRAVIOLET	f X-RAY	g GAMMA RAY	h GRAVITATIONAL RADIATION
A THE SUN		105 ■ ● Po Ra Sp	050 □ ● Im 062 ■ ● Im 072 ■ ◎ Sp 080 □ ○ Sp	050 □ ● Im 057 □ ◎ Im 062 ■ ● Im 064 □ ◎ Im 066 □ ◎ Sp 067 □ ◎ Sp 069 □ ◎ Sp 079 ■ ◎ Sp 080 □ ○ Sp	042 ■ ○ Sp 043 ■ ○ Sp 044 ■ ◎ Sp 050 □ ● Im 051 ■ ○ Im Sp 052 ■ ○ Im Sp 053 ■ ◎ Sp 054 ■ ● Sp 055 ■ ○ Sp 056 ■ ◎ Sp 058 ■ ○ Sp 059 ■ ○ Sp 060 □ ◎ Sp 061 ■ ◎ Sp 069 □ ◎ Sp 070 □ ○ Sp 079 ■ ◎ Sp 080 □ ○ Sp	045 □ ○ Sp 065 □ ● Im 068 □ ● Sp	046 ■ ● Sp	
B THE PLANETS		106 ■ ● Po Ra Sp	021 □ ● Im 022 □ ● Im 072 □ ◎ Sp 073 ■ ○ Ra Sp	020 □ ● Im 021 □ ● Im 022 □ ● Im	020 □ ● Im 021 □ ● Im 022 □ ● Im 037 ■ ○ Sp 04C ■ ● Im			
C INTERPLANETARY SPACE			074 ■ ◎ Sp					
D STARS, STELLAR SYSTEMS			029 □ ● Ra 030 ■ ○ Ph Sp 075 ■ ○ Sp 077 ■ ○ Sp	017 □ ● Im Ph 019 □ ● Im Ph 023 ■ ● Im Ph 030 ■ ○ Ph Sp	002 ■ ● Ph 023 ■ ● Im Ph 027 ■ ● Ph Sp 028 ■ ○ Im Sp 030 ■ ○ Ph Sp 031 ■ ◎ Sp 032 ■ ○ Sp 033 ■ ○ Sp 034 ■ ○ Sp 035 ■ ○ Sp 036 ■ ◎ Sp 113 ■ ● Im			
E INTERSTELLAR SPACE			029 □ ● Ra 078 ■ ○ Sp		002 ■ ● Ph 028 ■ ○ Im Sp 036 ■ ◎ Sp 039 ■ ● Ph Po 113 ■ ● Im	082 □ ● Sp 083 □ ● Sp		
F THE MILKY WAY		004 ■ ● Ra	029 □ ● Ra					
G GALAXIES			024 □ ● Im	018 □ ● Im 024 □ ● Im 026 ■ ● Im Ph	018 □ ● Im 024 □ ● Im 026 ■ ● Im Ph 101 ■ ● Im 113 ■ ● Im			
H INTERGALACTIC SPACE					038 ■ ○ Sp			
I SURVEYS' UNIDENTIFIED (UNDETECTED) OBJECTS	087S ■ ● Ph Sp 091S ■ ●	005S ■ ● Im In Ra 006S ■ ● Im Ra Sp	024 □ ● Im 063S □ ● Ra 076S ■ ○ Ra Sp	024 □ ● Im	024 □ ● Im 038 ■ ○ Sp 071S ■ ● Im 107S ■ ○ Sp 113 ■ ● Im	049S ■ ● Ph 081 □ ● Im 082 □ ● Sp 083 □ ● Sp 084 □ ● Im Ph 085S ■ ● Ph 086 ■ ● Ph Sp 089S ■ ● Ph 090S ■ ● Ph 095 ■ ● Im Ph 096 ■ ● Ph Sp 097 ■ ● Ph Sp 098 ■ ● Ph Sp 099 ■ ● Ph Sp 100 ■ ● Sp	048S ■ ● Ph 093S ■ ● Sp 102 ■ ● Ph Sp 103 ■ ◎ Ph Sp 104 ■ ○ Ph Sp	108S ■ ●

EACH ENTRY IN THE MATRIX INCLUDES:

ORDS-THREE DIGIT NUMBER (OBSERVATION REQUIREMENT DATA SHEETS

S (IF USED) INDICATES SURVEY

ANGULAR RESOLUTION θ (IF DIFFRACTION LIMITED $\theta = 1.22\ \lambda/D$; D = APERTURE DIAMETER)

■ COARSE: $2\lambda/D < \theta$; ALSO INDICATES ALL COSMIC RAY; NON-INTERFEROMETRIC VLF RADIO NON-FOCUSING X-RAY; GAMMA RAY, AND GRAVITATIONAL RADIATION

□ FINE: $\theta < 2\lambda/D$; ALSO INCLUDES ALL INTERFEROMETRIC VLF RADIO, AND FOCUSING GRAZING INCIDENCE X-RAY

063 S ■ ○ PoRaSp

WAVELENGTH (OR ENERGY) RESOLUTION $\Delta\lambda/\lambda$ (OR $\Delta E/E$)

● COARSE: $10^{-2} < \Delta\lambda/\lambda$; ALSO INCLUDES ALL COSMIC RAY AND GRAVITATIONAL RADIATION

○ INTERMEDIATE: $10^{-4} < \Delta\lambda/\lambda < 10^{-2}$

◎ FINE: $\Delta\lambda/\lambda < 10^{-4}$

TYPE OF OBSERVATION (UP TO 3 SYMBOLS)

Im IMAGERY
Ik INTERFEROMETRY
Ph PHOTOMETRY
Po POLARIMETRY
Ra RADIOMETRY
Sp SPECTROSCOPY

Figure 2-1. Observational Requirement Data Summary instruments. Indeed, in some cases they have to be designed to reject a considerable amount of excess energy in such a way as to avoid thermal distortions and even damage to the instrument. For all other celestial sources, observational instruments are generally designed with the objective of extracting as much information as possible from a very faint (observed) source of radiated energy. Therefore, the astronomical object classifications were reduced to merely solar and stellar, with planetary objects included in the stellar category.

With regard to radiation, the number of categories was also amenable to considerable reduction in numbers for purposes of instrument selection. From the instrument point of view, three basic categories appeared logical, corresponding to three regimes of handling of the radiated energy.

In the cosmic-ray, gamma-ray, and X-ray regimes, the instruments generally available do not meaningfully deflect the radiation from its original path. These devices, as explained in Section 1.4.1, are called "counters" in this report, are designed to discriminate among various radiation pulses (photons or particles) with regard to direction of approach and energy level. Those falling within certain limits of direction of approach and energy level are "counted," and the others are rejected.

In another broad region of the spectrum, embracing UV, visible, and IR radiation, as well as some overlap in the X-ray region, a different process of handling the incoming radiation provides a distinct identity. In this region, radiation coming from some specified direction can be redirected in an organized, meaningful manner (i.e., focused, whether by normal-incidence or grazing-incidence techniques) and then directed into some device that senses, detects, images, disperses, or otherwise processes the focused beam of radiated energy to extract information.

The third region convenient for instrument-oriented categorization is the very-low-frequency radio region (generally referred to here simply as the radio region). From the instrument point of view, this region may be described as one in which the wavelengths are no longer small with respect to the devices for collecting the radiated energy. Focusing is relatively imprecise; however, the use of long-baseline interferometry can provide useful angular measurements.

The result of the foregoing considerations of the categories appropriate to astronomy observation instrument selection was to reduce the 9 x 8 matrix shown in Figure 2-1 to a 3 x 2 matrix, comprising radio, UV-visible-IR, and high-energy radiation regimes and stellar and solar astronomical objects.

2.3 IDENTIFICATION OF GENERIC INSTRUMENT TYPES

Generic instrument types were identified by analysis of the basic observation specifications in the ORDS. An example of this procedure is illustrated in Figure 2-2. This figure shows the relationship of wavelength to the required angular resolution for the ORDS that fall in both the optical instrument category and the stellar astronomical object category. Each vertical line indicates the wavelength range and the angular resolution called for in one of the ORDS; the dot on each line indicates the wavelengths at which the angular resolution was specified.

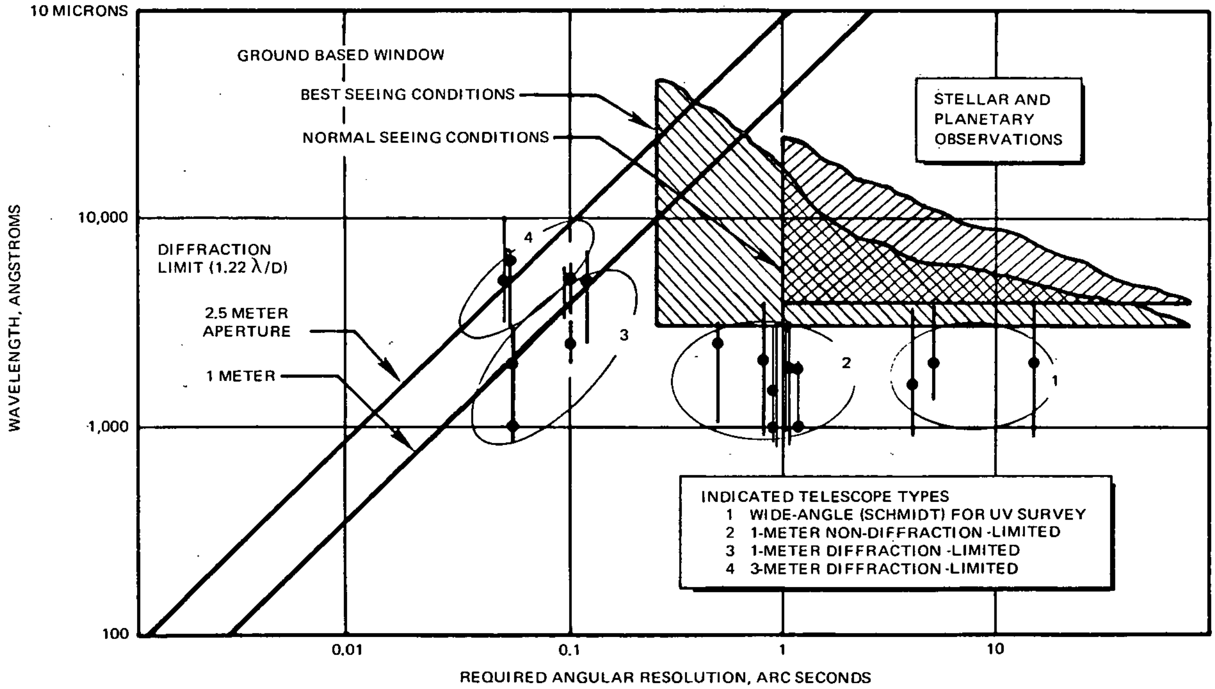

Figure 2-2. Observation Commonality Assessment

By examining the commonalities, or groupings, of the observation requirements plotted in Figure 2-2 with respect to the diffraction limitations inherent in optical telescope performance (slopping lines) and in light of the observations available from ground-based observatories (shaded areas), it was possible to identify general classes of instruments that would provide the specified observation capabilities.

The regions defined by Ellipses 1 and 2 identify observations at angular resolutions comparable to angular resolutions that can be achieved from ground-based observations but are extended into the UV wavelength region, in which radiation cannot pass through the atmosphere to reach ground-based telescopes. Region 1, with angular resolution in the neighborhood of 5 to 10 arc sec, deals with sky surveys in the UV region; while Region 2, with angular resolution in the neighborhool of 1 arc sec, deals with specific observations (spectroscopy, imagery, et cetera) of point sources, again in the UV region.

Regions 3 and 4 embrace both visible and UV wavelengths, because they relate to angular resolutions superior to any that can be achieved in ground-based observations (the latter are limited by random refraction of the incoming radiation by the atmosphere). The regions (ellipses) here must necessarily be aligned in a direction more or less parallel to the sloping lines, because these lines indicate the combinations of wavelength and angular resolution to which any telescope (as determined by its aperture) is inherently limited by diffraction effects. The ORDS in Region 3 tend to suggest a 1-m-aperture diffraction-limited telescope, and those in Region 4, a 2.5- or 3-m diffraction-limited telescope.

It is important to note that the sparsity of ORDS plotted in these regions reflects the fact that the set of observation requirements generated in Task A is merely representative of a complete program of astronomy. A more nearly complete set of observation requirements than those that could be derived within the scope of Task A would provide a more ample population in Regions 3 and 4 than that evidenced in Figure 2-2.

Analysis of this type was the first step in a selection process that eventually led to the establishment of the following types of instruments:

1. A wide-angle (Schmidt-type) telescope for sky survey work in the UV region similar to sky surveys that have been made in the visible region with ground-based Schmidt telescopes (0.3-m UV Schmidt telescope; OASF Instrument No. 33). This type of instrument can be upgraded with an advanced version in the late time period to perform some of the more advanced sky-survey observation requirements (1-m UV Schmidt telescope; OASF Instrument No. 13).
2. A telescope of large aperture but with less than the highest quality optics (i.e., non-diffraction-limited) to provide an adequate capability for a significant amount of spectrographic observation in the UV region. Some useful UV imaging can also be done with such a telescope (1-m non-diffraction-limited UV-visible-IR telescope; OASF Instrument No. 45).
3. A large-aperture telescope with high-quality optics (i.e., diffraction-limited) to extend ground-based observations that have already been made in the visible region down to much finer angular resolution. This instrument also provides a capability for observations of fine angular resolution in the UV region (1-m diffraction-limited UV-visible-IR telescope; OASF Instrument No. 34).
4. A very-large-aperture diffraction-limited telescope to extend the angular resolution and light-collecting capabilities of both visible and UV observations even further than the preceding instrument. This would extend the limits of the most distant stellar objects that could be detected. This instrument is a generation later than the 1-m diffraction-limited telescope (3-m diffraction-limited UV-visible-IR telescope; OASF Instrument No. 35).

2.4 INSTRUMENT SELECTION

Table 2-2 shows the grouping of the ORDS for instrument selection. Each group, which is identified alphabetically to facilitate further discussion, is associated with a given general nature of observation, as noted. The ORDS belonging to each group are indicated, and the most important elements of the commonalities affecting possible instrument design parameters for each group are displayed as "ORD-Suggested Values of Key Selection Parameters." The entries in this category represent a composite of the entries in the corresponding group of ORDS, and generally reflect the most stringent requirements set forth in the ORDS. Because it was not possible to meet all of the most stringent requirements in the derivation of instrument concepts, these ORDS-suggested values of key selection parameters should be regarded as

Table 2-1 (page 1 of 3)

OBSERVATION REQUIREMENT COMMONALITIES AND INSTRUMENT SELECTION

Group (for Identification in Text)	General Nature of Observations*	Observation Requirement Data Sheets (ORDS) Cited	ORDS-Suggested Values of Key Selection Parameters**						Instrument(s) Selected		
			Aperture (m)	Effective Focal Length (m)	Angular Resolu-tion	Field of View	Wavelength (or Energy Level)	Wavelength (or Energy) Resolution	OASF No.	Type	Derived From
A	Imaging, spectroscopy, and polarimetry of stellar and solar radio sources	004, 005, 006, 105, 106	---	---	1°	---	6 km (max.)	5%	32 30 40	Crossed-H tethered interferometer Terminated-loop tethered interferometer Filled aperture radio telescope	Large Space Structures Exp Study (Reference 1-1) (new) Kilometer Wave Orbiting Telescope (References 2-1 and 2-2)
B	Spectroscopy of stellar sources in IR	029, 063, 072, 073, 074, 075, 076, 077, 078	---	---	---	---	200 μ (max.)	±1% (energy flux)	14	Cooled Cassegrainian telescope	(new)
C	Spectroscopy and imaging of stellar sources in UV	002, 027, 028, 030, 031, 032, 033, 034, 037, 113	1.0	5 to 15	1 arc sec	---	---	---	45	Cassegrainian telescope	Goddard Experiment Package (GEP)
D	Imaging and spectroscopy of stellar sources in visible and UV	020, 021, 022, 035, 036, 040	1.0	30	0.1 arc sec (diff-lim @4,000 Å)	---	---	---	34	Cassegrainian telescope	Advanced Princeton Satellite (Reference 2-3)
E	Imaging and spectroscopy of remote, faint stellar sources	(a) 018, 023, 024, 039 (b) 026, 038	2.5	(a) 50 (b) 30	0.05 arc sec (diff-lim @5,000 Å)	---	---	---	35	Cassegrainian telescope	Manned Orbital Telescope (Reference 2-4)
F	Sky survey in UV	101, 107, 171	---	---	1 arc sec 0.5 arc sec	8° 5°	1,000 Å (min.)	---	33 13	All-reflective Schmidt telescopes	Nthwstn U. Schmidt (Reference 2-5) (new)

*Planetary objects included in general stellar category
**Final selections differed in some respects

Table 2-1 (page 2 of 3)

Group (for Identification in Text)	General Nature of Observations*	Observation Requirement Data Sheets (ORDS) Cited	ORDS-Suggested Values of Key Selection Parameters** Aperture (m)	Effective Focal Length (m)	Angular Resolution	Field of View	Wavelength (or Energy Level)	Wavelength (or Energy Resolution	Instrument(s) Selected OASF No.	Type	Derived From
G	Photography of outer solar corona	062	---	---	45 arc sec	15^{o}	---	---	36	Externally occulted coronagraphs	ATM Exp S052 (Reference 2-6)
									37		ATM Exp S052 (Reference 2-6)
H	Imaging and spectroscopy of solar features in UV-visible-near-IR	050, 064, 069	1	40	0. 1 arc sec (diff-lim @4, 000 Å)	---	---	---	44	Gregorian optics telescope	ATM Solar Telescope (JPL) (Reference 2-7)
		053, 057, 066, 067, 069, 079, 080	1. 5	75	0. 1 arc sec (diff-lim @6, 000 Å)				46	Gregorian optics	ATM Solar Telescope (JPL) (Reference 2-7)
J	Spectroscopy of solar features in extreme UV (XUV)	042, 058 043, 044, 051, 060	---	---	1 arc sec	---	300 Å (min.)	0. 5 Å	04	Herschelian (off-axis) telescopes	ATM Exp S055 (Reference 2-8)
					0. 5 arc sec		700 Å (typ)	0. 25 Å	05		ATM Exp S055 (Reference 2-8)
K	Spectroheliography of solar features in XUV	052 070	---	---	---	---	170 Å (min.)	2 Å	06	Spectroheliograph telescopes	ATM Exp S053 (Reference 2-9)
							304 Å (min.)	0. 5 Å	07		ATM Exp S053 (Reference 2-9)'
L	High-resolution spectroscopy of solar features in XUV	054, 055 056, 059, 061	---	---	---	---	170 Å (min.)	0. 5 Å	08	Type II grazing-incidence telescopes	(new)
							170 Å (min.)	0. 01 Å	09		(new)
M	Imaging of solar flares in X-ray region	065	---	---	1 arc sec	$1/2^{o}$	2 to 10 Å (range)	---	39	Type I grazing-incidence telescope	ATM Exp S056 (Reference 2-10)
N	Spectroscopy of solar flares in X-ray region	045, 068	---	---	---	---	1 Å (min.)	0. 1 Å	11	Single-reflection grazing-incidence telescope	(new)

*Planetary objects included in general stellar category
**Final selections differed in some respects

Table 2-1 (page 2 of 3)

Group (for Identification in Text)	General Nature of Observations*	Observation Requirement Data Sheets (ORDS) Cited	ORDS-Suggested Values of Key Selection Parameters** Aperture (m)	Effective Focal Length (m)	Angular Resolution	Field of View	Wavelength (or Energy Level)	Wavelength (or Energy) Resolution	Instrument(s) Selected OASF No.	Type	Derived From
P	Imaging and spectroscopy of stellar sources in X-ray region	081, 082, 083, 084	500 cm^2 collecting area	---	0.1 arc sec	2°	1 to 24 Å (range)	1%	19	Type I grazing-incidence telescope	Large Space Structures Exp Study (Reference 2-11)
Q	Sky survey and spectroscopy of stellar sources in X-ray region	085, 090, 095, 096, 097, 100	---	---	0.1°	3°	0.7 to 20 keV (range)	10%	20	Proportional counter array	EMR Exp No. 9 (Reference 2-12)
R	Sky survey and spectroscopy of stellar sources in X-ray region	049, 086, 089	---	---	3°	6°	10 to 300 MeV (range)	10%	22	Scintillation counter	EMR Exp No. 3 (Reference 2-12)
S	Spectroscopy and photometry of stellar and solar sources in gamma-ray region	046, 102	---	---	3°	6°	0.3 to 20 MeV (range)	5%	23 42	Scintillation counters	EMR Exp No. 5 (Reference 2-12)
T	Spectroscopy and photometry of stellar sources in X-ray and gamma-ray region	098, 099, 103, 104	---	---	3°	6°	10 keV to 20 MeV (range)	1 keV	25	Solid-state counter	EMR Exp No. 7 (Reference 2-12)
U	Sky survey and spectroscopy of stellar sources gamma-ray regions	048, 093	---	---	0.5°	30°	20 MeV to 1 GeV (range)	50%	43	Digitized spark chamber	EMR Exp No. 8 (Reference 2-12)
V	Spectroscopy, flux, and position/electron ratio of cosmic-ray electrons	087, 091	500 cm^2 collecting area	---	---	1 step radian	100 MeV to 100 GeV (range)	10%	27	Gas Cerenkov counter	(new)

*Planetary objects included in general stellar category
**Final selections differed in some respects

design objectives that were worked for but not always achieved. The full descriptions of the instruments that were eventually selected constitute the main bulk of this volume and appear in Section 3. For purposes of Table 2-1, the final selections are merely summarized in terms of (1) the instrument type and (2) the ongoing instrument development activity from which the selected instrument was derived.

2.4.1 Key Selection Parameters

In Table 2-1, the numerous blanks in the tabulation of "ORDS-Suggested Values of Key Selection Parameters" reflect the fact that different instrument parameters assume primary significance as different types of astronomy are considered. An example of this type of distinction may be seen in comparing imagery and spectroscopy.

For imagery, angular resolution is of principal importance, because it defines the amount of detail that can be transmitted in the focused optical beam. Linked to this consideration is the technology limitation that exists with regard to the fineness of image resolution that can be captured on a recording medium (photographic emulsion or electronic imaging device). If the fineness of the detail in the focused optical beam exceeds the fineness capabilities of the recording medium, then the full capability of the optics will not be realized unless the image is magnified, i.e., spread out, to match the resolution minimum of the recording medium. Image size is proportional to the effective focal length of the optical system, so that a long effective focal length is usually important for imaging. The aperture of the optical collector may be considered next in importance, because for faint astronomical sources, the spreading out of the image reduces the intensity of the radiation that impinges on the recording medium (photographic emulsion chiefly considered here) and the ability to record the image may be lost if some threshold value is not reached. A larger aperture, of course, increases the radiation intensity on the recording medium to compensate for this.

A spectroscopic instrument, on the other hand, may be primarily influenced by other criteria. Especially in the case of stellar sources, spectroscopic observations of precise spectral resolution depend upon the gathering of as much energy as possible, so that an optical system that provides an unobscured aperture is in some cases very important. Furthermore, it is desirable to keep the collected energy in as narrow a beam as possible to permit the use of spectroscopic elements (e. g., diffraction gratings) that are small. In order to do this, a small image size, achieved through short effective focal length, is an important consideration.

2.4.2 Instrument Selection Example

The selection of the 3-m diffraction limited UV-visible-IR stellar telescope (OASF Instrument No. 35) is explained below as an example of the process that was followed throughout the instrument selection phase of Task B. This case exhibits the typical pattern, including the following:

1. Consideration of the specific values of the key selection parameters, followed by preliminary conceptual layout of an instrument to satisfy these parameters.
2. Discussion of the preliminary conceptual layout with scientific contributors, and revision of conceptual design concepts, if appropriate, in accordance with the advice of these consultants.
3. Consideration of known current instrument development activities that may provide a start toward the conceptual instrument design.

Group E in Table 2-1 contains the ORDS for which a large visible-wavelength telescope is indicated. On the basis of both energy collection and angular resolution requirements, a 2.5-m aperture is recommended. Angular resolution is specified as 0.05 arc-sec in conjunction with the requirements in many of the ORDS (Subgroup a) for imaging. To achieve this angular resolution with this aperture at the wavelengths of the visible region, selection of a diffraction-limited (i. e., optics of highest quality) collector is implied. The requirement for a large scale factor (i. e., large image size) for imaging prompted recommendations for an effective focal length of about 50 m. Two of the ORDS (Subgroup b) indicate a requirement for spectroscopy and recommended effective focal lengths in the neighborhood of 30 m, since a small image is advantageous for spectroscopy by keeping the light in a relatively narrow, compact beam. Therefore, dual secondary mirrors were initially considered, as indicated by Options a and b corresponding to Subgroups a and b.

The type of optical system considered for this instrument and for several others is the classical Cassegrainian telescope (Figure 2-3). This arrangement is frequently most advantageous because it provides a combination of satisfactory features, including (1) a short telescope tube for rigidity, as determined by the focal length of the primary mirror; (2) capability for a long effective focal length (EFL), even with a short primary focal length, by virtue of the magnification provided by the secondary mirror, (3) low obscuration of the primary collector area, by virtue of the small secondary mirror; (4) convenient in-line arrangement of the instrumentation section in the main tube behind the primary mirror; and (5) availability of well-established techniques for figuring (shaping) the reflective surfaces, since both the primary and the secondary mirror are axisymmetrical.

Among other questions, that of using dual secondary mirrors, was discussed with the scientific contributors, and it appeared from their discussion that the problems of alignment and calibration in remote mechanical switching from one secondary mirror to another would very possibly defeat the purpose of the line imaging capabilities sought by the longer focal length (50-m) optical system. In addition, it was learned that the high-resolution limits of the field of view would be compromised by the dual-secondary design, as

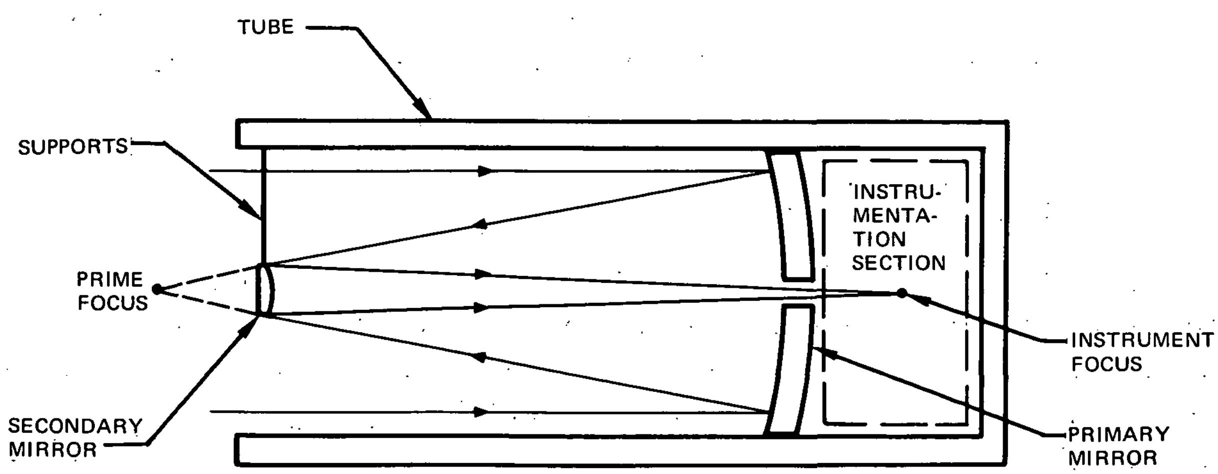

Figure 2-3. Cassegrainian Telescope

compared with a design providing a single secondary and in which the figuring of the primary and secondary reflectors were specifically matched to each other (Reference 2-13). (This type of matched figuring for the primary and secondary reflectors of a Cassegrainian optical system so as to maintain high quality angular resolution over the entire field of view is known as Ritchey-Chretien optics.) For these reasons, the consideration of dual secondary mirrors was dropped in favor of a single secondary providing an effective focal length at some compromise value between 30 m and 50 m.

In comparing this generic type of instrument (2.5-m aperture, 30- to 50-m effective focal length, diffraction-limited, Cassegrainian optics telescope) to known instrument concepts, it was apparent that the progress in the design of a 3-m optical telescope, the manned orbital telescope (MOT) (Reference 2-4), offered an opportunity to associate this requirement with a current development activity. In further corroboration of this choice, a small number of ORDS in Group A called for an angular resolution that would require a 3-m aperture. This instrument design concept also offered an effective focal length of 45 m, a suitable compromise between 30 m and 50 m. Therefore, the MOT concept was adopted as the basis for the OASF instrument for satisfying the requirements of this group of ORDS.

2.4.3 Individual Instrument Selections

The salient points in the selection of the remaining instruments are discussed below in the order in which the respective groups are listed in Table 2-2.

2.4.3.1 Radio Telescopes

Group A shows that the important parameters in selecting radio astronomy telescopes are the wavelength and the angular resolution. To achieve angular resolution of 1° with wavelengths up to 6 km, antennas of tremendous size would be required. Therefore, interferometers (pairs of antennas separated by several kilometers) were considered (Instruments No. 32 and 30). A filled-aperture type of kilometer-wave telescope was also considered (Instrument No. 40).

2.4.3.2 Normal-Incidence Telescopes for Stellar Use

In Group B, the IR telescope (Instrument No. 14), because of the relatively long wavelengths in which it operates, is concerned principally with the problem of "noise" generated within the telescope itself because of its temperature. The telescope must be cooled below the temperature at which it would emit significant radiation in the wavelength region it is attempting to observe. The desired temperature (in this case about 70° to $80^{\circ}K$) is determined by the maximum wavelength, which governs the design accordingly. The principal feature of the design therefore is the cooling provision rather than the optics. The optics are relatively straightforward; because at the long wavelengths, even diffraction-limited optics do not represent an angular resolution that is difficult to achieve within the present technology. (The absence of requirements for imaging in the IR region apparently reflects the absence from the present technology of any image-recording media for these long wavelengths.)

Groups C, D, and E represent increasing capability in optical collectors in the UV-visible near-IR region. The trend of the key parameters shows increasing focal length and decreasing angular resolution, both of which contribute to the achievement of finer imaging capabilities. As a secondary consideration, increasing aperture is also a key parameter added to meet the diffraction requirements and the light-gathering requirements for the fine imaging. (Instruments No. 45, 34, and 35, respectively.)

The requirement for sky surveys in the UV region are considered in Group F. The key parameters affecting the design of the telescopes are field of view (which relates to the time required to photograph the entire sky), and angular resolution, which establishes the quality (limiting magnitude) of the survey. Consideration was also given to the focal length of the primary reflector, as this parameter influenced the light blockage on the primary collector that is caused by the imaging device (camera) as constrained by the wide field of view. The problem of energy collection is also alluded to by the notation of the 1,000 Å minimum wavelength, at which normal incidence reflectivity drops off considerably. This consideration determined the all-reflective design of the optical system, since at this wavelength almost no light is transmitted through any optical medium (e.g., glass). Schmidt telescopes were selected because of their well established capability to cover a wide field of view. (Instruments No. 33 and 13.)

2.4.3.3 Normal Incidence Telescopes for Solar Use

The considerable potential for astronomical observations of the sun is enormous because (1) it is the strongest observed astronomical source and (2) it is close enough for its individual features to be studied. The progressive instrument design steps that must be taken to realize this potential are shown in Groups G, H, J, K, L, M, and N. (Groups L, M, and N will be described in the next section, which covers grazing incidence telescopes.)

Starting with the region around the sun in which observable solar phenomena occur (the solar corona), Group G provides cameras (coronagraphs) for photographing this region (Instruments No. 36 and 37). Occultation devices (opaque disks) are used to blank out the overpoweringly bright radiation from the sun itself so that the coronal phenomena may be photographed. Similarly, the coronal region itself is divided into (1) the brighter region within about 6 solar radii of the sun and (2) the region from there out to about 30 solar radii. Key instrument design parameters are the field of view, which is determined by the size of a disk 30 solar radii in diameter as seen from the Earth, and the angular resolution, which determines the quality of the photography. The separation into two instruments provides several advantages: (1) each of the two instruments is relatively small compared to one instrument of unwieldy proportions, (2) the inner coronagraph, which requires a much smaller field of view, provides higher resolution for a given image size than the outer coronagraph, this being desirable because the features in the inner coronagraph are much more interesting; and (3) the radiation flux levels encountered in solar corona vary by six to eight orders of magnitude between the region of 1 solar radius and 30 solar radii and the requirement for recording media (film) with such a wide range of response is considerably relaxed by splitting this region into two.

White light photography of the surface of the sun is considered in Group H. The key parameter here is effective focal length, a large value of this parameter being necessary in order to get large images of the solar phenomena. Fine angular resolution is also necessary in order to achieve high-quality imaging. The apertures reflect the diffraction requirements to achieve high-quality angular resolution. The telescopes selected (Instruments No. 44 and 46) are characterized by Gregorian optics rather than the more common Cassegrainian optics, because this arrangement is more amenable to rejecting large amounts of extraneous solar radiation to minimize thermal distortion problems in the telescope.

As shorter wavelength solar radiation is considered in the observation requirements, the problems associated with decreasing normal-incidence reflectivity in the extreme ultraviolet (XUV) region are evidenced in the successive telescope designs resulting from Groups J, K. L, M. and N. (Groups L, M, and N will be described in the next section, which covers grazing incidence telescopes; however, they are a part of this general trend.)

The off-axis telescope design, Group J, is utilized to minimize obscuration of the optical path and to eliminate all reflections except the single focusing reflection performed by the primary mirror. This design provides spectroscopy with wavelength resolution to a fraction of 1 Å down to wavelengths between 300 and 700 Å, using a normal-incidence spectrograph. (Instruments No. 04 and 05.)

In order to conduct spectroscopy at wavelengths down to about 170 Å, slitless spectrography must be combined with off-axis design in order to utilize the light that would be intercepted by the slit. This is done in the spectroheliographs of Group K, in which the diffraction grating is ruled directly on the primary reflector. These instruments (Instrument No. 06 and 07) extend the range of spectroscopy down to 170 Å.

2.4.3.4 Grazing-Incidence Optical Telescopes

Solar observations in the XUV region (Group L) are extended to include finer spectral resolution capabilities than could be achieved with any normal-incidence device by the inclusion of grazing-incidence telescopes (Instruments No. 08 and 09) for that purpose. The increased reflectivity of grazing-incidence optics at wavelengths around 170 A, as compared with normal-incidence optics, permits the use of the slit in the spectrograph and, consequently, provides clear separation of the various spectral lines, as opposed to the overlapping images of the solar disk that characterize the slitless spectroheliograph data.

Imaging and spectroscopy of solar phenomena in the X-ray region (about 1 to 40 A) are provided by instruments selected for Groups M and N. Although not explicitly shown in Table 2-2, the ORDS in these groups call for simultaneous imaging and spectroscopy. To meet this requirement, two instruments had to be provided, one for each of these functions, and the two instruments had to be used simultaneously. For the imaging telescope (Instrument No. 39), angular resolution and field of view contribute to the determination of the design characteristics. For the spectroscopic telescope (Instruments No. 11) as well as for the imaging telescope, the wavelength range, through its influence on the acceptable angles of grazing influence, contributes to the determination of the design.

The observation requirements for imaging and spectroscopy of stellar sources in the X-ray region are considered in Group P. Since the combination of angular resolution and field of view do not appear to be attainable with the technology anticipated for the time period of this study, the instrument selected (Instrument No. 19) is limited essentially to as large a size as appears feasible for the launch capabilities anticipated. Although the collecting area suggested in the ORDS (500 cm^2) can be achieved with this size instrument, neither the 2^o field of view nor the 0.1 arc-sec angular resolution that were suggested could be confidently postulated within the time period considered in this study.

2.4.3.5 High-Energy Radiation Counters

Groups Q, R, S, T, U, and V show the progression of types of detectors through the various energy levels (equivalent to wavelengths) in the high-energy radiation region. A proportional counter array (Instrument No. 20) in the X-ray region up to about 20 keV (Group Q) is suitable for sky surveys to identify discrete X-ray sources for further examination by the stellar X-ray telescope described in Group P. At higher energy levels (Groups R and S), scintillation counters of various design (Instruments No. 22, 23, and 42) can provide sky surveys and spectroscopy, although to energy (spectral) resolutions no better than 5 to 10%. The solid-state counter (Instrument No. 25) can cover the same range to a more precise energy resolution (Group T) as a follow-on to the scintillation counters in a later time period.

The spark chamber (Instrument No. 43) extends the energy level that can be observed up to 1 GeV (Group U); and the Cerenkov counter (Instrument No. 27) provides observation to 100 GeV (Group V).

The considerations discussed above provided the selection of a set of instruments that could satisfy the observation requirements of the baseline astronomy program. These instruments were then analyzed at the conceptual design level to provide descriptive information (observation capabilities; physical characteristics; orbital support requirements such as electrical power, stabilization, and data handling; development cost estimates, et cetera) needed in Task C for analysis of orbital support facilities and for development of an overall astronomy program plan. Detailed instrument descriptions resulting from this conceptual design analysis are presented in the next section.

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Section 3
ASTRONOMY INSTRUMENT DESCRIPTIONS

3.1 SUMMARY MATRIXES OF ASTRONOMY INSTRUMENTS

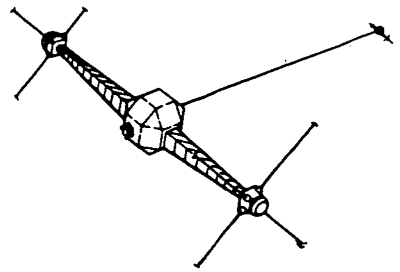
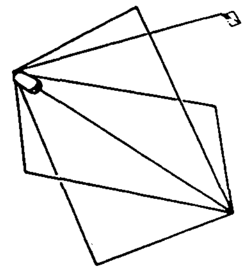
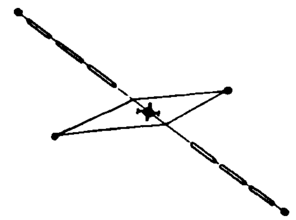
A series of summary matrixes has been prepared to provide a compact overview of the entire set of instruments selected for the baseline astronomy program. These matrixes highlight major instrument categories, the distinction between the instrument "front-ends" and back-ends," and the distinction between designs for solar and stellar observations.

This baseline set of instruments is the final result of (1) an analysis of the ORDS, (2) discussion with scientific contributors, and (3) utilization of NASA-available instruments.

Figure 3-1 shows the radio telescopes. For this category of instrument, antenna parameters are considered particularly important to the instrument description, because they tend to establish the individual identify and characteristics of the overall instrument.

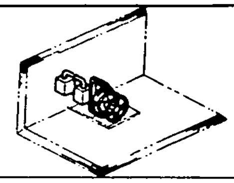
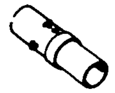
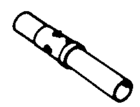
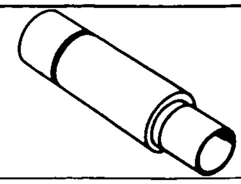
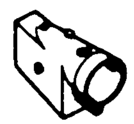
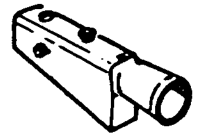
Stellar and solar normal incidence optical telescopes are summarized in Figures 3-2 and 3-3. The two matrixes are similar in that they each deal with UV, visible and IR portions of the electromagnetic spectrum. The upper portions of these matrixes tabulate the characteristics of the optical collectors. Various spectrographs, cameras, interferometers, detectors, and other instrumentation devices are presented in the lower portions of the figures, which also show, by their matrix interrelationship, the association of the collectors ("front-ends") with the instrumentation devices ("back-ends"), and the ORDS to which these combinations are applicable. Grazing-incidence optical telescopes for both solar and stellar applications are shown in a similar fashion in Figure 3-4.

Figure 3-5 summarizes the high-energy radiation counters; the capabilities of these instruments extend from 0.7 keV to 100 GeV.

				
INSTRUMENT		CROSSED–H TETHERED INTERFEROMETER	TERMINATED–LOOP TETHERED INTERFEROMETER	KILOMETER WAVE ORBITING TELESCOPE (KWOT)
(SECTION IN TEXT) (BOOK 1)		(3.2.1)	(3.2.2)	(3.2.3)
OASF INSTRUMENT NO.		32	30	41
COLLECTOR CHARACTERISTICS	FREQUENCY RANGE	LOW: 0.5-2.5 MHz MID: 2.5-5.0 MHz HIGH: 5.0-10 MHz	0.05 MHz TO 15 MHz	0.1 MHz TO 10 MHz
	TYPE OF POLARIZATION	DIVERSE	LINEAR	NOT AVAILABLE
	E–PLANE BEAMWIDTH	35°- 75°* 1.7° **	1°	1.7°**
	H–PLANE BEAMWIDTH	1.7° * 134-180°**	90°	19.9°*
	IMPEDANCE RATIO	10	7	NOT AVAILABLE
	DIMENSIONAL ADJUSTMENT REQUIRED IN ORBIT	TETHER LENGTH	TETHER LENGTH	MINOR DIAGONAL
	ANTENNA DIMENSIONS	(ADJUSTABLE) 150 M x 150 M x 30 M (MAX.)	45.8 M x 45.8 M x 45.8 M AND 18.1 M x 18.1 M	10 km x 10 km
	TETHER LENGTH	10 km (MAX.)	40 km	N/A
	LENGTH (LAUNCH CONFIGURATION) (m;ft)	3.3;10.8	2.4;7.9	3.1;10.2
	VOLUME (LAUNCH CONFIGURATION) (m^3;ft^3)	10;353	0.75;26.4	1.5;53.5
	WEIGHT (kg;lb)	1,900;4,200	1,450;3,200	640;1,410
	TIME PERIOD	INTERMEDIATE	INTERMEDIATE	LATE
	ORDS TO WHICH APPLICABLE	004,005S,006S, 105,106	004,005S,006S, 105,106	004,005S,006S, 105,106
INSTRUMENTATION DEVICES	FULL-FREQUENCY-SWEEP CAPABILITY	NO	YES	YES
	SWEPT FREQUENCY RADIOMETRY RECEIVERS	50 kHz FREQUENCY RESOLUTION	50 kHz FREQUENCY RESOLUTION	NOT AVAILABLE
	WIDE-BAND RADIOMETRY RECEIVERS	70 dB DYNAMIC RANGE	70 dB DYNAMIC RANGE	70dB DYNAMIC RANGE

* AS H–PLANE INTERFEROMETER
** AS E–PLANE INTERFEROMETER

Figure 3-1. Radio Telescopes

							
INSTRUMENT		1-METER INFRARED	1-METER NON-DIFF-LIM UV-VIS-IR	1-METER DIFF-LIM UV-VIS-IR	3-METER DIFF-Lim UV-VIS-IR	0.3-METER UV SCHMIDT	1-METER UV SCHMIDT
(SECTION IN TEXT) (BOOK 1)		(3.2.4)	(3.2.5)	(3.2.6)	(3.2.13)	(3.2.7)	(3.2.14)
OASF INSTRUMENT NUMBER		14	45	34	35	33	13
COLLECTOR CHARACTERISTICS							
APERTURE	(m)	1.0	1.0	1.017	3.04	0.3	1.0
EFFECTIVE FOCAL LENGTH	(m)	10.0	5.0	10.17	45	0.91	4.0
UNOBSCURED COLLECTING AREA	(cm^2)	7,050	6,290	6,930	63,200	706	7,850
WAVELENGTH (MINIMUM)	(Å)	0.7 μ	< 900	900	900	1,000	1,000
WAVELENGTH (MAXIMUM)	(Å)	1,000 μ	> 12,000	6,000	12,000	> 2,000	5,000
ON-AXIS ANGULAR RESOLUTION IN FOV AT GIVEN WAVELENGTH	(arc-sec at Å)	1 AT 4 μ	0.2 AT 4,000	0.1 AT 4,000	0.04 AT 5,000	0.25 AT 1,200	0.1 AT 4,000
FINE GUIDANCE RESOLUTION	(arc sec)	± 0.1	± 0.05	± 0.01	± 0.005	± 0.5	± 0.05
FIELD OF VIEW (FOV)	(arc-min)	5	10	2	15	10 *	5 *
AUTOMATIC GUIDANCE ACCURACY	(arc-sec)	1	0.1	1	INTERMED. 30 FINE 10	5	0.25
POOREST ANGULAR RESOLUTION IN FOV AT GIVEN WAVELENGTH	(arc-sec at Å)	1 AT 4 μ	1 AT 4,000	0.15 AT 4,000	0.1 AT 5,000	0.5 AT 1,200	0.25 AT 4,000
LENGTH, STOWED POSITION	(m;ft)	1.75;5.75	2.8;9.2	2.68;8.8	15.6;51.2	3.08;10.1	9.07;29.6
VOLUME, STOWED POSITION	(m^3;ft^3)	50;1,760	3.5;124	4.1;145	270;9,520	2.5;88	53;1,870
WEIGHT, INCLUDING INSTRUMENTATION DEVICES	(kg;lb)	1,000;2,200 (INCLUDING SHIELD)	1,000,2,200	240;530	12,000;26,500	430;950	930;2,050
VIEWFINDER FIELD OF VIEW	(degrees)	2	5	5	2	5	5
TIME PERIOD		INTERMEDIATE	INTERMEDIATE	INTERMEDIATE	LATE	INTERMEDIATE	LATE
ORDS TO WHICH APPLICABLE		029, 063S, 072 THRU 078	002, 027, 028, 030, 031, 032, 033, 034, 037, 113	020, 021, 022 035, 036, 040	018, 023, 024, 026, 038, 039	101,107S	071S
INSTRUMENTATION DEVICES							
NORMAL-INCIDENCE SPECTROGRAPH	WAVELENGTH RANGE SPECTRAL DISPERSION WAVELENGTH RESOLUTION RECORDING SCALE		1,000-3,000Å 100Å/mm 2Å AT 1,500Å 13.8 arc sec/mm TYPICAL INTERCHANGE GRATING ORDS 033, 037		800-3,000A 24Å/mm 0.5Å AT 2,000Å 13.8 arc sec/mm TYPICAL INTERCHANGE GRATING ORDS 028, 031, 032, 034	900-4,000Å 100Å/mm 2Å AT 1,200Å 226 arc sec/mm SLITLESS PLANE GRATING ORDS 107S	
ECHELLE SPECTROGRAPH	WAVELENGTH RANGE SPECTRAL DISPERSION WAVELENGTH RESOLUTION RECORDING SCALE		800-3,000Å 10Å /mm 0.2Å AT 2,000Å 13.8 arc sec/mm TYPICAL INTERCHANGE GRATING ORDS 031, 032, 034	800-3,000Å 4.65Å/mm 0.1Å AT 2,000Å 20.3 arc sec ORDS 035, 036			
SLITLESS SPECTROGRAPH	WAVELENGTH RANGE SPECTRAL DISPERSION WAVELENGTH RESOLUTION RECORDING SCALE		800-4,000Å 50Å/mm 2.5Å AT 2,000Å 13.8 arc sec/mm IMAGE INTENSIFIER + FILM ORDS 028				
PLATE CAMERA	SIZE FIELD OF VIEW RECORDING SCALE		25 x 25 mm 5-3/4 arc min. 13.8 arc sec/mm ORDS 113		70 mm / 225 mm 5 arc min. / 15 arc min. 4.6 arc sec/mm / 4.6 arc sec/mm ORDS 018, 023, 024, 026	150 x 150 mm 10° 226 arc sec/mm ORDS 101	15 x 15 in. 10° 55.5 (arc sec)/mm ORDS 071S
	SIZE RECORDING SCALE				35 x 50 mm 4.6 arc sec/mm ORDS 038		
FILTER ASSEMBLY					200 Å BANDS 500 Å BANDS ORDS 018, 023, 024, 026	0.5, 0.2 7μ BAND ORDS 107S	500 Å BANDS ORDS 071S
FIELD LENS AND/OR IMAGE TUBE			PHOTO MULTIPLIER IMAGE INTENSIFIER ORDS 002, 027, 028, 030	20-POWER RELAY LENS + S.E.C. VIDICON ORDS 020, 021, 022, 040	2 POWER LENS + 16mm, 1,000-line VIDICON ORDS 024		
PHOTOPOLARIMETER					0.5% POLARIZATION λ = 1050-3000 Å ORDS 039		
SPECTROPHOTOMETER			800-3,200Å AND 3,200-12,000Å 10-100Å RESOLUTION ORDS 002, 027, 030				
INTERFEROMETER		RESOLVING POWER = 4 PARTS IN 10^4 INTERFEROMETER CONTROL ORDS 072–075, 077, 078					
RADIOMETER	SPECTRAL DETECTIVITY	† SPECTRAL D* = 10^{13} WITH DETECTOR COOLING TO 4K ORDS 029, 076S					
SOLID STATE DETECTOR MATRIX	SPECTRAL DETECTIVITY	† SPECTRAL D* = 10^{13} WITH DETECTOR COOLING TO 4K ORDS 063S					
MAGNETIC TAPE RECORDER		35 mm DIGITAL ORDS 029, 063S, 072, 073, 079					

† See Table II-1, Reference 3-5

Figure 3-2. Normal Incidence Stellar Telescopes

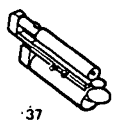
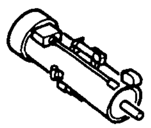
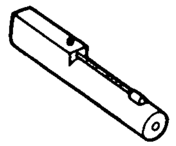
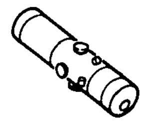
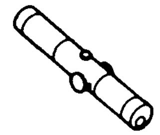
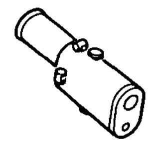
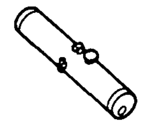
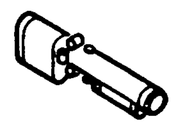
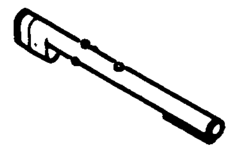
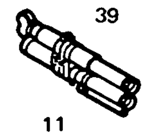
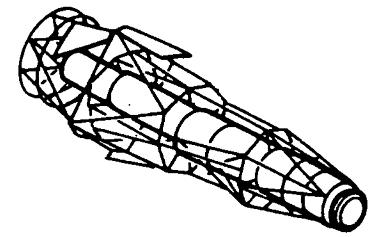
			 36 37							
	INSTRUMENT		1-TO-6 SOLAR RADII CORONAGRAPH (USED TOGETHER)	5-TO-30 SOLAR RADII CORONAGRAPH (USED TOGETHER)	0.8-METER UV VISUAL	1.5-METER DIFF-LIM UV-VISUAL	0.2-METER UV (OFF-AXIS)	0.5-METER UV (OFF-AXIS)	0.25-METER XUV SPECTRO-HELIOGRAPH	0.125-METER XUV HIGH DISPERSION SPECTROHELIOGRAPH
	(SECTION IN TEXT) (BOOK 1)		(3.2.8)	(3.2.9)	(3.2.10)	(3.2.15)	(3.2.11)	(3.2.16)	(3.2.12)	(3.2.17)
	OASF INSTRUMENT NO.		36	37	44	46	04	05	06	07
COLLECTOR CHARACTERISTICS	APERTURE	(m)	0.0245	0.040	0.80	1.5	0.2	0.5	0.25	0.125
	EFFECTIVE FOCAL LENGTH	(m)	0.315	0.090	39.2	75	2.4	6.0	3.0	2.5
	UNOBSCURED COLLECTING AREA	(cm^2)	4.48	11.9	4280	17200	315	1360	490	122
	WAVELENGTH (MINIMUM)	(Å)	4,000	4,000	1,200	<1,300	300	170	170	304
	WAVELENGTH (MAXIMUM)	(Å)	10,000	10,000	10,000	>12,000	>1,500	>1,500	650	1,216
	ON-AXIS ANGULAR RESOLUTION AT GIVEN WAVELENGTH	(arc-sec at Å)	10 at 5,000	30 at 5,000	0.16 at 5,000	0.1 at 6,200	1 at 800	0.5 at 800	1 at 170	1 at 600
	FINE GUIDANCE RESOLUTION	(arc sec)	± 5		± 0.02	± 0.05	± 0.1	± 0.05	± 0.02	± 0.02
	FIELD OF VIEW (FOV)	(arc min)	3.25°	15°	2.6	1.1	2	2	32	10
	AUTOMATIC GUIDANCE ACCURACY	(arc-sec)	15	15	1	15	15	15	0.1	0.1
	POOREST ANGULAR RESOLUTION IN FOV AT GIVEN WAVELENGTH	(arc-sec at Å)	45 at 5,000	1 arc min. at 5,000	0.196 at 5,000	0.1 at 6,200	1.5 at 800	1 at 800	1 at 170	1 at 600
	LENGTH, STOWED POSITION	(m;ft)	3.7;12.15	2.8;9.2	3.56;11.8	12.3;40.4	3.6;11.8	9;29.6	3.44;11.3	3.44;11.3
	VOLUME STOWED POSITION	(m^3;ft^3)	COMBINED 2.3;81		3.25;115	32.5;1,150	1.6;56.5	10.8;38.1	3;106	3;106
	WEIGHT, INCLUDING INSTRUMENTATION DEVICES	(kg;lb)	COMBINED 400;880		800;1,760	1,600;3,530	65;143	1,800;3,970	300;660	320;710
	VIEWFINDER FIELD OF VIEW	(arc min)	40	40	300	32	40	40	15°	15°
	TIME PERIOD		INTERMEDIATE	INTERMEDIATE	INTERMEDIATE	LATE	INTERMEDIATE	LATE	INTERMEDIATE	LATE
	ORDS TO WHICH APPLICABLE		062	062	050,064,069	053,057,064 066,069,079	042,058	043,044, 051,060	052	070
INSTRUMENTATION DEVICES:	NORMAL-INCIDENCE SPECTROGRAPH	WAVELENGTH RANGE SPECTRAL DISPERSION WAVELENGTH RESOLUTION RECORDING SCALE					300-1500Å 10Å / mm 0.2Å at 300Å 86 arc sec/mm ORDS 042, 058	300-1500Å 1Å / mm 0.02Å at 800Å 34 arc sec/mm ORDS 043, 044, 060		
	ECHELLE SPECTROGRAPH	WAVELENGTH RANGE SPECTRAL DISPERSION WAVELENGTH RESOLUTION RECORDING SCALE			1,500-7,500Å 0.5Å/mm 0.01Å at 3,000Å 4.43 arc sec/mm ORDS 069	1,300-11,000Å 0.1Å/mm 0.002Å at 3,000 2.75 arc sec/mm ORDS 053 069 079				
	SLITLESS SPECTROHELIOGRAPH	WAVELENGTH RANGE SPECTRAL DISPERSION WAVELENGTH RESOLUTION RECORDING SCALE						170-650Å 1Å/mm 0.02Å at 800Å 34 arc sec/mm ORDS 051	170-650Å 1Å/mm 0.015Å at 170Å 69 arc sec/mm ORDS 052	304-1216Å 1Å/mm 0.015Å at 600Å 21 arc sec/mm ORDS 070
	NARROW-BAND LYOT FILTER	BANDPASS			±0.25Å ORDS 064	±0.1Å ORDS 057 064				
	CINE-FRAME CAMERA, 35 mm	FIELD OF VIEW RECORDING SCALE	3.25° 656 arc sec/mm ORDS 062	15° 2,700 arc sec/mm ORDS 062	2.6 arc min. 4.43 arc sec/mm 35x35 mm 35x100 mm ORDS 050 064					
	PLATE CAMERA	FIELD OF VIEW RECORDING SCALE FORMAT				1.1 arc min. 2.75 arc sec/mm 35x100 mm ORDS 057 064	2 arc min. 86 arc sec/mm 35x120 mm ORDS 042 058	2 arc min 34 arc sec/mm 35x600 mm ORDS 043 044 051 060	32 arc min. 69 arc sec/mm 35x495 mm ORDS 052	10 arc min. 21 arc sec/mm 35x250 mm (Grazing) ORDS 070
	SOLAR MAGNETOGRAPH	BANDPASS				0.05Å/mm (SPECTROHELIOGRAPH) ORDS 066				

Figure 3-3. Normal Incidence Solar Telescopes



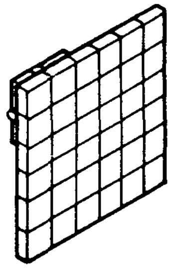
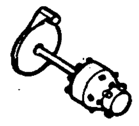
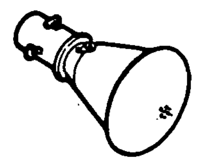






	INSTRUMENT		SOLAR				STELLAR
			0.25-METER XUV	0.5-METER XUV	0.25-METER IMAGING X-RAY (USED TOGETHER)	0.225-METER SPECTROGRAPHIC X-RAY (USED TOGETHER)	1-METER X-RAY
	(SECTION IN TEXT)	(BOOK 2)	(3.2.18)	(3.2.22)	(3.2.19)	(3.2.20)	(3.2.21)
	OASF INSTRUMENT NUMBER		08	09	39	11	19
COLLECTOR CHARACTERISTICS	APERTURE	(m)	0.25	0.50	0.25	0.225	1.0
	EFFECTIVE FOCAL LENGTH	(m)	3.0	6.0	2.4	2.4	10.0
	UNOBSCURED COLLECTING AREA	(cm^2)	125	500	50	20	500
	WAVELENGTH (MINIMUM)	(Å)	170	170	2	1	2
	WAVELENGTH (MAXIMUM)	(Å)	> 650	> 650	10	40	100
	ON-AXIS ANGULAR RESOLUTION AT GIVEN WAVELENGTH	(arc sec at Å)	2.5 at 300	0.5 at 300	5 at 6	5 at 6	5 at 6
	FINE GUIDANCE RESOLUTION	(arc sec)	± 0.1	± 0.02	± 1		± 0.25
	FIELD OF VIEW (FOV)	(arc min)	2	2	30	10	10
	AUTOMATIC GUIDANCE ACCURACY	(arc sec)	1	0.2	(MANUAL)	(MANUAL)	15
	POOREST ANGULAR RESOLUTION IN FOV AT GIVEN WAVELENGTH	(arc sec at Å)	2.5 at 300	0.5 at 300	20 at 6	20 at 6	20 at 6
	LENGTH, STOWED POSITION	(m;ft)	3.16;10.4	6.4;21.0	3.12;10.2	2.95;9.7	5.71;18.8
	VOLUME, STOWED POSITION	(m^3;ft^3)	0.44;15.5	2.3;81	COMBINED 0.65;23.0		200;7,050
	WEIGHT, INCLUDING INSTRUMENTATION DEVICES	(kg;lb)	85;187	400;880	COMBINED 80;176		1,220;2,690
	VIEWFINDER FIELD OF VIEW	(degrees)	5	5	2/3	2/3	3
	TIME PERIOD		INTERMEDIATE	LATE	INTERMEDIATE	INTERMEDIATE	LATE
	ORDS TO WHICH APPLICABLE		054, 055, 059	055,056,061	065	045,068	081, 082, 083, 084
INSTRUMENTATION DEVICES	GRAZING-INCIDENCE SPECTROGRAPH	WAVELENGTH RANGE SPECTRAL DISPERSION WAVELENGTH RESOLUTION	170-650Å 10Å/mm 0.5Å at 300Å ORDS 054,055 059	170-650Å 1Å/mm 0.1Å at 304Å ORDS 055, 061			
	PLATE CAMERA, GRAZING INCIDENCE	FIELD OF VIEW RECORDING SCALE FORMAT	2 arc min. 69 arc sec/mm 35 x 44 mm ORDS 054,055 059	2 arc min. 34.4 arc sec/mm 70 x 450 mm ORDS 055, 061			20.6 arc sec/mm 35 mm ORDS 081 084
	CINE-FRAME CAMERA, 35 mm	FIELD OF VIEW RECORDING SCALE			30 arc min. 86 arc sec/min. ORDS 065		
	X-RAY IMAGE INTENSIFIER PLUS VIDICON	FIELD OF VIEW RECORDING SCALE			30 arc min. 86 arc sec/mm (ALTERNATIVE TO CAMERA) ORDS 065		
	CRYSTAL SPECTROMETER	WAVELENGTH RANGE WAVELENGTH RESOLUTION				1.5-10Å 0.1Å at 3Å ORDS 045, 068	1% at 3 keV ORDS 083
	X-RAY GRAZING INCIDENCE SPECTROMETER	WAVELENGTH RANGE WAVELENGTH RESOLUTION				1.5-60Å 0.1Å at 3Å ORDS 045	
	FIELD LENS AND/OR IMAGE TUBE						X-RAY IMAGE INTENSIFIER GAIN = 7 ORDS 081
	CHANNEL SPECTROMETER/ PROPORTIONAL COUNTER						6% RESOLUTION at 10 keV ORDS 082

Figure 3-4. Grazing Incidence Telescopes

							
INSTRUMENT	0.7-keV to 20-keV Proportional Counter Array	10-keV to 300-keV Scintillation Counter	300-keV to 1-MeV Scintillation Counter	1 MeV to 5-MeV Scintillation Counter	25-MeV to 1-GeV Digitized Spark Chamber	10-keV to 20-MeV Solid State Counter	20-MeV to 100-GeV Gas Cerenkov Counter
(SECTION IN TEXT) (BOOK 2)	(3.2.23)	(3.2.24)	(3.2.25)	(3.2.26)	(3.2.27)	(3.2.28)	(3.2.29)
OASF INSTRUMENT NUMBER	20	22	23	42	43	25	27
EFFECTIVE COLLECTOR AREA (cm^2)	1.3 x 10^5	300	100	100	230	1000	500
ENERGY RANGE	0.7 keV TO 20 KeV	10 keV TO 300 keV	300 keV TO 1 MeV	1 MeV TO 5 MeV	25 MeV TO 1 GeV	10 keV TO 20 MeV	20 MeV TO 100 GeV
ANGULAR RESOLUTION (degrees)	1	3	3	3	2.5	3	8 arc min.
FINE GUIDANCE RESOLUTION	± 3.3 sec	± 1 min.	± 1 min.	± 5 min.	± 30 sec	N/A	± 15 sec
FIELD OF VIEW (degrees)	3	6	6	[illegible]	60	6	60
TOTAL SIGNAL COUNT (photons/sec-keV)	1 x 10^4	3 x 10^{-2}	10^{-6}	10^{-6}	10^{-8}	10^{-5}	10^{-5} PARTICLES/ sec-MeV
EXPECTED COUNT IN TOTAL BAND (photons/sec)	600 TO 5 x 10^5	10 TO 10^4	0.02 TO 2	0.02 TO 2	10^{-2} TO 1	2 TO 20	0.05 TO 50 (ELECTRONS/SEC AT 0.1 GeV)
ENERGY RESOLUTION	10% AT 10 keV	20% AT 50 keV	8% AT 600 keV	5% AT 1 MeV	35% AT 100 MeV	3 keV AT 1 MeV 8 keV AT 20 MeV	10% AT 1 GeV
TOTAL NOISE (ENVIRONMENTAL)	*	*	*	*	*	*	*
LENGTH (m;ft)	4.3;14.1	1.5;4.9	1.2;3.9	1.0;3.3	1.5;4.9	1.2;3.9	3.7;12.1
VOLUME (m^3;ft^3)	8.8;310	0.65;23.0	0.84;29.6	0.4;14.1	0.5;17.6	0.4;14.1	9;318
WEIGHT (kg;lb)	2,700;5,950	290;640	300;660	200;440	90;198	350;770	800;1,760
RECORDING MEDIUM	MAGNETIC TAPE 11 HOURS SKY SCAN	MAGNETIC TAPE 10 MIN/OBSER-VATION	MAGNETIC TAPE 100 HR/OBSER-VATION	MAGNETIC TAPE 100 HR/OBSER-VATION	DIGITAL	MAGNETIC TAPE 100 HR/OBSER-VATION	VIDICON/FILM
GUIDANCE STABILITY REQUIRED (degrees)	0.1	1.0	0.3	0.3	±0.5	0.3	0.05
VIEWFINDER FIELD OF VIEW (degrees)	15	8	8	8	8	8	2.0
TIME PERIOD	INTERMEDIATE	INTERMEDIATE	INTERMEDIATE	INTERMEDIATE	INTERMEDIATE	LATE	LATE
ORDS TO WHICH APPLICABLE	085S,095, 096,097,100	049S,086,089S	046, 102	046, 102	048S,093S	046,098,099,103,104	087S,091S

* ADDITIONAL DATA REQUIRED BEFORE ENVIRONMENTAL NOISE CAN BE DEFINED.

Figure 3-5. High-Energy Radiation Counters

3.1.1 Astronomy-Program Effectiveness of Task B Instruments

A display of the elements that contribute to effectiveness of the various instruments derived in Task B is presented in Table 3-1. No attempt is made here to establish a relative program effectiveness, or ranking, among the instruments, for several reasons:

1. The instruments are identified with widely diverse regions of the electromagnetic spectrum; hence any measure of the value of observations performed would be subjective.
2. The ORDS themselves, being merely representative of a complete baseline research program in astronomy, are not necessarily well balanced with respect to various areas of astronomy. Therefore, any attempt to tabulate data such as numbers of ORDS satisfied could be misleading.
3. Economic factors, which are not reflected in this figure, would have to be considered in any attempt to delineate program effectiveness of the instruments.

The symbols used in Table 3-1 are explained as follows:

1. ■ Instrument Fully Satisfies the ORDS--The instrument, utilizing present technology and presently postulated state-of-the-art advances, would have the required performance characteristics with respect to the desired observation requirements, as defined in the indicated ORDS. Instrument packaging to meet the requirements imposed by in-orbit operation, and mirror figuring to stated limits, are considered to be within postulated state-of-the-art advances.

2. ▲ Instrument Theoretically Permits Full Satisfaction of ORDS--Postulated instrument performance is predicated on the desired ORDS observation requirements. Although performance falls short of some of the specified observation parameters (such as detector sensitivity, response speed, or field of view), it could satisfy these requirements when the instrument is developed to, or close to, its theoretical limit.
3. ● Instrument Partially Satisfied the ORDS--A qualified fulfillment of the observation requirements as stated in the applicable ORDS. Instrument capability falls short of some of the specified observation parameters, such as spectral range, spectral resolution, spectral dispersion, field of view, or angular resolution.
4. ☒ ORDS Not Covered by Task B Instruments--None of Task B instruments presented provides any significant accomplishment with respect to the particular ORDS observation requirements. This classification may reflect a lack of any feasible instrument concept for the time period of the study. Alternatively, it may reflect a compromise in instrument versatility because of selection of an instrument already under development.

Table 3-1

ASTRONOMY PROGRAM EFFECTIVENESS OF TASK B INSTRUMENTS

ASTRONOMICAL SOURCE	INSTRUMENT CATEGORY		INTERMEDIATE TIME PERIOD																			LATE TIME PERIOD												ORDS NOT COVERED BY INSTRUMENTS	ORDS NUMBER
			RADIO TELESCOPES		OPTICAL TELESCOPE												RADIATION COUNTERS					RADIO TELESCOPES			OPTICAL TELESCOPES							RADIATION COUNTERS			
					NORMAL INCIDENCE										GRAZING INCIDENCE										NORMAL INCIDENCE					GRAZING INCIDENCE					
					STELLAR				SOLAR																STELLAR		SOLAR			STEL-LAR	SOLAR				
	INSTRUMENT NAME		CROSSED-H ANTENNA	ORTHOGONAL-TERMINATED-LOOP-ANTENNA	1-METER INFRARED	1-METER NON-DIF-LIM UV-VIS-IR	1-METER DIF-LIM UV-VIS-IR	0.3-METER UV SCHMIDT	1-TO-6 SOLAR-RADII CORONAGRAPH	5-TO-30 SOLAR-RADII CORONAGRAPH	0.8-METER UV-VIS	0.2-METER UV (OFF-AXIS)	0.25-METER XUV SPECTROHELIOGRAPH	0.25-METER XUV	0.25-METER IMAGING X-RAY	0.225-METER SPECTROGRAPHIC X-RAY	0.7 KEV TO 20 KEV PROPORTIONAL COUNTER ARRAY	10 KEV TO 300 KEV SCINTILLATION COUNTER	300 KEV TO 1 MEV SCINTILLATION COUNTER	1 MEV TO 5 MEV SCINTILLATION COUNTER	25 MEV TO 1 GEV DIGITIZED SPARK CHAMBER	CROSSED-H TETHERED INTERFEROMETER	TERMINATED-LOOP TETHERED INTERFEROMETER	(KWOT) KILOMETER WAVE ORBITING TELESCOPE	3-METER DIF-LIM UV-VIS-IR	1-METER UV SCHMIDT	1.5-METER DIF-LIM-UV-VIS	0.5-METER UV (OFF-AXIS)	0.125-METER XUV HIGH-DISPERSION SPECTROHELIOGRAPH	1-METER X-RAY	0.5-METER XUV	10 KEV TO 20 MEV SOLID STATE COUNTER	20 MEV TO 100 GEV GAS CERENKOV COUNTER		
	INSTRUMENT NUMBER / RADIATION	ORDS NUMBER	31	29	14	45	34	33	36	37	44	04	06	08	39	11	20	22	23	42	43	32	30	41	35	13	46	05	07	19	09	25	27		
STARS	UV	002				■																													002
SKY	VLF	004	●	■																		▲	■	■											004
SKY	VLF	005S																				▲	■	■											005S
RADIO SOURCES	VLF	006S																				▲	■	▲											006S
STARS	VISIBLE	017																																X	017
GALAXIES	UV, VISIBLE	018																							■										018
STARS	VISIBLE	019																																X	019
MERCURY	UV, VISIBLE	020					■																												020
MARS	UV, VISIBLE, IR	021					■																												021
MARS	UV, VISIBLE, IR	022					■																												022
STARS	UV, VISIBLE	023																							■										023
GALAXIES, QUASARS	UV, VISIBLE, IR	024																							■										024
STARS	UV, VISIBLE	026																							■										026
STARS	UV	027				■																													027
NEBULAE	UV	028				■																													028
STARS, GALAXIES, NEBULAE, ETC	IR	029			▲																														029
STARS	UV, VISIBLE, IR	030				■																													030
STARS	UV	031				■																													031
STARS	UV	032				■																													032
STARS, INTERSTELLAR GAS	UV	033				■																													033
STARS	UV	034				■																													034
STARS	UV	035					●																												035
STARS, INTERSTELLAR GAS	UV	036					●																												036
VENUS, MARS, JUPITER, SATURN	UV	037				■																													037
QUASARS	UV	038																							■										038
STARS	UV	039																							■										039
VENUS	UV	040					■																												040
SUN	UV	042										■																							042
SUN	UV	043																										■							043
SUN	UV	044																										●							044
SUN	X-RAY	045														●																			045
SUN	GAMMA RAY	046																	●	●												■			046
SKY, GAMMA RAY SOURCES	GAMMA RAY	048S																			●														048S
SKY	X-RAY	049S																▲																	049S
SUN	UV, VISIBLE, IR	050									■																								050
SUN	UV	051																										■							051
SUN	UV	052											■																●						052
SUN	UV	053																									■								053
SUN	UV	054												■																					054
SUN	UV	055												●																	■				055
SUN	UV	056																													●				056
SUN	VISIBLE	057																									■								057
SUN	UV	058										■																							058
SUN	UV	059												■																					059
SUN	UV	060																										▲							060
SUN	UV	061																													▲				061
SUN	VISIBLE, IR	062							●	●																									062
STARS, QUASARS, ETC.	IR	063S			▲																														063S
SUN	VISIBLE	064									●																■								064
SUN	X-RAY	065													●																				065
SUN	VISIBLE	066																									▲								066
SUN	VISIBLE	067																																X	067
SUN	X-RAY	068														●																			068
SUN	UV, VISIBLE	069									●																■								069
SUN	UV	070											●																■						070
STARS, NEBULAE, GALAXIES	UV	071S																								■									071S
PLANETS, LARGE SATELLITES	IR	072			▲																														072
PLANETS, LARGE SATELLITES	IR	073			●																														073
COMETS	IR	074			▲																														074
STARS	IR	075			▲																														075
INTERSTELLAR MATTER	IR	076S			▲																														076S
INTERSTELLAR MATTER	IR	077			●																														077
INTERSTELLAR MATTER	IR	078			●																														078
SUN	UV, VISIBLE, IR	079																									■								079
SUN	UV, VISIBLE, IR	080																									▲								080
X-RAY SOURCES	X-RAY	081																												●					081
X-RAY SOURCES	X-RAY	082																												▲					082
X-RAY SOURCES	X-RAY	083																												▲					083
X-RAY SOURCES	X-RAY	084																												●					084
SKY	X-RAY	085S															●																		085S
X-RAY SOURCES	X-RAY	086																●																	086
SKY	COSMIC RAY	087S																															▲		087S
SKY	X-RAY	089S																●																	089S
SKY	X-RAY	090S																																X	090S
SKY	COSMIC RAY	091S																															●		091S
SKY	GAMMA RAY	093S																			●														093S
X-RAY SOURCES	X-RAY	095															●																		095
X-RAY SOURCES	X-RAY	096															●																		096
X-RAY SOURCES	X-RAY	097															●																		097
X-RAY SOURCES	X-RAY	098																														▲			098
X-RAY SOURCES	X-RAY	099																														▲			099
X-RAY SOURCES	X-RAY	100															▲																		100
GALAXIES	UV	101						■																											101
GAMMA RAY SOURCES	GAMMA RAY	102																	●	●															102
GAMMA RAY SOURCES	GAMMA RAY	103																														●			103
GAMMA RAY SOURCES	GAMMA RAY	104																														●			104
SUN	VLF	105		■																		▲	■	▲											105
JUPITER	VLF	106		■																		▲	■	▲											106
STARS, NEBULAE	UV	107S						■																											107S
SKY	GRAVITATIONAL	108S																																X	108S
STARS, GALAXIES, NEBULAE	UV	113				■																													113

■ INSTRUMENT FULLY SATISFIES ORDS

▲ INSTRUMENT THEORETICALLY PERMITS FULL SATISFACTION OF ORDS

● INSTRUMENT PARTIALLY SATISFIES ORDS

X ORDS NOT COVERED BY TASK B INSTRUMENTS

3.1.2 Estimates of Development Times and Costs

The estimates of development times and costs for the astronomy instruments, shown in Section 3.2 are limited to estimates of the Phase D portions of the instrument programs, since that is adequate to the requirement for deriving a logical, evolutionary plan for the astronomy program in Task C.

The OASF has been divided into four phases, so as to agree with NASA planning practices. These phases are as follows:

1. Phase A--Program definition.
2. Phase B--Preliminary definition.
3. Phase C--Final definition.
4. Phase D--Development and Operation.

This report is roughly equivalent to Phase A. Phase B, consisting mainly of systems engineering and related disciplines, contains no specific design requirements. Phase C is a continuation of Phase B with a further evolution to preliminary design of the specific instruments. At the end of Phase C all tradeoff analyses must be completed and the decisions relating to the choice of particular instrument design options should be made. The costs in the Development portion of Phase D include design, breadboarding. engineering model fabrication, project verification model fabrication, fabrication of models for qualification testing, and qualification testing, Phase D operations costs include refurbishment of the project verification model to flight quality as backup, flight article fabrication, and engineering support at the Manned Spacecraft Center (MSC) and Kennedy Space Center (KSC).

Development costs, development schedules, and numbers of deliverable hardware items for the various instruments are shown in a series of figures and tables that are included in Section 3.2, below, as part of the overall description of each instrument.

In developing Phase D costs for the various instruments, cost analyses were made of representative instruments of each type. These cost analyses were based on actual costs incurred in the development and fabrication of similar hardware already developed, with appropriate adjustments for differences in complexity and research requirements, on a component-by-component basis.

Experience factors were used where applicable to reflect an improving cost/effectiveness with each subsequent design of a given general type. The costs shown for the individual instruments in the following pages are engineering estimates based on these analyses, and significant figures beyond the second have been left in the tabulated material for arithmetical convenience only. Some individual cost items in the tables (identified by *) were omitted in cases where the lack of extra detail would not significantly affect the overall estimate for the instrument.

An important aspect of these instrument Phase D cost estimates is the commonality in instrument development that could be exploited in considering the evolutionary astronomy program as a whole. Commonalities in development efforts for different instruments (such as in a second-generation growth version of a given instrument) were taken advantage of so as to achieve the greatest economy in overall program costs. Therefore, some of the instrument cost estimates shown in Section 3. 2, below, reflect assumptions that other instruments developed earlier in the program reduce the development cost estimate for the instrument in question. These assumptions, where they are made, are identified in footnotes in the appropriate "Task Cost Estimate--Phase D" tables in Section 3. 2. Another assumption that is sometimes made, and footnoted as appropriate, is that a single contractor will develop the optics for both instruments in a sequence. In addition, the entire set of instrument-development cost estimates is predicated on Cluster 1 and Cluster 2 of the ATM series having flown. In cases where these types of program-derived development commonalities are assumed, the cost estimates are significantly smaller than they would be if the instruments were to be developed independently.

Schedules were devised with regard to the influence on overall program logistics. Primary consideration was given to the logical evolution from earlier instruments to their more sophisticated descendents, and the necessary development intervals were allowed between instruments whose development cost could be commonized as explained in the preceding paragraph. Thereby, full advantage could be taken of the learning process. By creating schedules on an overall basis, it was possible to maximize the usefulness of each launch. Manpower loading was assumed to be flexible; i.e., no allowance was made for loss in manpower efficiency which might occur when greater than the normal number personnel are assigned to a project at a given time.

In the individual development schedules shown in Section 3.2, the general bar chart layouts of the component activities for the various subsystems (detectors, collecting optics, etc.) as well as for the basic instrument system development, and also for the interface with the OASF launches in the overall astronomy program, are essentially similar from instrument to instrument. The major differences are in the predecessor activity interfaces shown at the Phase D Authority To Proceed (zero-month point) and the instrument launch date. The evolutionary plan presented in Task C is based on the matching of each instrument launch date shown here with the appropriate OASF launch (the one indicated in the instrument development schedule). Furthermore, to accomplish Phase D within the time and within the cost estimated for a given instrument, the predecessor activities are considered to have taken place before the Phase D Authority To Proceed date for that instrument. Without these predecessor activities having taken place, the time and the cost necessary to accomplish Phase D for the given instrument would both have to be increased.

A summary of Phase D costs, separated into operations and development for each instrument, is presented in Table 3-2.

Table 3-2

PHASE D TASK COST ESTIMATES
($ Thousands)

Section in Text	Instrument Name	OASF Instrument Number	Development	Operations	Total Phase D
3.2.1	Crossed-H tethered interferometer	32	26,780	12,375	39,155
3.2.2	Terminated-loop tethered interferometer	30	23,600	10,908	34,508
3.2.3	Kilometer wave orbiting telescope	41	80,950	37,348	118,298
3.2.4	1-meter IR telescope	14	4,285	1,980	6,265
3.2.5	1-meter non-diffraction-limited UV-visible-IR telescope	45	10,729	4,961	15,690
3.2.6	1-meter diffraction-limited UV-visible-IR telescope	34	6,719	3,104	9,823
3.2.7	0.3-meter UV Schmidt telescope	33	3,265	1,677	4,942
3.2.8	1- to 6-solar-radii coronagraph	36	1,285	593	1,878
3.2.9	5- to 30-solar-radii coronagraph	37	2,715	1,577	4,292
3.2.10	0.8-meter UV-visible-IR telescope	44	6,824	3,128	9,952
3.2.11	0.2-meter UV off-axis telescope	04	2,250	1,040	3,290
3.2.12	0.25-meter XUV spectroheliograph	06	2,385	1,102	3,487
3.2.13	3-meter diffraction-limited UV-visible-IR telescope	35	176,950	81,697	258,647
3.2.14	1-meter UV Schmidt telescope	13	23,705	10,949	34,654
3.2.15	1.5-meter diffraction-limited UV-visual-IR telescope	46	5,896	2,722	8,618
3.2.16	0.5-meter UV off-axis telescope	05	4,010	1,852	5,862
3.2.17	0.125-meter XUV high-dispersion-spectroheliograph	07	2,385	1,102	3,487
3.2.18	0.25-meter XUV grazing incidence telescope	08	3,915	1,805	5,720
3.2.19	0.25-meter imaging X-ray grazing incidence telescope	39	3,020	1,511	4,531
3.2.20	0.225-meter spectrographic X-ray grazing incidence telescope	11	3,269	1,510	4,779
3.2.21	1-meter X-ray grazing incidence telescope	19	4,630	2,141	6,771
3.2.22	0.5-meter XUV grazing incidence telescope	09	4,560	2,059	6,619
3.2.23	0.7 keV to 20 keV proportional counter array	20	1,890	873	2,763
3.2.24	10 keV to 300 keV scintillation counter	22	1,930	892	2,822
3.2.25	300 keV to 1 MeV scintillation counter	23	1,435	663	2,098
3.2.26	1 MeV to 5 MeV scintillation counter	42	1,435	663	2,098
3.2.27	25 MeV to 1 GeV digitized spark chamber	43	4,320	1,948	6,268
3.2.28	10 keV to 20 MeV solid state counter	25	1,180	546	1,726
3.2.29	20 MeV to 100 GeV gas Cerenkov counter	27	1,376	637	2,013

3.1.3 Flight Crew Skills

The instrument descriptions in Section 3.2 include discussions of the utilization of man in the deployment, alignment, calibration, operation, and maintenance of each instrument. Crew skills identified in those discussions are referenced by number; Table 3-3 summarizes these flight crew skills and their numerical identification.

Table 3-3

FLIGHT CREWSKILL SUMMARY

No.	Name
1	Biological Technician
2	Microbiological Technician
3	Biochemist
4	Physiologist
5	Astronomer/Astrophysicist (Navigator)
6	Physicist
7	Nuclear Physicist
8	Photo Technician/Cartographer
9	Thermodynamicist
10	Electronic Engineer (Navigator/Radar Specialist)
11	Mechanical Technician (Engineer)
12	Electromechanical Technician (general)
13	Physician
14	Optical Technician
15	Optical Scientist
16	Meteorologist
17	Microwave Specialist (Communications/Radar)
18	Oceanographer
19	Physical Geologist
20	Photo Geologist
21	Observer (general)

3.2 DESCRIPTION OF ASTRONOMY INSTRUMENTS

The astronomy instruments resulting from the selection process described in Section 2 are described in detail below.

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3.2.1 Crossed-H Tethered Interferometer Radio Telescope--OASF Instrument No. 32

3.2.1.1 General Characteristics

The crossed-H interferometer (Figure 3-6)* is a long-wave radio astronomy instrument concept advanced in the Large Space Structures Experiment Study conducted by the Convair Division of General Dynamics in coordination with the scientific community (Reference 1-1). The system provides high resolution over a wide frequency band utilizing interferometer effects and dimensional variations. It was conceived to fulfill the threefold purpose of (1) evaluating man's role in the deployment, maintenance, and repair of large space structures; (2) evaluating technology of large space structures; (3) satisfying a user-oriented requirement such as radio astronomy. It consists of a symmetrically shaped center body with extendable booms that support retractable wire-mesh dipoles resembling a turnstile configuration. Both beams and dipole lengths are adjustable in three steps to permit operation over three frequency bands: 0.5 to 2.5 MHz, 2.5 to 5 MHz, and 5 to 10 MHz.

The dipole antennas are the basic sensors. A pair of orthogonal dipoles is arrayed with a second pair to give an end-fire pattern with polarization diversity.

The center body encloses most of the mechanisms, the observation electronics, and the power system. Solar cells are mounted on the body surface.

The booms extend and retract by telescoping.

Each antenna has its independent attitude-control system, including a horizon seeker and/or star tracker. Thrusters are located at boom tips and center body to provide the 6^{o} of motion. Momentum wheels can be added.

The tether joining the two antennas is extendable and retractable between 10,000 and 1,000 m. The tether serves to (1) permit utilization of the gravity

*For convenience, the basic figure for each instrument is a foldout located at the conclusion of the appropriate section.

gradient as a primary stabilizing force and (2) provide a means of controlling the distance between the antennas. The antennas can be redocked into the launch configuration.

The variable geometry crossed-H interferometer concept satisfies the long-wave radio astronomy user requirements, even when structural and dynamic problems inherent in this type of observation are considered. Important features of this concept are:

1. An end-fire radiation pattern, which eliminates the hemispherical ambiguities in antenna response.
2. Variable tether length, which makes possible the use of the interferometer, together with data-correlation processes, to achieve an unambiguous mapping resolution equivalent to that of a two-dimensional filled-aperture array. This achieves a performance that could be matched, using conventional techniques, only by a vastly more complex antenna structure.
3. Variable dipole spacing and length, which permits operation over the broad frequency range from 0.5 to 10 MHz.
4. Ability to lock-on or slew the end-fire dipole assemblies to continuously monitor one sector of the sky. This permits use of the instrument to study time-varying sources, such as the sun, when events of special interest occur.
5. For strong time-varying sources, the entire range, either from 0.5 to 5.0 MHz or from 2.5 to 10.0 MHz, can be observed simultaneously by tuning the two ends separately (either 0.5-2.5/2.5-5.0 MHz or 2.5-5.0/5.0-10 MHz).
6. Polarization measurements in two orthogonal directions are performed continuously during all observation periods and modes.

Other design features that contribute to the feasibility of the crossed-H interferometer are deployment reliability, refurbishment capability, and reasonable cost.

The crossed-H interferometer concept is derived in part from the Tethered Orbiting Interferometer (TOI) concept of Dr. R. G. Stone of the Goddard Space Flight Center, which uses the tethered-antenna-pair interferometer principle. Instead of crossed-H antennas as basic sensors, the TOI uses simple dipoles. Much of the research concerning gravity-gradient tethered antennas was done by Johns Hopkins University, together with the TOI program.

3.2.1.2 Design Criteria

Principal measurement objectives of a long-wave radio astronomy system are (1) the spectral brightness and polarization mapping of essentially time-stationary sources for frequencies below 10 MHz and (2) spectral brightness and polarization monitoring of strong time-varying sources within the solar system for frequencies below 10 MHz.

Earth-based radio telescopes are limited in their usefulness in varying degrees below roughly 30 MHz by the reflection, absorption, refraction, and polarization rotation effects of the ionosphere. They are also adversely affected by interference from man-made signals and atmospheric noises originating on the Earth. These limitations increase in severity with decreasing frequency, becoming very severe at about 10 MHz and intolerable at frequencies below about 5 MHz. Space-borne long-wave radio astronomy telescopes operating outside the ionospheric blanket avoid many of these problems associated with Earth-based telescopes. Below frequencies of 4 or 5 MHz, space-borne long-wave radio astronomy telescopes are the sole means of obtaining long-wave radio astronomy measurement data.

To be useful, then, satellite-borne long-wave radio astronomy telescopes must, among other things, to able to operate at frequencies below 5 MHz, must be able to resolve small angles for mapping, must be capable of monitoring time-varying sources, and be able to measure the polarization of the incident radiation. During analysis and evaluation phases of the program, a listing of typical long-wave radio astronomy user requirements was developed as an aid in evaluating various satellite-borne telescope concepts; these user requirements are summarized in Table 3-4.

Outputs of the phasing and combining circuit, lead to detection and correlation portions of the radiometer equipment. Envelope or power detectors would give a measure of energy incident on each of the channels. Correlation or product detectors, measuring correlation between inputs from the two ends of the interferometer, would yield values of Fourier components of the sky-spatial radiant distribution. Later these could be processed through ground-based computers to obtain maps of sky brightness distribution. A representative correlation detector is a type developed by Hubbard and Erickson.

Table 3-4

DESIGN CRITERIA
Crossed-H Tethered Interferometer
Radio Telescope
OASF Instrument No. 32

Lifetime	Minimum of 1 year desired
Orbit altitude	Minimum of synchronous
Effective beamwidth	100 degrees^2 at 1 MHz desired--less than 10° in one direction, but could be greater for solar and planetary astronomy. Interferometers should be used if possible for improving this resolution to 2°.
Pointing accuracy	1/2 beamwidth minimum to 1/10 for aspect determinations. In case of a sweeping mode or drift mode antenna, pointing direction must be known to within 1/10 half-power beam-width or better.
Pointing stability	Approximately 1/10 beamwidth or better.
Bandwidth	500 kHz to 10 MHz desired, with emphasis on lower half. Possible extension to 200 kHz.
Spectral resolution	Good desired, and depends only on electronics for any one antenna.
Sensitivity	Unfilled apertures entirely adequate.
Lock-on time	1/2 sec to several hours for time-varying phenomena. For most observations, however, an antenna arrangement with as slow a drift-rate as possible--of up to approximately 1°/sec suffices.
Tolerance	Perfer $1/20\lambda$, but $1/16\lambda$ is adequate. (At 1 MHz, a = 300 m)
Orientation	Eliminate antenna-pattern directional ambiguity.

About 15 pass bands, i. e., five in each of the three principal divisions of the 0. 5 to 10 MHz frequency range, would give a reasonable spectral sampling for the interferometer mapping mission.

A circuit feature that could be provided would include servo-controlled filter and end-fire phasing elements which would permit swept-frequency measurements to be made. This capability is most desirable for the observation of strong time-varying sources.

Capability of observation of all extraterrestrial radio phenomena will be assured by incorporation of radiometry filters and power detectors, swept frequency receivers, and wideband receivers of sufficient dynamic range.

Wideband noise sources will probably be employed for calibration purposes.

3.2.1.3 Detailed Characteristics

Basic characteristics of the crossed-H tethered interferometer radio telescope have been summarized in Figure 3-1 in Section 3.1.

Additional instrument details are tabulated in Tables 3-5 and 3-6.

Impedance Considerations

Figure 3-7 is a Smith chart plot of the anticipated input impedance of a single dipole operating over the designated frequency ranges without compensating networks. The 0.5- to 2.5-MHz range is the widest range and, consequently, has the maximum impedance variation.

The higher bands are identical in ratio and, therefore, display the same impedance characteristics.

Antenna Dimensions

Dipole dimensions as adjusted for each frequency range are shown in Table 3-7.

Radiation Patterns

Dipole end-fire arrays have directive radiation patterns designed to enhance reception in one hemisphere. Referring to the coordinate system in Figure 3-8, radiation pattern of the array is expressed by:

$$E_\theta = \sin \frac{\left[\frac{\pi d}{\lambda}(\sin\theta\cos\phi + 1)\right]}{\sin\left(\frac{2\pi d}{\lambda}\right)} \frac{\left[\cos\left(\frac{\pi L}{\lambda}\cos\theta\right) - \cos\left(\frac{\pi L}{\lambda}\right)\right]}{\left[\sin\theta \;\; 1 - \cos\left(\frac{\pi L}{\lambda}\right)\right]}$$

where

$$d/\lambda = 0.25$$
$$L/\lambda = 1.25$$

Figures 3-9 through 3-11 are radiation patterns calculated at low-, mid-, and high-frequency points for a mixed dipole length and spacing.

Additional instrument details have been tabulated in Tables 3-5 and 3-6.

Table 3-5

COLLECTOR PARAMETERS
Crossed-H Tethered Interferometer - Radio Telescope
OASF Instrument No. 32

Aperture	150 m x 150 m x 30 m x 10 km
Total field of view	$130^{\circ} \times 90^{\circ}$
Angular resolution	
On axis	1.7° at 100 m
Poorest in field of view	5° at 100 m
Minimum wavelength	30 m
Maximum wavelength	600 m

Table 3-6

INTERFACE CHARACTERISTICS
Crossed-H Tethered Interferometer - Radio Telescope
OASF Instrument No. 32

General	
System weight (less expendables)	1,900 kg
System volume (launch configuration)	$10\ m^3$
System shape (launch configuration)	Spheroidal pod with extendable booms and STEM dipoles retracted
Method of accomplishing...	
Deployment	Extension of STEM and telescoping booms
Alignment	Gravity gradient and pneumatic
Calibration	Calibrated noise source
Operation	Remote
Experiment change	Ground activated
Stowage requirements (launch)	
Mechanical	Protective core
Electrical	N/A
Experiment data handling	
Format	Partially processed rf cov-converted to digital
Processing	Transmission to ground-based computer
Recording media	Tape
Mode of data recovery	Ground-based S-band receiver
Pointing requirements	
Pointing accuracy (acquisition)	$\pm 5^{\circ}$
Power consumption	
Standby	200 W
Operate	614 W

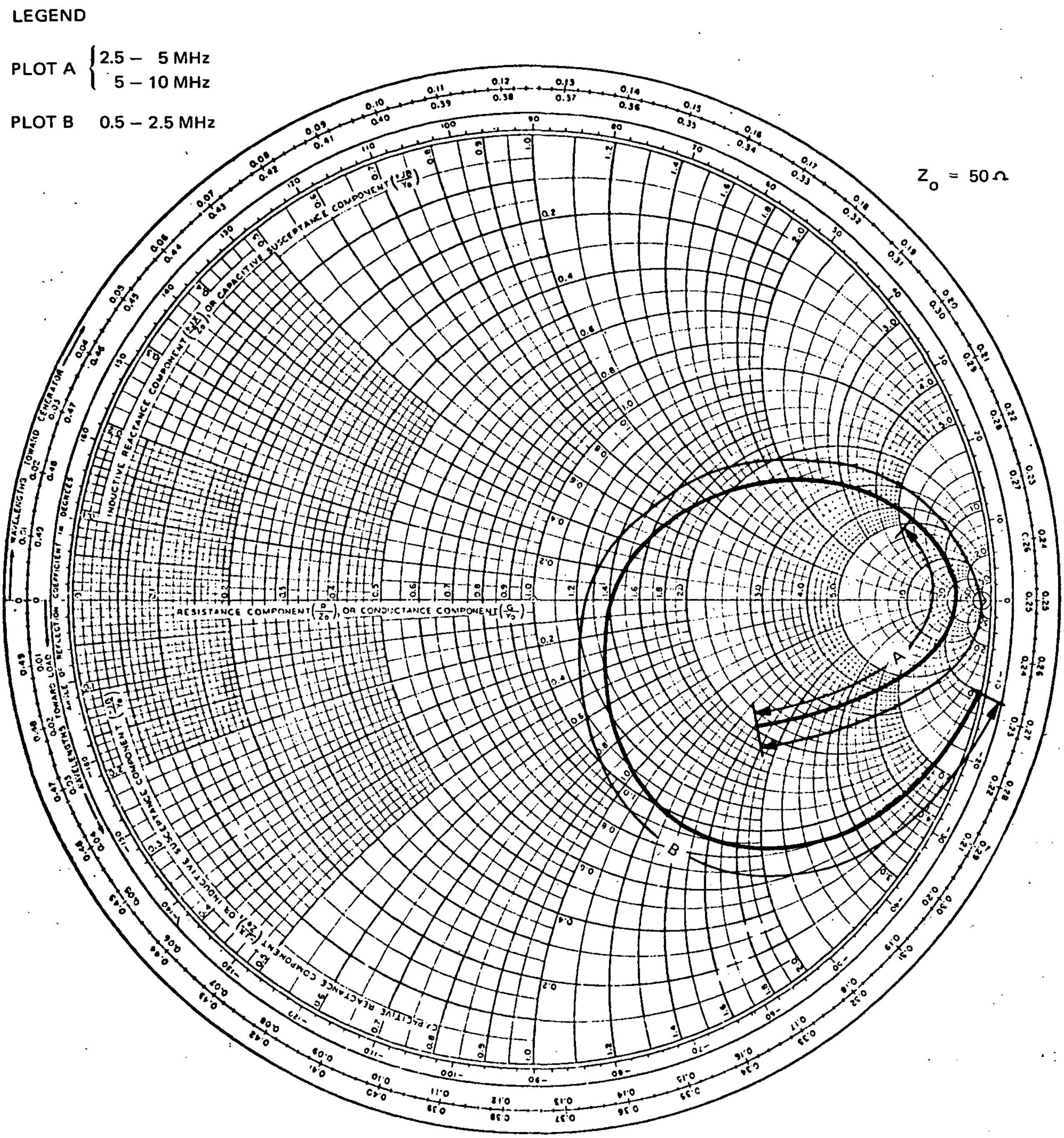


Figure 3-7. Impedance Coordinates

Table 3-7

CROSSED-H DIPOLE DIMENSIONS

Frequency (MHz)	Dipole Length (m)	Dipole Spacing (m)	L/λ	d/λ
0.5	150	30	1/4	1/20
2.5			5/4	1/4
2.5	75	15	5/8	1/8
5				
5	37.5	7.5	5/8	1/8
10			5/4	1/4

3.2.1.4 Utilization of Man

The normal deployment and operation mode of the Crossed-H Tethered Interferometer Radio Telescope (OASF Instrument No. 32) is automatic. However, yearly resupply of consumables is required, and EVA may be utilized for inspection, maintenance, repair, and updating of components.

Deployment

Neither man nor EVA is needed; deployment is automatic.

Alignment

No alignment is needed. If the antenna has been properly deployed, it will be in the proper configuration. Antenna dimensional accuracy is not critical.

Calibration

Standard radio objects are scanned; the receiver contains built-in standards.

Operation

Operation is automatic and preprogrammed. Observations are telemetered to an orbital support facility or directly to an Earth receiver. Manned activity near the antenna during its operation is undesirable because it might interfere with the observations.

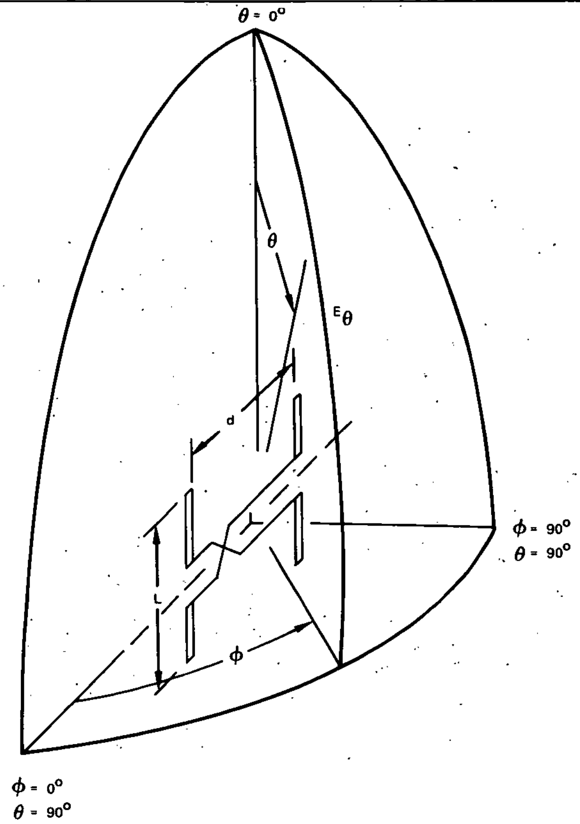
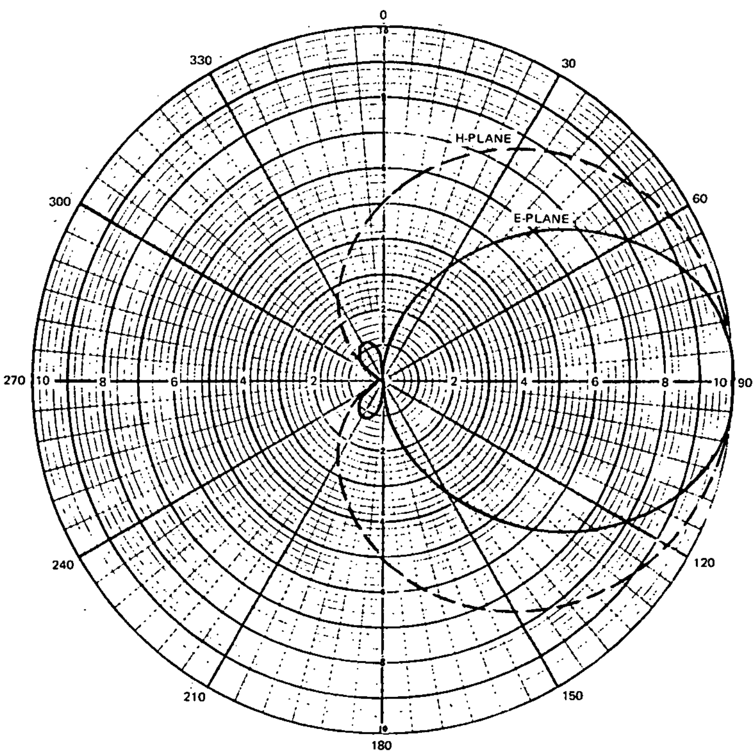
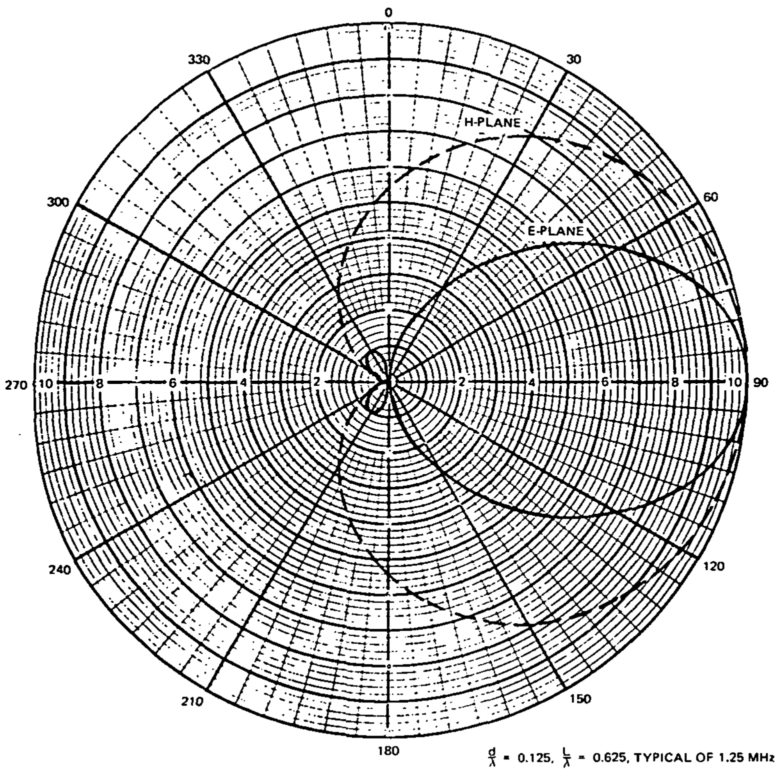


Figure 3-8. Dipole End-Fire Array, Coordinate System



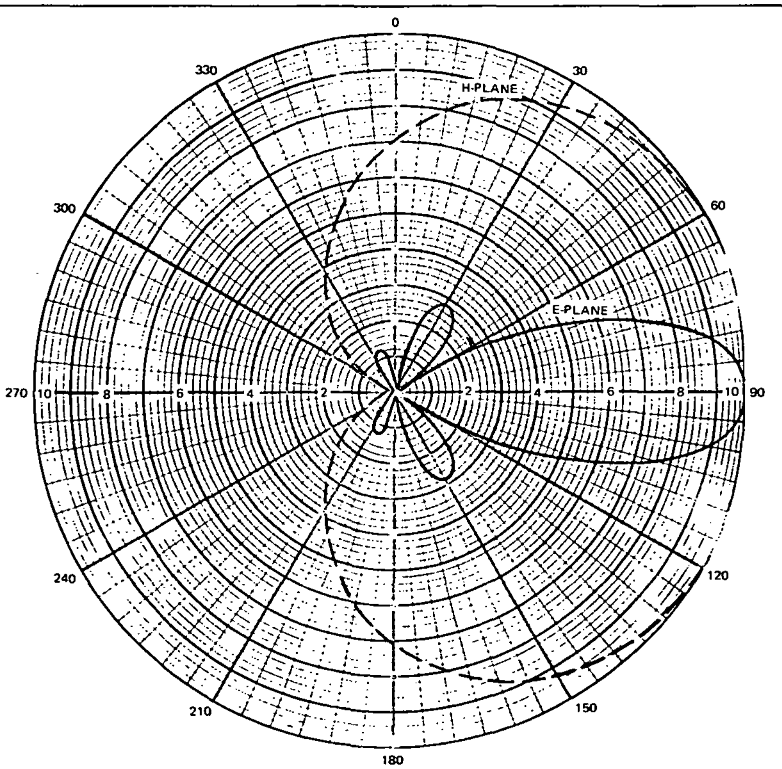
$\frac{d}{\lambda}$ = 0.05, $\frac{L}{\lambda}$ = 0.25, TYPICAL OF 0.5 MHz

Figure 3-9. Radiation Patterns of End-Fire Array



$\frac{d}{\lambda}$ = 0.125, $\frac{L}{\lambda}$ = 0.625, TYPICAL OF 1.25 MHz

Figure 3-10. Radiation Patterns of End-Fire Array



$\frac{d}{\lambda}$ = 0.25, $\frac{L}{\lambda}$ = 1.25, TYPICAL OF 2.5 MHz

Figure 3-11. Radiation Patterns of End-Fire Array

Scheduled Maintenance

One resupply of attitude-control gas per year, well before the supply is exhausted, is required. At the same time, EVA may be utilized not only to replace failed components, but also to make adjustments to restore the system to peak operating condition and to replace components suspected of impending failure. The scientific quality of the antenna and the receiving system can also be upgraded by the introduction of new, more-sophisticated electronic modules.

Unscheduled Maintenance

Because the instrument is operated in a high orbit (synchronous or higher) and is normally left unattended between annual resupply and maintenance events, unscheduled maintenance, if required, would be combined with resupply and normal maintenance. In case of a system breakdown, the resupply, repair, and maintenance described above under Scheduled Maintenance may be rescheduled for an earlier date.

(If stabilizing jets fail and an antenna is tumbling without control, it would be dangerous for an astronaut to approach and the antenna would probably be abandoned.)

3.2.1.5 Supporting Research and Technology

Supporting Research and Technology (SRT) requirements associated with the Crossed-H Tethered Interferometer (Instrument No. 32) are listed below. Full descriptions of SRT items are given in Section 4.3.

Research and Advance Technology

Investigate techniques for erection of large structures in space (SRT 53).

Advance Development

Assess materials for internal use to determine if rapid aging and breakdown are caused by internal atmosphere (SRT 82).

Assess materials for external use to evaluate (1) hard-vacuum effects on materials, finishes, etc., and (2) development of processing, handling, and assembly techniques (SRT 83).

3.2.1.6 Development Cost and Schedules

The Phase D cost is shown in Table 3-8, which shows both development and operations costs. The development schedule is shown in Figure 3-12. Quantities of equipment required in development are shown in Table 3-9.

3.2.1.7 Instrumentation Section

The following paragraphs discuss characteristics associated with the instrumentation contained in the instrumentation section.

Receiver

Receiver instrumentation used in conjunction with the crossed-H interferometer is shown in the simplified block diagram of Figure 3-13. The diagram shows a method of providing the phasing necessary to obtain the desired end-fire radiation patterns. Energy received at each dipole is amplified by a wide-band amplifier, then sent through band-pass filters that separate different portions of the spectrum for transmission through different circuits. This separation into narrow-frequency bands is necessary if good front-to-back ratios of reception are to be obtained throughout the frequency band with the end-fire arrays, because of the mutual impedance properties of the dipoles in the arrays. At each narrow-frequency band the end-fire phasing components insert the phase shift and magnitude transformations required for proper cardioid pattern shape.

As a single antenna, it is sufficient to note that the receiver will be capable of frequency and power resolution by the use of eight wide-band and three swept-frequency radiometry receivers.

Time-varying sources can be observed by making the two antenna configurations different so that two frequency bands may be observed simultaneously, because two satellites will be launched together.

Table 3-8

TASK COST ESTIMATE--PHASE D
Crossed-H Tethered Interferometer Radio Telescope
(OASF Instrument No. 32)
($ thousands)

Development total	26, 780		
Engineering		1, 980	
Detectors		*	
Collectors		1, 200	
Antenna array			1, 200
Guidance		1, 600	
Star tracker			600
Gas system			1, 000
Electronics			*
Housing		9, 000	
Structure			*
Deployment mech			1, 000
Power supply			8, 000
Experiment package		13, 000	
Tape recorders			400
Satellite to GRD communication system			600
Receivers			12, 000
Major hardware articles		*	
Mockup			*
Engineering model			*
Project verification model			*
Qualification model			*
Operations total	12, 375		
Flight instrument		8, 035	
Backup flight instrument		3, 215	
Engineering support		1, 125	
Phase D total	39, 155		

*Cost item not derived where overall estimate for instrument is not significantly affected.

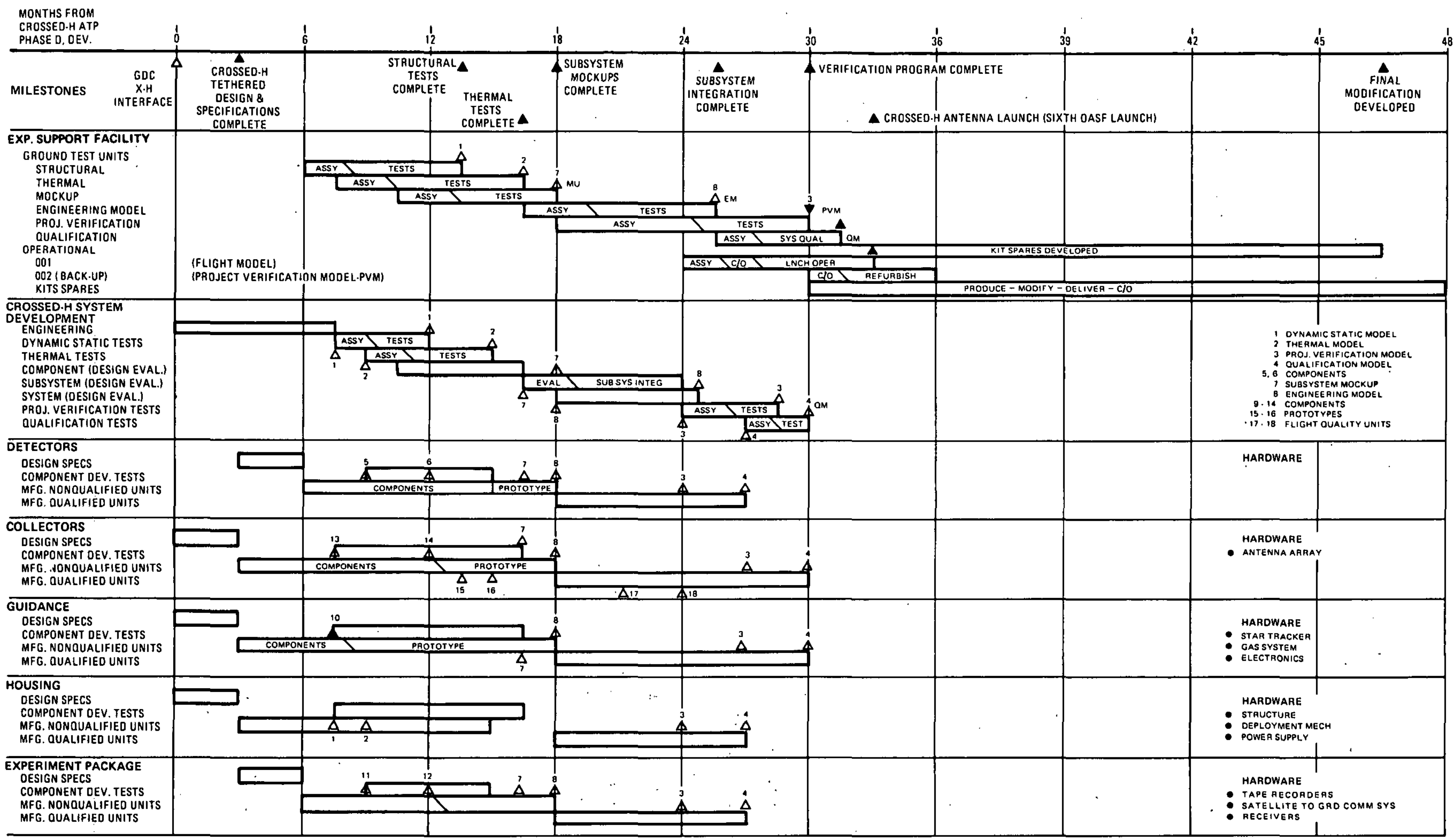


Figure 3-12. Development Schedule, Crossed-H Tethered Interferometer Radio Telescope (OASF Instrument No. 32)

Table 3-9

PRIMARY INSTRUMENT EQUIPMENT LIST--DEVELOPMENT PHASE D
Crossed-H Antenna Tethered Interferometer Radio Telescope
(OASF Instrument No. 32)

Functional System (Major Element)	Subsystem	Assemblies	Quantity		
			Bread-Board	Proto-type	Flight Quality
Crossed -H Tethered Interfer-ometer	Detectors	--	--	--	--
	Collectors	Antenna array	--	2	2
	Guidance	Star tracker Gas system Electronics	1 1 1	2 2 2	2 2 2
	Housing	Structure Deployment mech Power supply	-- -- --	1 1 1	2 2 2
	Experi-ment package	Tape recorders Satellite to grd comm sys Receivers	2 2 2	2 2 2	2 2 2
	Major hardware articles	Mockup Engineering model Project verification model Qualification model	1 -- -- --	-- 1 60%* --	-- -- 40%* 1

*Obtained from subsystem development quantities

It will be noted that the circuit is designed to provide a dual set of cardioid patterns simultaneously (through use of a dual hybrid and phasing network arrangement, if reception [and null] of each is in a direction opposite to that of the other). Thus, data from opposite hemispheres can be simultaneously obtained.

Band-pass filters also serve the function of limiting the spectral spread of any one set of observed data so that phase-shift techniques rather than more difficult transmission delay techniques can be used in the synthetic aperture correlation process. Filter pass-bandwidths on the order of 2 or 3 kHz appear to provide appropriate system performance.

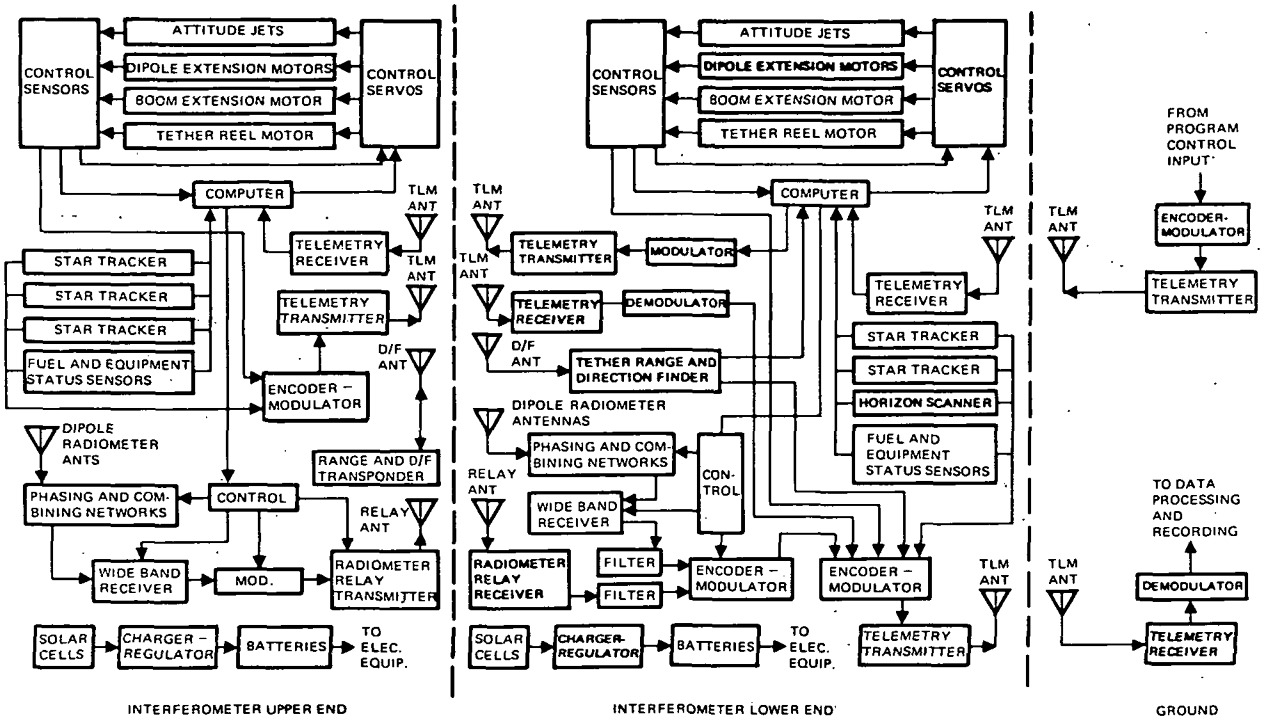


Figure 3-13. Simplified Equipment Block Diagram

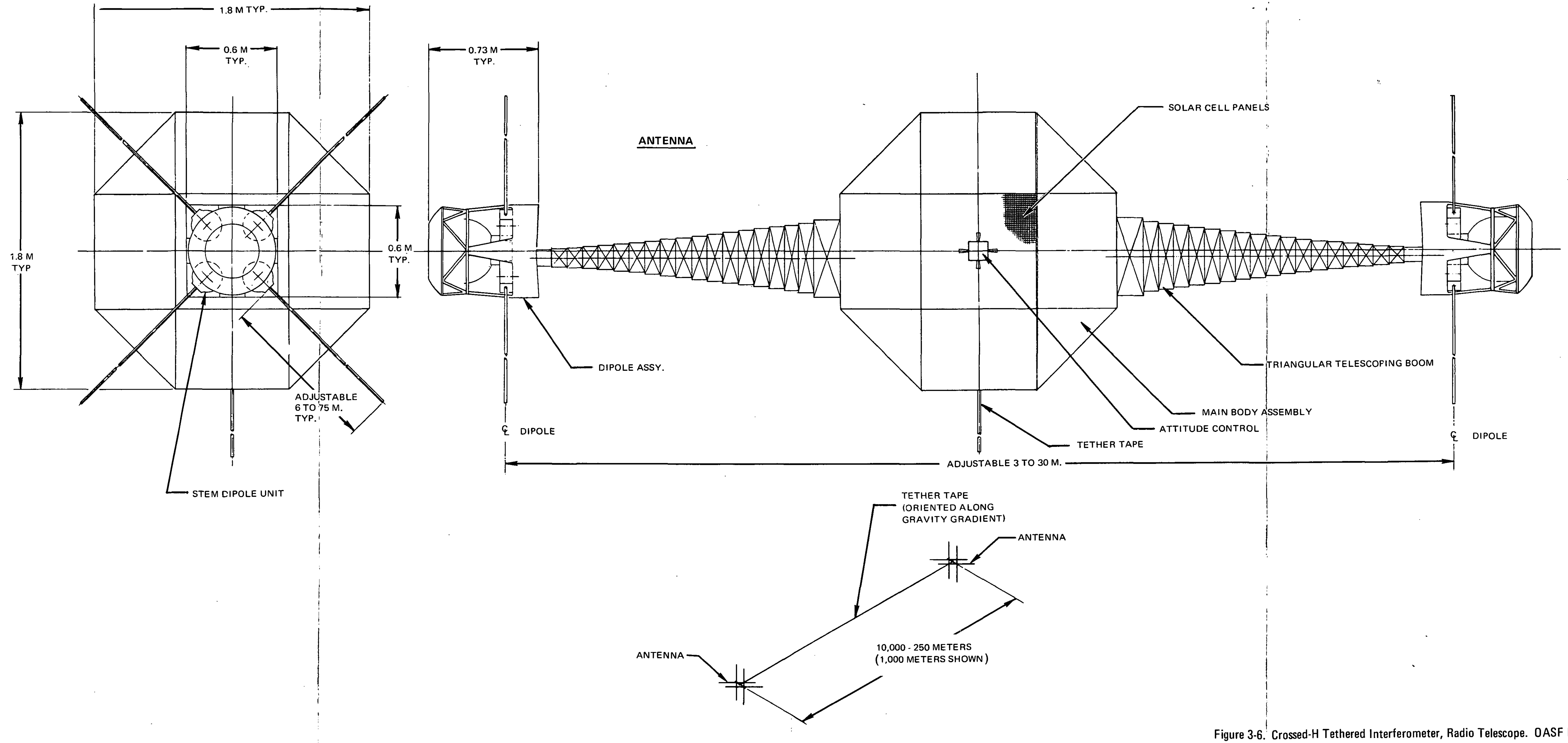


Figure 3-6. Crossed-H Tethered Interferometer, Radio Telescope. OASF Instrument No. 32

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3.2.2 Terminated-Loop Tethered Interferometer Radio Telescope - OASF Instrument No. 30

3.2.2.1 General Characteristics

This instrument concept consists of two terminated loop antenna modules connected by a tether of variable length (Figure 3-14). For ease of storage and deployment, the loop assumes a square configuration. Two adjacent legs of the loop can then be Storable Tubular Extendable Member (STEM) elements. Extending from the apex formed by these two legs, along a neutral axis between them, is a third STEM used to deploy the other two sides of the loop. These sides are conductive tapes stored on reels and automatically deploy with the STEMS. The deployment concept is represented in Figure 3-15. Each module would contain total power and swept frequency receivers and a variable antenna structure.

One module, the Base Module, would have for its antenna, two orthogonal-terminated-loops 107 ft (32.6 m) on the side which would be capable of operating from 50 kHz to 15 MHz with polarization determination capability. The other, the Remote Module, would be a smaller single- (linearly polarized) terminated-loop 42 feet (12.8 m) on a side. Together the tethered pair of antennas would act as an interferometer with an angular resolution of 1°.

Alignment of both antennas is augmented by the gravity gradient existing between them.

Electrical power and alignment pneumatic storage required to enable the module to remain in orbit for a year are reasonable. Weight of the two modules combined is estimated to be a maximum of 1,450 kg.

Distance measuring equipment such as a radio theodolite accurately measures the linear distance between both modules, and star trackers are used to accurately fix their angular orientation with respect to space. These data are used in the process of aperture synthesis.

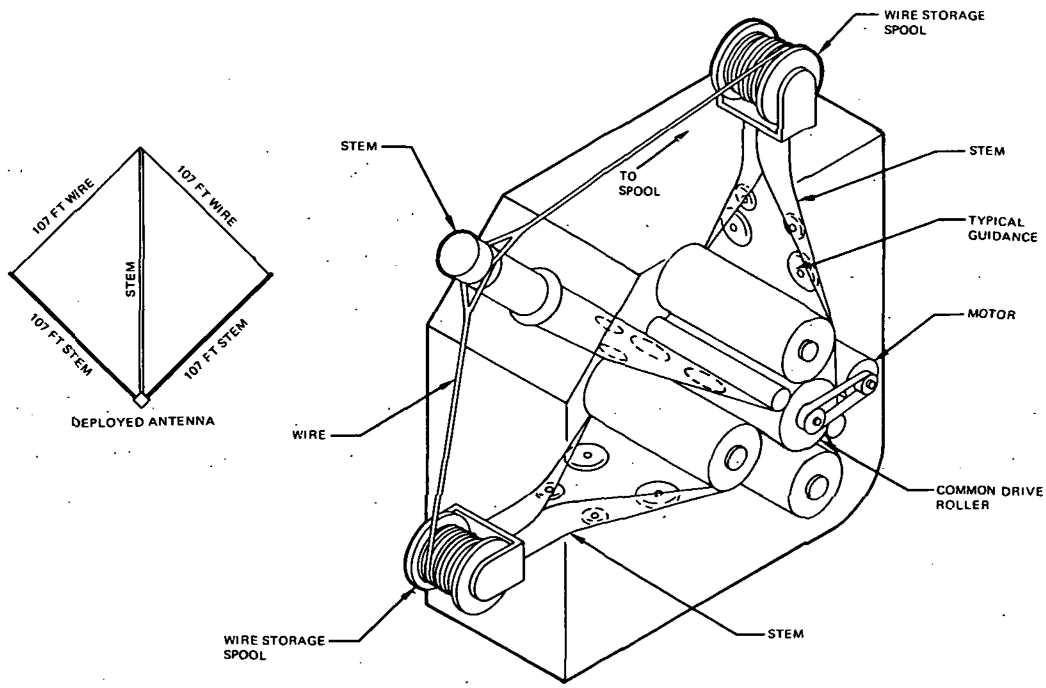

Figure 3-15. Deployment Concept Terminated Loop Antenna

Unique Features

Over the frequency range, its input impedance remains basically resistive. This is unlike the highly reactive impedance of electrically small lossless antennas and presents a smaller interface problem when combined with receiving equipment.

The radiation pattern remains essentially constant and directive without requiring complicated phasing circuitry.

Allowing for the low sensitivity that is tolerable at the brightness levels anticipated on the radio frequency range, the antenna can be extremely small relative to the lowest operating frequency wavelength.

Concept of a tethered-orthogonal-loop and small-plane-loop resulted directly from fitting an equipment capability to baseline research program specifications. Resulting equipment is regarded as having minimum weight and volume required for the task.

That multibeam techniques may be fully exploited, it is suggested that all radiometer data be transmitted to ground in a raw digitized state.

Predecessor Developments

Work that preceded the suggested tethered terminated loop is most significantly concentrated in the following programs:

1. TOI--Tethered Orbiting Interferometer.
2. Crossed-H Interferometer.

The terminated loop antenna concept has been known for over a decade and had been used in direction-finding applications.

3.2.2.2 Design Criteria

Specific criteria for this equipment are the Observation Requirements Data Sheet (ORDS) which are a compilation or research objectives as gathered from the scientific community by Douglas Aircraft Company.

They are briefly stated below:

1. Average Low Frequency Medium Frequency and High High Frequency (MF and LF) Radio Emission From The Galaxy.

   "Sky brightness" will be monitored by a radiometer. 1,500-, 600-, 300-, 150-, 60-, and 30-m bands will be observed with a bandwidth of 5% (or less).

2. Survey Low Frequency, Medium Frequency and High Frequency Sky Radiation.

   It is desired to scan the entire sky with 10° angular resolution for radio emission between 0.2 and 10 MHz. Bandwidth will be 5% or less of the observed frequency.

3. Survey Low Frequency, Medium Frequency, and High Frequency Discrete Sources.

   Discrete radio sources will be detected using a "radio telescope" having 1° angular resolution, and their spectra will be monitored in the range 0.2 to 10 MHz. Bandwidth will be less than 5% of the observed frequencies.

4. Obtain LF, MF, and HF Spectral and Polarization Measurements of the Solar Corona.

   Dynamic spectra of solar bursts in the frequency range 50 kHz to 15 MHz will be obtained by rapidly sweeping this range with a radiometer.

5. LF, MF, and HF Radio Observations of Jupiter.

Planet Jupiter will be monitored for radio emission in the 50 kHz to 15 MHz frequency range, principally to obtain dynamic spectra of its diameter and longer wavelength bursts. Electron density and temperature structure of Jovian trapped particle belts can be determined from this data.

Resolution

Angular resolution of the system is determined in along-track direction by the interferometer fringe lobes and in the cross-track direction by the antenna beamwidth of the synthesized aperture.

In the interferometer mode, the interference fringe lobe pattern is given by

$$\theta = 2 \sin^{-1} \left(\frac{\lambda}{2d}\right)$$

This can be approximated for small angles near broadside by

$$\theta \approx \frac{\lambda}{d}$$

where

λ = wavelength

d = Distance between the two antennas

θ = beamwidth between first nulls measured from broadside

The term θ represents twice the angular resolution of the interferometer and is plotted in Figure 3-16 as a function of baseline separation and frequency. Figure 3-16 also shows the time required to pass through the fringe lobe (or maximum time available to integrate the fringe lobe data).

Limit of Resolution

Maximum usable separation of the antenna elements will be governed by the ORDS requirements for resolution and effects of coronal scattering.

For observations in the quadrants in a direction opposite to that of the sun, scattering angle is

$$\phi_0 \text{ (opposition) } \approx \frac{\lambda^2}{R^2}$$

where

λ = wavelength in meters

R = distance to sun in solar radii

In vicinity of Earth, R = 215.

Table 3-10 summarizes order of magnitude of this effect, and also indicates maximum usable aperture. It can be seen that a resolution of about 1° is the limit set by coronal scattering at a wavelength of 600 m, and that the maximum usable aperture is about 34 km or about 17 nmi.

Design of the terminated loop is based on an analysis to determine the minimum sensitivity allowable. Resulting antenna efficiencies and scattering angles are shown in Tables 3-11 and 3-12.

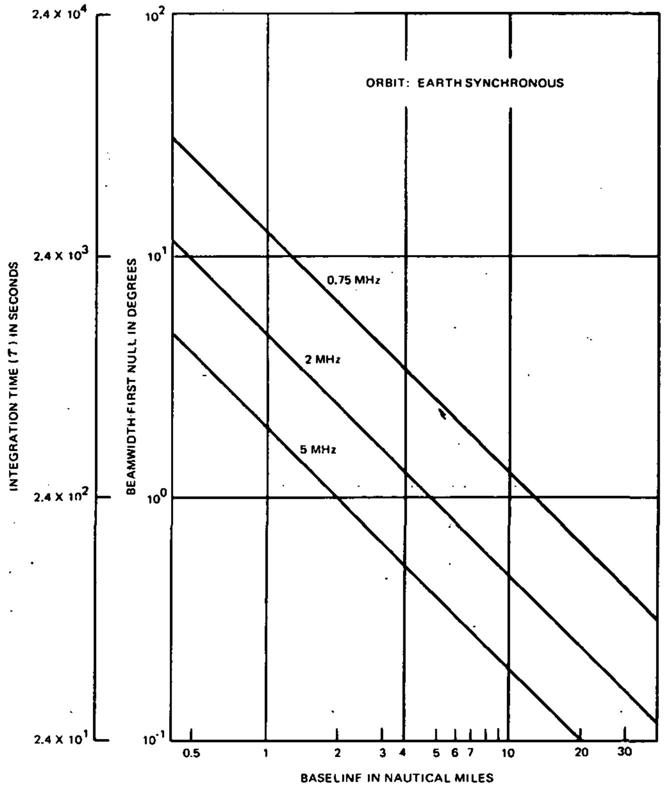

Figure 3-16. Beamwidth and Integration Time per Fringe Lobe

Table 3-10

COLLECTOR PARAMETERS
Terminated-Loop Tethered Interferometer Radio Telescope
OASF Instrument No. 30

Aperture	40 km
Total field of view	$132^o \times 90^o$
Angular resolution	
On axis	1^o at 1,000 m
Poorest in field of view	5^o at 1,000 m
Minimum wavelength	20 m
Maximum wavelength	6,000 m

Table 3-11

MINIMUM ALLOWABLE ANTENNA EFFICIENCIES

Frequency (MHz)	Efficiency (dB)
15	-14
10	-16
0.85	-39
0.2	-51
0.05	-63

Table 3-12

SCATTERING ANGLES

λ (m)	ϕ_0 (opposition)	Maximum Usable Aperature (km)
30	14 in.	430
100	2.7 ft	130
300	24 ft	43
1,000	4.5^o	13

3.2.2.3 Detailed Characteristics

Basic characteristics have been summarized in Figure 3-1. Additional instrument details are tabulated in Tables 3-10 and 3-13. Results are conservative because an istropic antenna and a 10 dBa background level is assumed.

Impedance Consideration

A terminated loop can be designed to have an equivalent circuit equal to a radiation resistance in series with a terminating resistor.

At the low end of the bank where the loop is extremely small in terms of wavelengths, the terminating resistor (numerically equal to the receiver input impedance) is much greater than the radiation resistance. Therefore, though the antenna is lossy, the receiver and antenna are virtually matched.

At the highest operating frequency the loop perimeter should not exceed one wavelength. Thus the maximum loop area is equal to $\frac{\lambda^2}{16}$ for a square loop with a length of a side equal to $\frac{\lambda}{4}$.

Applying the fomula for radiation resistance of a small loop:

$$R = 320\,\pi^4 \left(\frac{A}{\lambda^2}\right)^2$$

where

R = Loop radiation resistance
A = Loop Area
λ = Wavelength

the loop is found to have a radiation resistance of 122 ohms and mismatch to a 50-ohm receiver is about 3.5:1.

Antenna Dimension

Considering the design criteria discussed above, antenna efficiency at the lowest frequency should be at least minus 63 dB. This indicates a required loop area of 1,040 m^2 or a square loop side dimension of 31.7 m or 107 ft.

Table 3-13

INTERFACE CHARACTERISTICS
Terminated-Loop Tethered-Interferometer
Radio Telescope--OASF Instrument No. 30

General	
System weight (less expendables)	1,450 kg
System volume (launch configuration)	2 ft^3
System shape (launch configuration)	Two, 2/3 m diam x 2 m long cylinders with STEM elements retracted and attitude control tanks external.
Method of accomplishing . . .	
Deployment	Extension of STEM Loop elements
Alignment	Gravity gradient and pneumatic
Calibration	Calibrated noise source
Operation	Remote
Experiment change	Ground-activated
Stowage requirements (launch)	
Mechanical	Plastic bag protective cover
Electrical	None
Experiment data handling	
Format	Analog rf converted to digital
Processing	Raw transmission to ground based computer
Recording media	Tape, raw data transmitted to ground
Mode of data recovery	Ground-based S-band receiver
Pointing requirements	
Pointing accuracy (acquisition)	5° (angle)
Power consumption	
Stowed	--
Standby	260 W
Operate	800 W

At the highest frequency of 15 MHz, the loop perimeter exceeds one wavelength. This can be compensated for by adding a capacitively coupled smaller loop at the apex of the larger loop as shown schematically in Figure 3-17. The smaller loop should become effective at approximately 2 MHz where the circumference of the 107-ft equals one wavelength.

The above procedure can be applied to the smaller frequency range required (0.2 MHz to 10 MHz) where an efficiency of -51 dB at 0.2 MHz is expected. Resulting loop edge dimension is 42 ft. Here the loop exceeds a wavelength at approximately 8 MHz where the high frequency section should cross over.

Referring to the coordinate system represented in Figure 3-18, the terminated loops normalized radiation pattern is expressed as

$$E_\phi = jL \left\{ \Sigma K_q^1 \cos (q+1)_\phi (-1)^{q+\frac{1}{2}} \left(\sin p\frac{A\pi}{2} \right) + \Sigma K_s^1 \cos (s+1)_\phi (-1)^{s+\frac{1}{2}} - \frac{J_1 K}{p^2 A^2} \sin p \frac{A\pi}{2} \right\}$$

where

A = Loop circumference in wavelengths

L = Normalizing constant

c = Velocity of radiation in space

v = Velocity of radiation along the loop

$p = \frac{c}{v}$

$k = A \sin \theta$

s = Any positive even integer including 0, and q = any positive odd integer

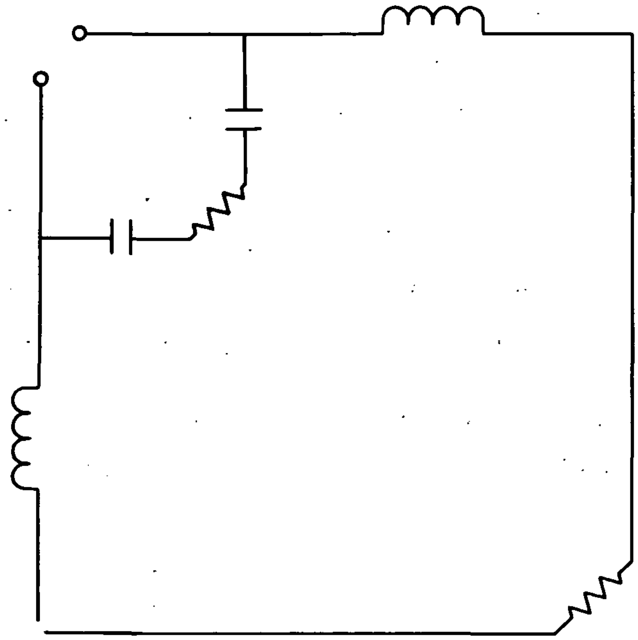

Figure 3-17. Schematic Representation of High Frequency Loop Within Larger Loop

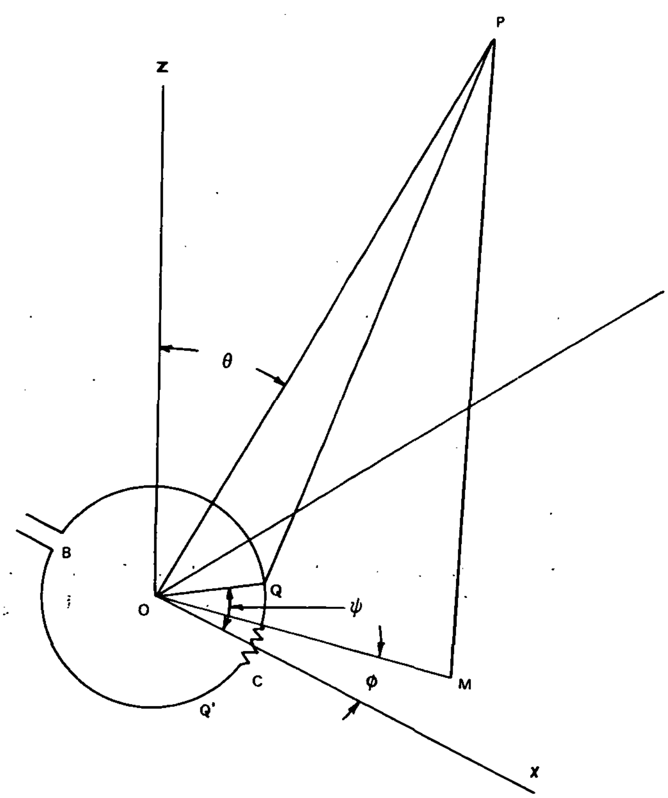

Figure 3-18. Coordinate System used in Radiation Pattern

$J_1(k)$, $J_q(k)$, $J_s(k)$, etc., are Bessel Function of the first kind

$$k_q = \frac{J_q(k) + J_{q+2}(k)}{p^2 A^2 - (q+1)^2}$$

$$k_s = \frac{J_s(k) + J_{s+2}(k)}{p^2 A^2 - (s+1)^2}$$

$$k_p^1 = \frac{J_q(k) - J_{q+2}(k)}{p^2 A^2 - (s+1)^2}$$

$$k_s^1 = \frac{J_s(k) - J_{s+2}(k)}{p^2 A^2 - (q+1)^2}$$

Figure 3-19 depicts E plane radiation patterns computed from the above formula.

It can be seen that the pattern remains relatively constant and directive even when the loop is extremely small in terms of wavelength. One of the major advantages of the terminated loop is that it remains this way without using a frequency dependent phasing network.

Basic characteristics have been summarized in Figure 3-1.

3.2.2.4 Utilization of Man

The normal deployment and operation mode of the Terminated-Loop Tethered Interferometer Radio Telescope (OASF Instrument No. 30) is automatic. However, yearly resupply of consumables is required, and EVA may be utilized for inspection, maintenance, repair, and updating of components.

<u>Deployment</u>

Neither men nor EVA is needed; deployment is automatic.

<u>Alignment</u>

No alignment is needed. If the antenna has been properly deployed it will be in the proper configuration. Antenna dimensional accuracy is not critical.

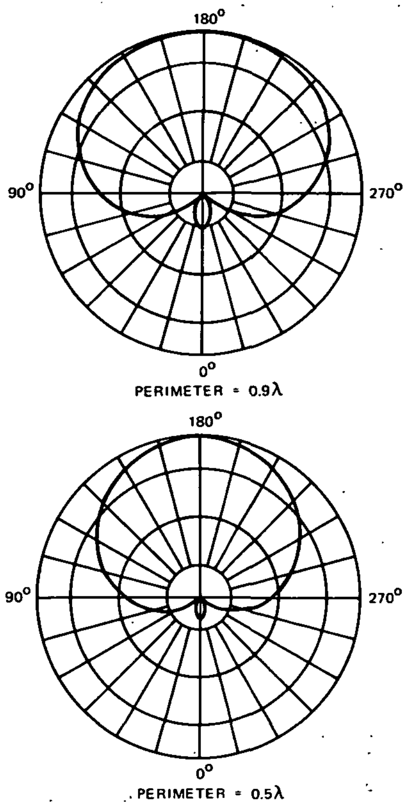

Figure 3-19. E Plane Radiation Pattern

Calibration

Standard radio objects are scanned; the receiver also contains built-in standards.

Operation

Operation is automatic and preprogrammed. Observations are telemetered to an orbital support facility or directly to an Earth receiver. Manned activity near the antenna during its operation is undesirable because it might interfere with the observations.

Scheduled Maintenance

One resupply of attitude-control gas per year, well before the supply is exhausted, is required. At the same time, EVA may be utilized not only to replace failed components, but also to make adjustments to restore the system to peak operating condition and to replace components suspected of impending failure. The scientific quality of the antenna and the receiving system can also be upgraded by the introduction of new, more-sophisticated electronic modules.

Unscheduled Maintenance

Because the instrument is operated in a high orbit (synchronous or higher) and is normally left unattended between annual resupply and maintenance events, unscheduled maintenance, if required, would be combined with resupply and normal maintenance. In case of a system breakdown, the resupply, repair, and maintenance described above under Scheduled Maintenance may be rescheduled for an earlier date.

(If stabilizing jets fail and an antenna is tumbling without control, it would be dangerous for an astronaut to approach and the antenna would probably be abandoned.)

3.2.2.5 Supporting Research and Technology

Supporting Research and Technology (SRT) requirements associated with the Terminated Loop Tethered Interferometer (Instrument No. 30) are listed below. Full description of SRT items are given in Section 4.3.

Research and Advance Technology

Investigate techniques for erection of large structures in space (SRT 53).

Advance Development

Assess materials for internal use to determine if rapid aging and breakdown are caused by internal atmosphere (SRT 82).

Assess materials for external use to evaluate (1) hard vacuum effects on materials, finishes, etc., and (2) development of processing, handling, and assembly techniques (SRT 83).

3.2.2.6 Development Cost and Schedules

The Phase D cost is shown in Table 3-14, which shows both development and operations costs. The development schedule is shown in Figure 3-20. Quantities of equipment required in development are shown in Table 3-15.

Table 3-14

TASK COST ESTIMATE--PHASE D
Terminated-Loop Tethered Interferometer
Radio Telescope (OASF Instrument No. 30)
($ thousands)

Development total	23,600		
Engineering		1,750	
Detectors		*	
Collectors		1,250	
(2) Antenna arrays (107 ft and 42 ft)			1,250
Guidance		1,600	
(2) Star trackers			600
(2) Gas systems			1,000
(2) Electronics			*
Housing		10,000	
Structure			*
(2) Deployment mech			2,000
(2) Tether system			*
(2) Power system			8,000
Experiment package		9,000	
(4) Tape recorders			400
(2) Satellite to GRD comm system			600
(2) Receivers			8,000
Operations total	10,908		
Flight Instrument		7,080	
Backup flight instrument		2,835	
Engineering support		993	
Phase D total	34,508		

*Cost item not derived where overall estimate for instrument is not significantly affected.

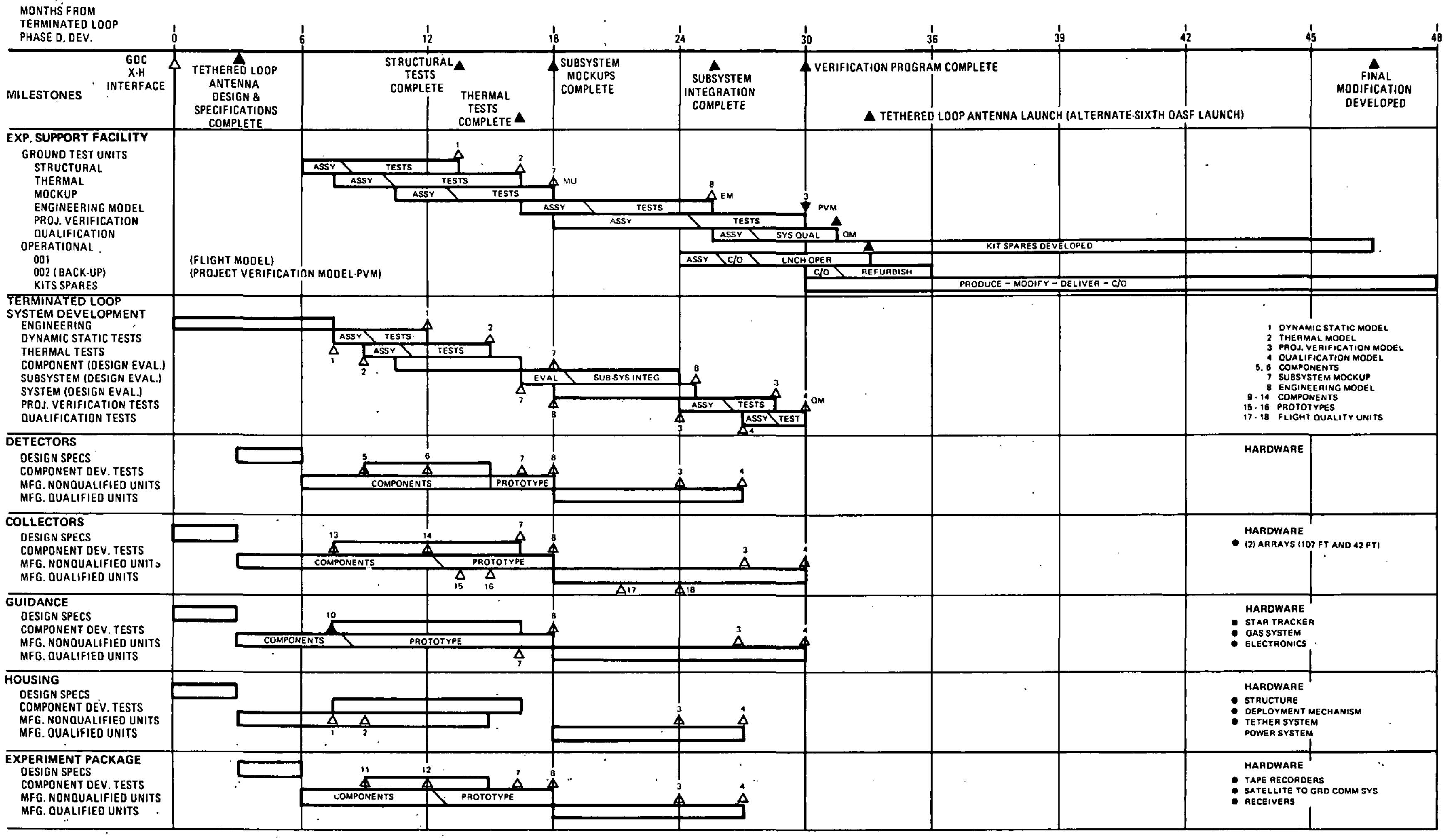

Figure 3-20. Development Schedule, Terminated-Loop Tethered Interferometer Radio Telescope (OASF Instrument No. 30)

Table 3-15

PRIMARY INSTRUMENT EQUIPMENT LIST--DEVELOPMENT PHASE D
(Terminated-Loop Tethered-Interferometer Radio Telescope
OASF Instrument No. 30)

Functional System (Major Element)	Subsystem	Assemblies	Quantity		
			Bread-Board	Proto-Type	Flight Quality
Terminated loop tethered interferometer	Detectors	---	---	---	---
	Collectors	(2) Antenna arrays (107 ft and 42 ft)	2	2	2
	Guidance	Star tracker	1	2	2
		Gas system	1	2	2
		Electronics	1	2	2
	Housing	Structure	---	1	2
		Deployment mech	---	1	2
		Tether system	---	1	2
		Power system	---	1	2
	Experiment package	Tape recorders	2	2	2
		Satellite to GRD comm sys	2	2	2
		Receivers	2	2	2
	Major hardware articles	Mockup	1	---	---
		Engineering model	---	1	---
		Project verification model	---	60%*	40%*
		Qualification model	---	---	1

*Obtained from subsystem development quantities.

3.2.2.7 Instrumentation Section

The following paragraph contains characteristics associated with the instrumentation section.

Radiometer Design Criteria

Operating frequency range, which extends from 50 kHz to 15 MHz, is a range in which electronic components have been most highly developed. In addition, the operating environment can be controlled, and there is a store of knowledge that relates to the survival of solid-state components over the range of environment to be encountered during the non-operating condition to guide selection of components. Thus, whether instrumentation requirements indicate an extension in the capability of existing hardware, or new conceptual design there is a complete confidence in their realizability.

Receiver Design Criteria

Temperature resolution (ΔT) of a radiometry receiver can be written as

$$\frac{\Delta T}{T_a} = \frac{K}{\sqrt{B_\tau}}$$

The equation indicates that resolution of the system can be improved by increasing either predetection bandwidth (B) or postdetection time constant (τ); predetection bandwidth will be determined by the frequency resolution required and postdetection time constant will be determined by observation time allowed.

To satisfy all radiometer requirements a compromise cannot be made between temperature and frequency resolution. The logical choice then, is a receiving system with a wideband front end which, after preamplification, splits the power to frequency discriminator and power detection circuits.

Receiver Detailed Characteristics

Measurement requirements indicate that both swept and fixed channel receivers are to be used so that measurements of a dynamic event can be made. Thus it is anticipated that the entire frequency range must be covered nearly instantaneously.

Electronics are block diagrammed in Figure 3-21. One sweeping receiver and 40 fixed tuned receivers are used at the 107-ft antenna.

Output at the antenna terminals will be distributed by a broadband multicoupler, which will provide inputs to the sweeping receiver and the 40 fixed channels. The sweeping receiver and fixed channels are total power radiometers. Calibration signals will be provided at regular intervals and upon command derived from recognition circuits.

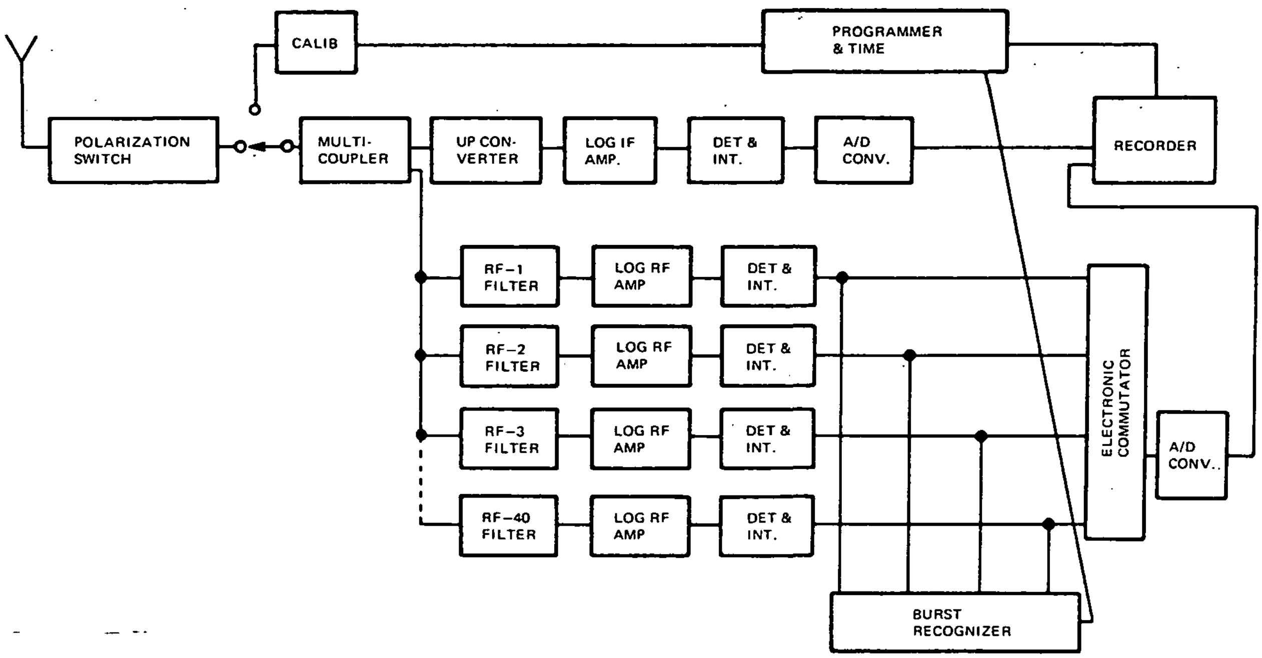

Figure 3-21. Block Diagram of Radiometer

The sweeping receiver will be provided with a digitally tuned signal derived from a crystal-controlled frequency synthesizer, to eliminate the need for special frequency calibration. The synthesizer will sweep each band in about 30 steps within 2 sec. Analog output of the log IF and log rf amplifiers will be converted to a digital number and recorded. Fixed channels can be manually tuned to spot channels away from rf interference. Bandwidth of each fixed channel will be 5% of its tuned frequency and the gain of each channel will be approximately compensated. Bandwidth of the log IF amplifiers in each sweeping receiver will be 5% of the geometric mean of band frequency limits. Thus, bandwidths will be 5, 20, 80 and 350 kHz.

Logarithmic amplifiers of the sweeping receiver (log IF) and fixed channel receiver (log rf) should cover a 50-dB dynamic range. Output of the fixed channel receivers, which when dc coupled to an integrator, will provide variable (in the range of 0.001 to 1 sec) integration time constants for fixed channels. Output of the sweeping receiver log IF amplifier will be integrated over a 50 msec period with an integration time constant of 10 msec. Power resolution of the sweeping receivers will therefore be about 2% and 14% for high and low bands respectively. Power resolution of the fixed channels will vary accordingly to the setting of the integrator time constant and bandwidth of the channel being monitored.

Output of the fixed channels is used for burst recognition as well as for burst analysis. Accordingly output of each fixed channel will be connected to burst recognition circuitry, as well as an electronic commutator whose output can be digitized and stored on tape or transmitted to ground.

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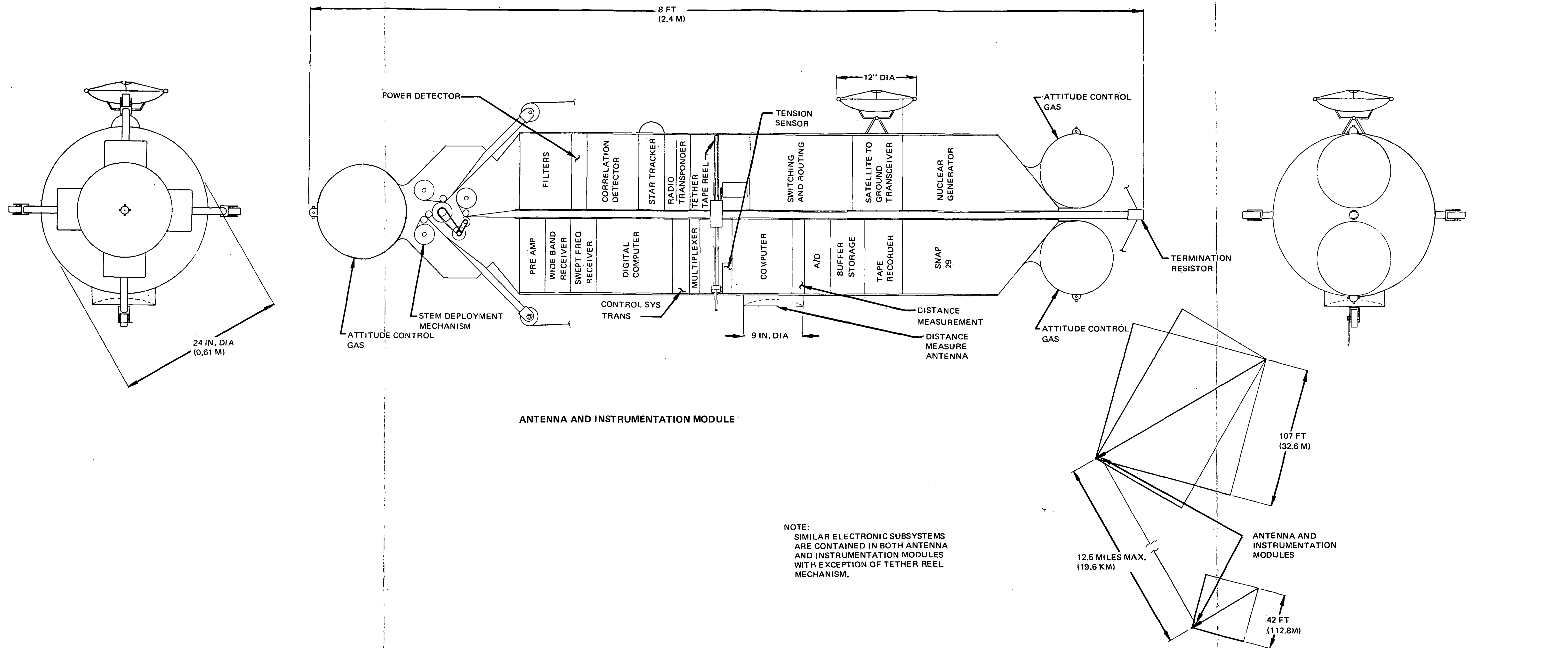

Figure 3-14. Terminated-Loop Tethered Interferometer, Radio Telescope. OASF Instrument No. 30

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3.2.3 Kilometer Wave Orbiting Telescope (KWOT)--OASF Instrument No. 41

3.2.3.1 General Characteristics

The KWOT Structure (Figure 3-22) resembles a rhombus, for example, a parallelogram with equal sides. A cross-member is coincident with the minor diagonal of the rhombus and extends beyond it in both directions. The major diagonal of the rhombic configuration, and the cross-member based on the minor diagonal, are each 10 km long. The four sides of the rhombic configuration are conductors and constitute the rhombic antenna. Mounted along the cross-member, on the portions outside the rhombus, are conducting sections that act as dipole elements of the interferometer array. Four identical 100-lb subsatellites (A, B, C, and D in Figure 3-22) are attached to the two acute vertices of the rhombic antenna and to each end of the cross-member. The subsatellites contain solar cells, radio receivers, short-range telemetry transmitters, and navigational radio beacons. Each subsatellite also contains 16 identical radio-controlled low-thrust microrockets pointed outward in six directions. These microrockets enable the subsatellites to control the shape and orientation of the structure. Signals from the rhombic antenna and/or the dipole elements are collected by the (unmanned) "central observatory." The central observatory contains the basic electronic instrumentation for the radio astronomy observations as well as communications equipment for relaying data to other orbiting vehicles or to ground stations. The final stage of the KWOT launch vehicle is in a synchronous orbit related to that of the KWOT and contains instrumentation for attitude control through the subsatellites, for data processing, and for communication relay between the central observatory and ground stations.

Several weeks may be required to deploy KWOT after it is launched into orbit. As the system is slowly rotated, the spin axis is slowly precessed. Thus the entire sky can be scanned in less than a year.

Unique features of KWOT are:

1. Relatively large frequency range capability.
2. Versatility.
3. Small launch package compared to deployed system.

3.2.3.2 Predecessor Instrument Developments

The rhombic antenna has been used extensively since 1931. A modest level of effort on KWOT has been under way since the latter part of 1964. A presentation on large structures in space (which dealt primarily with the KWOT concept) was made to the President's Scientific Advisory Subcommittee on Space Science in August 1965. The Woods Hole Summer Study Group of the National Academy of Sciences recommended that further study be made on such structures. The most recent study was initiated in November 1965 under a NASA grant. The first phase of an engineering feasibility study of KWOT was completed by the University of Michigan Radio Observatory in October 1966 (Reference 2-1).

Although the rhombic antenna has been used extensively since 1931, and many papers have been written on various parameters of the rhombic, some areas that are of interest to space applications have not yet been considered. One important effect that has not been studied is the change in the rhombic pattern because of the use of thin, lightweight conductors. This factor is of interest because the weight requirements of the system necessitate the utilization of lightweight conductors.

Studies concerned with obtaining a useful approximate analytic solution for the current distribution on a long, straight, perfectly conducting wire have only recently yielded results (References 3-1 through 3-3). There have also been contributions in the determination of current distribution on straight lossy conductors, but those published to date have not covered all of the important physical aspects of the problem.

Work to date has shown that in general the length of each wire on modified rhombic antennas must be greater by approximately one wavelength than the direct distance between the two verticles of the antenna. This property should allow one to extend the frequency range of the antenna by varying the vertex spacing. Some general results concerning the reduction of sidelobe levels have been obtained by suitable spatial tapering.

3.2.3.3 Design Criteria

The following criteria have been applied to KWOT:

1. Life Time--minimum of 1 year desired.
2. Orbit Altitude--minimum of synchronous.
3. Effective Beamwidth--80°.
4. Pointing Accuracy--0.1°.
5. Bandwidth--0.1 MHz to 10 MHz with emphasis on lower half.
6. Spectral Resolution--a few percent for the lower bandwidth spectrum.

3.2.3.4 KOWT Subsystem Requirements

Attitude Subsystem

The primary importance of measuring and controlling subsatellite attitudes is to assure that the thrust vector is aligned in the proper direction. Any spurious velocity adds to other sources of spurious velocity components, increasing the net velocity error, and hence shortening the time interval between velocity corrections. If this spurious velocity component is no more than 10% of the desired change in velocity, it should not materially degrade the position control. This standard will be achieved if the direction of the applied thrust is controlled with an accuracy of $\pm 5^{\circ}$. Attitude of the subsatellite when thrusters are fired must be known to within $\pm 5^{\circ}$.

Position Subsystem

The primary importance of measuring and controlling positions of the remote units is to maintain proper configuration of the antenna elements (the rhombic, and the dipoles which make up the interferometer). Early studies of electrical properties indicate that positions of each antenna elements should be maintained within an accuracy of ±50 m, with respect to a common frame of reference. To control position with this accuracy, it should be possible to measure it with still more accuracy, perhaps ±5 m.

If the positions of the subsatellites are sensed by radar or an optical device, the accuracy requirement of ±5 m implies a range accuracy of ±5 m at 5 km, or ±0.1%, and an angular accuracy of 0.001 rad, or 0.058° (3.44 arc-min).

Pointing Subsystem

Beam position must ultimately be determined with an error which is a small fraction of the smallest dimension of the narrowest beam that can be anticipated, or about $\pm 0.1^{\circ}$. About half of this error has been assigned to the position measuring subsystem; about $\pm 0.05^{\circ}$ can be allowed in the pointing subsystem.

Implementation of the pointing subsystem may be based upon measuring apparent positions of any two celestial bodies whose actual positions with respect to KWOT are known.

Communications Subsystem

The communications subsystem consists of internal data links between the various units of KWOT, and external data links between the KWOT central observatory and the ground stations. Each link carries different types of data, and hence has its own specifications. There are no communications direct from subsatellite to subsatellite, or from subsatellite to ground.

All KWOT units generate basic status information, such as temperatures, and solar cell and battery parameters.

The dipole elements generate scientific information, which must be relayed to the central observatory along with the basic status information. An information bandwidth of 2 to 10 MHz is required for each dipole unit with the information carried in analog form, probably amplitude modulation. Dipole units receive no command and control information, except possibly for simple on-off signals.

The Scientific Maneuvering Subsatellites generate scientific information and basic status information, similar to that generated in the dipole units. In addition, they generate attitude information and status information concerning the attitude control and propulsion systems. They must accept command and control signals to control the thrusters and possibly the attitude sensors. The interferometer subsatellites hold no scientific information, but otherwise have the same requirements as the rhombic subsatellites.

The central observatory receives all scientific information from the subsatellites and the dipole units in broadband analog form, processes it, converting it to narrow-band digital form, and relays it to the ground, directly or via satellite relay. In addition, it receives commands from the ground and status information from the subsatellites and generates command and control signals to the subsatellites and relays the status information to ground.

Command and Control Subsystem

Command and control subsystem accepts inputs in the form of commands from the ground, error signals from attitudes and position-sensing subsystems, signals from the pointing system, and status signals from various subsatellites. From this information, it generates control signals to the thrusters throughout the configuration, so that the proper attitude and position of each body is maintained, and the antenna beam is pointed and moved as commanded from the ground. This task requires sufficient precision that digital techniques are indicated, and is of sufficient magnitude and complexity that services of a general-purpose, stored-program digital computer on board the spacecraft are probably required. This computer will be shared with the data subsystem.

Backup control loops of a simple analog nature should also be provided, to be switched in the event of computer failure. These analog control loops could control the attitude, position, and pointing with sufficient accuracy to permit continued operation of the system in the basic scanning modes, but at the cost of a much more rapid consumption of thruster fuel, and hence a shorter useful life for the system.

Data Subsystem

The basic function of the data subsystem is the processing of all data collected in KWOT system, including scientific, housekeeping, status, attitude, position and pointing data. The data subsystem must prepare information for transmission to ground, and for the use of the command and control subsystem.

Scientific information, as it is presented to the data subsystem, would consist of several analog voltage signals, perhaps 10, representing the output of several radiometers. The data subsystem must sample some or all of these channels according to a sequence which is specified by ground command, convert these values to digital numbers, store and encode them for transmission to earth. Very likely it would also be called upon to perform some numeric processing upon this information, also under control of ground commands.

Status and housekeeping information would be handled in the data subsystem in a number of ways. First, certain key parameters will be tested to detect conditions which present a hazard to the system. Out-of-limit temperatures or power-supply voltages would be in this category. Any condition that might lead to a runaway condition in the control system should also be monitored closely. Such conditions might include malfunction of the thruster valves in any subsatellites, or noise in the transmission of the control signals.

Second, enough status and housekeeping information must be sent to the ground to permit performance of all KWOT subsystems to be monitored, including the data subsystem.

Third, some of the status and housekeeping information will be analyzed in the on-board computer, and the computer will modify the mode of operation of various subsystems to adopt to changing conditions, either internal or external. For example, if it is found that the present mode of operation is depleting the charge on the batteries, the system might change to a mode that will use less current until the charge is built up again.

Radio Astronomy Instrumentation

The radio astronomy subsystem consists of preamplifier and relay units located in the dipole units and rhombic subsatellites and radiometer units located in the central observatory.

The preamplifier and relay units amplify radio-frequency signals appearing at the terminals of the antenna elements, both dipoles and rhombic, and transform them to a high frequency for transmission to the central observatory. The simplest implementation would be a broad-band preamplifier, covering the entire range over which KWOT is to operate (perhaps

0.1 MHz to 10 MHz). The transmitters, receivers, and antennas for relaying the radio astronomy information from the dipole units and rhombic subsatellites to the central observatory are included in the communications system.

The facilitiy for combining signals from various antenna elements is located in the central observatory. After the broad-band signal from each element is recovered by demodulation of the signals relayed to the central observatory, and the particular frequency bands upon which KWOT is operating at the moment are selected by filters, these signals must be combined to synthesize two or more beams. The phase of each dipole signal must be corrected for the propagation delay introduced in transmission from the subsatellite to the central observatory, and then all dipole signals are linearly mixed to synthesize the interferometer signal. The interferometer signal is then correlated independently with each of the two rhombic signals to synthesize two narrow beams, one pointing in each direction along the major axis of the rhombic.

Internal noise calibration is required, and it is desirable to switch one or more noise sources periodically into the signal path.

3.2.3.5 Detailed Characteristics

KWOT consists of a rhombic antenna with a "central observatory" and an array of dipoles forming an interferometer along extensions of the minor diagonal of the rhombus. The KWOT coordinate system is shown in Figure 3-23. The units of the system are (see also Figure 3-22):

1. The central observatory (Figure 3-24).
2. Two scientific maneuvering subsatellites, at each acute apex of the rhombus (Figure 3-25).
3. Two scientific maneuvering subsatellites, one at each end of the extensions of the minor axis of the rhombus (Figure 3-25).
4. Six dipole units, one for each dipole element of the interferometer array.

The deployment sequence of the system is shown in Figure 3-26. Weights and volumes are shown in Table 3-16. KWOT parameters are presented in Table 3-17. Additional details about the instrument are provided in Tables 3-18 and 3-19.

Table 3-16

KWOT WEIGHT AND SIZE
(OASF Instrument No. 41)

Equipment Item	Weight (lb)	Volume		Dimensions		Shape	
		Stored	Operation	Stored	Operation	Stored	Operation
1. Central observatory	635	~26 ft^3	~26 ft^3	50 x 50 x 60 in., including protrusions	229 x 229 x 60 in.	Rectangular with minor protrusions (solar cell arrays stowed)	Rectangular with four 30 ft^2 solar cell arrays
2. Major diagonal SMS (includes payload of R.A. equip.; filament dispensers)	211.7 (each)	6.5 ft^3 (each)	6.5 ft^3 (each)	37.0 x 25.0 x 18.25 in., including protrusions	Same	Rectangular	Rectangular
3. Minor diagonal SMS (includes payload of two reel out dispensers)	157.4 (each)	6.5 ft^3 (each)	6.5 ft^3 (each)	37.0 x 25.0 x 18.25 in., including protrusions	Same	Rectangular	Rectangular
4. Dipole unit D_1 D_2 D_5 D_6 D_3 D_4	7.50 (each) 9.12 (each)	0.23 ft^3 (each)	0.23 ft^3 (each)	8.6 diam x 8.3 lg. (in.)	Same	Cylinder	Cylinder
Total	1422.3	53.5 ft^3	53.5 ft^3	124 x 124 x 60 in. including protrusions	10 x 10 km	X-shaped	Rhombic

Table 3-17

SUMMARY OF KWOT PARAMETERS
(OASF Instrument No. 41)

Physical:

Diameter (approx): 10 km, 6.2 mi, 30λ at 1 MHz

Rhombic:

Leg: 17λ
Semi-major axis = 16.53λ = 4,960 m
Semi-minor axis = 3.91λ = 1,172 m
Half angle at vertex: 13.3°

Central obs: 29 x 29 x 60 in., plus solar panels

Wt: 635 lb — Power: 74 W avg, 272 max.

SMS: 37 x 25 x 18 in.

Wt: 212 or 157 lb — Power: 7.8 W avg, 94 W max.

Dipole unit: 9.6 in. diam x 8.25 in.

Wt: 7.5 or 9.1 lb — Power: 1.46 W

Stowed configuration of entire system: X-shape, with four SMS's attached by end faces to four side faces of C. O. length of X, tip-to-tip, 103 in.; Maximum thickness: 60 in.

Total weight: 1,411.44 lb

Dynamic:

Scan rate: 1 rev/hour = 6°/min = 0.001776 rad/sec

Precession rate (max.): 1/2°/hours = 12°/day = 180°/15 days

Centrifugal force at SMS's: 0.00159 g = g/630

SMS velocity: 873 cm/sec = 28.6 fps = 19.54 mi/hr

Orbit: Synchronous (24-hour period), circular, zero inclination

Electric:

Rhombic: 17λ legs, 13.3° half-angle at apex.

Beam 6.3° x 16.1° ellipse = 80 sq deg $\cong$ 1/300 celestial sphere.

Dipoles:

Fringes of 30λ pair: 1^{0}.91, peak to peak.

First null, 30λ filled aperture: 1°.91.

Period of highest spatial freq (at 1 rev/hour = 6°/min $\rightarrow$ 10 sec/degree scan rate): 19.1 sec.

Table 3-18

COLLECTOR PARAMETERS--KWOT
(OASF Instrument No. 41)

Aperture	10 km
Total field of view	80^o
Angular resolution, on-axis	1.7^o
Minimum wavelength	30 m
Maximum wavelength	3,000 m

F. Determine orientation of the system frame of reference with respect to the celestial sphere.

G. Generate all primary power needed within the unit.

2. Rhombic Subsatellite (Figure 3-25; also A and C, Figure 3-22)

A. Measure the RF energy delivered by the rhombic.

B. Integrate, encode, and transmit these measurements to the central observatory.

C. Receive control signals from central observatory to control both radiometers and thrusters.

D. Return proper transponder signals to central body tracking system.

E. Measure its own orientation with respect to the system frame of reference, correct by thrusters and/or reaction wheels.

F. Generate all primary power needed in the unit.

G. Sense all necessary housekeeping data, and transmit to the central observatory.

3. Interferometer Subsatellite (Figure 3-25; also B and D, Figure 3-22)

A. Receive control signals from the central observatory to control thrusters.

B. Return proper transponder signals to central observatory tracking system.

C. Measure its own orientation with respect to the system frame of reference, and correct by thrusters and/or reaction wheels.

D. Generate all primary power needed in the unit.

E. Sense all necessary housekeeping data, and transmit it to the central observatory.

Table 3-19

INTERFACE CHARACTERISTICS--KWOT
(OASF Instrument No. 41)

General

System weight (less expendables): 312 kg

System volume (launch configuration): 1.1 cu m

System shape (launch configuration): Rhombic interferometer cross-member

Methods of accomplishing. . .

Deployment: Thrustors and centrifugal force

Alignment: Maneuverable subsatellites

Calibration: Separate calibrator spacecraft

Operation: Remote

Experiment Change: Ground-activated

Stowage requirements (launch)

Mechanical: LEM adapter

Electrical: N/A

Experiment data handling

Format: Partially processed rf converted to digital

Processing: Transmission to ground-based computer; some on-board analysis

Recording media: Tape

Mode of data recovery: Ground-based receiver

Pointing requirements

Pointing accuracy (acquisition): $\pm 0.1^{\circ}$

Power consumption

Stowed: None

Standby: 83 W

Operate: 366 W

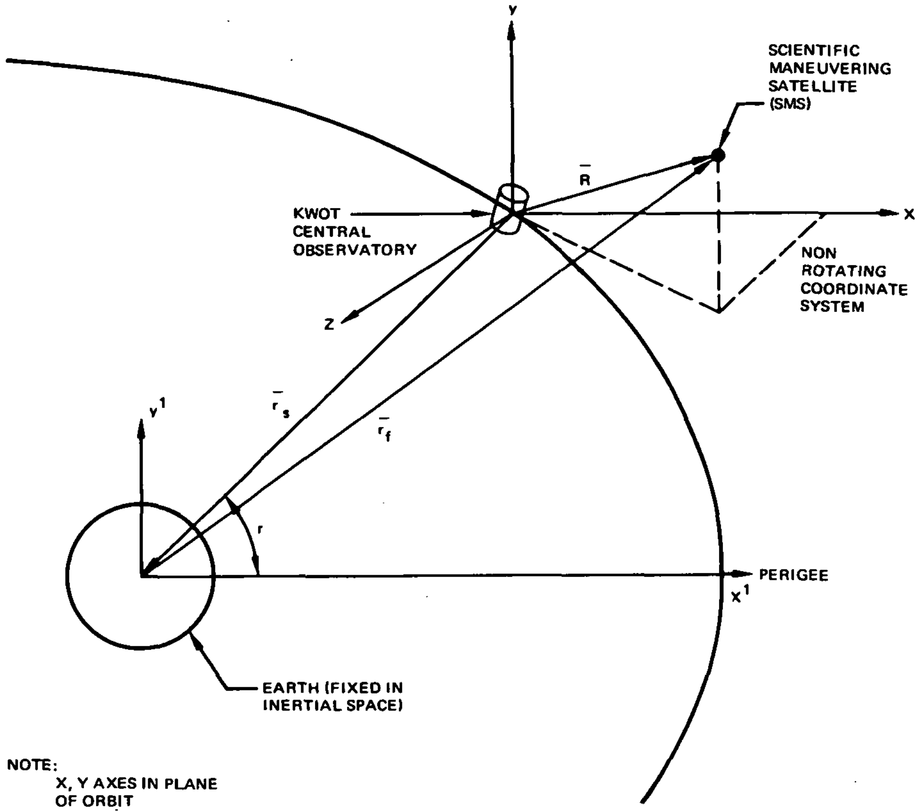

Figure 3-23. KWOT Coordinate System

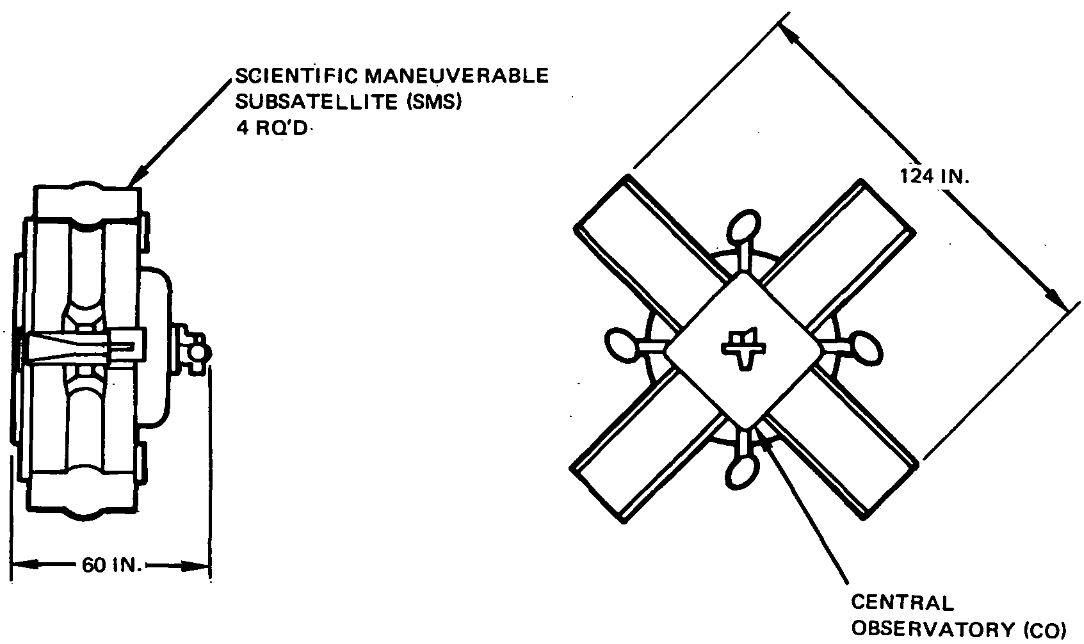

Figure 3-24. Kilometer Wave Orbiting Telescope (KWOT) – Launch Configuration

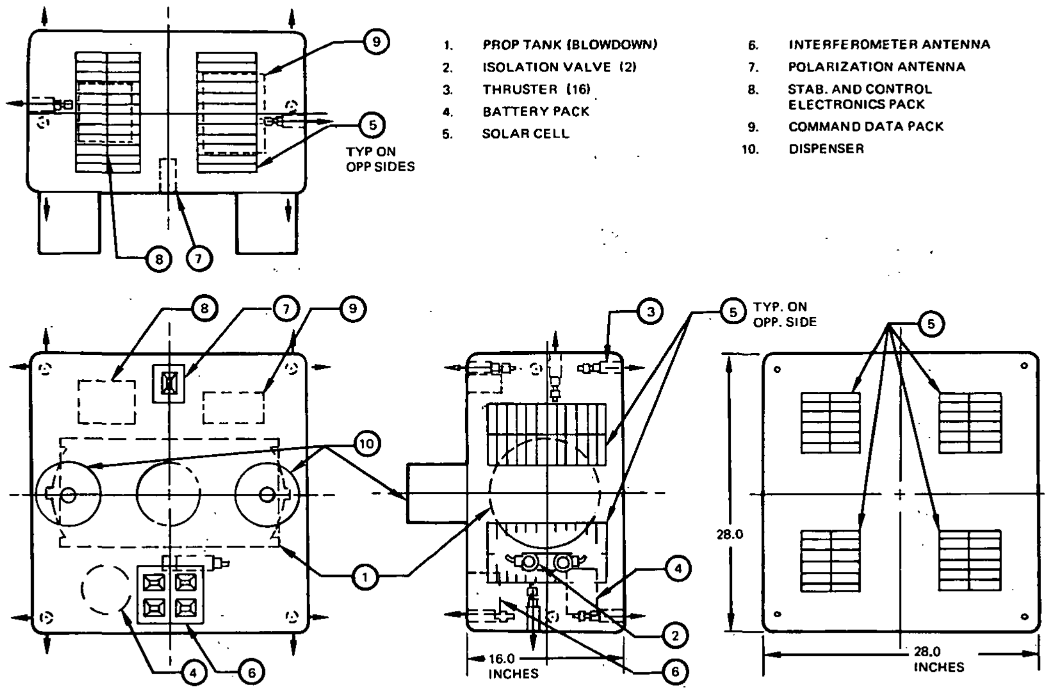

Figure 3-25. Scientific Maneuvering Satellite – KWOT

For the normal sky survey mode of operation this entire assemblage is rotated about the center with a period of about 1 hour. The dipole units are much simpler than the other units and serve to relay the dipole signals to the central observatory. Functions of the various units are outlined below:

1. Central observatory. (Figure 3-24)
   A. House entire system during launch.
   B. Deploy other components and lines.
   C. Receive commands from ground, interpret them, and relay to other units when appropriate.
   D. Receive data (radiometer, status, orientation, position, et cetera) from other units. Store, process, encode, and transmit it to ground.
   E. Track positions of the outer system components, with respect to the system frame of reference.

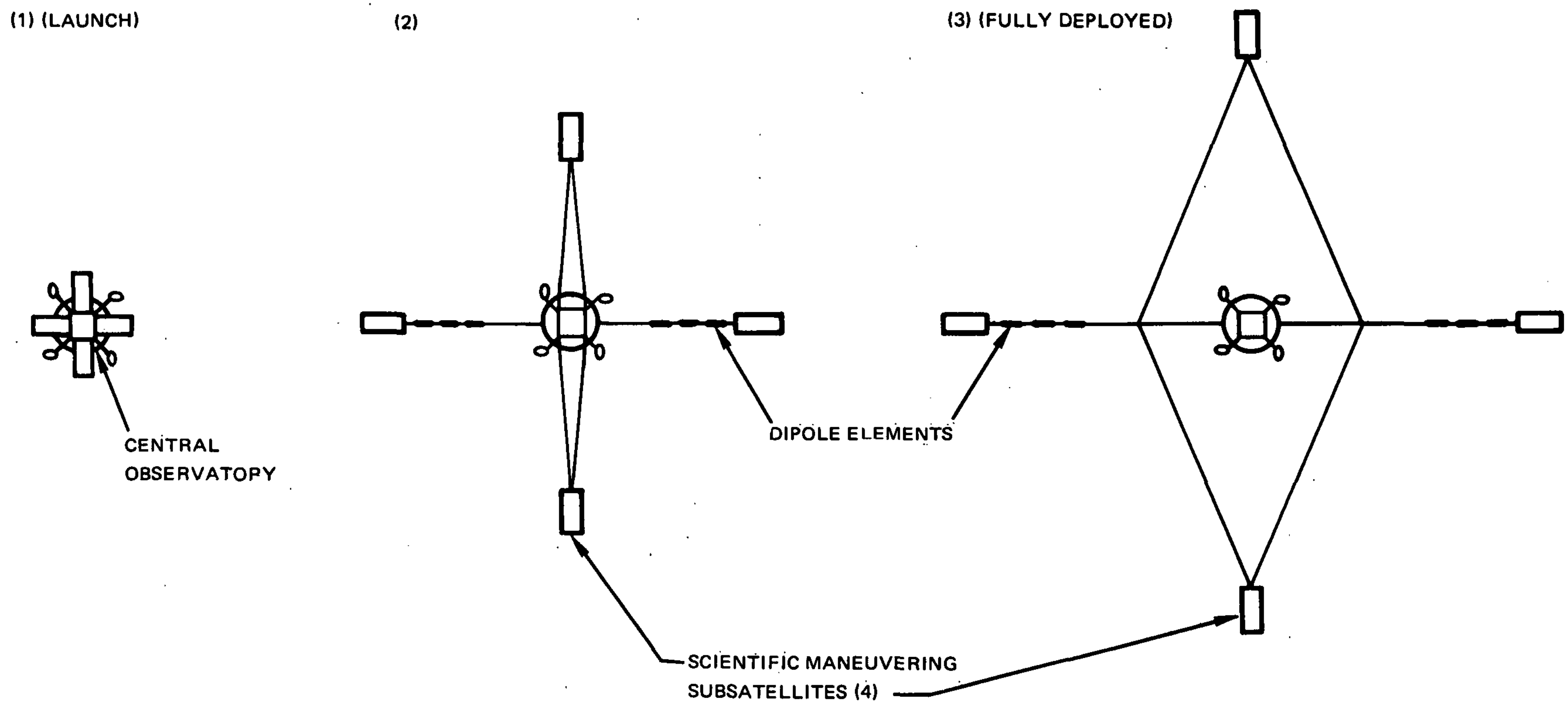

Figure 3-26. KWOT Deployment Sequence

3.2.3.6 Utilization of Man

Findings as to the potential for man to assist in the erection operation have generally been quite pessimistic. For this and other reasons, KWOT studies assume that man will be available only for servicing. This would upgrade the long-term reliability of the system, and its ultimate desirability would depend on tradeoff stuides involving the cost of fewer units with man in the picture, compared to more units with man out of the picture. Such an analysis, however was deemed to be beyond the scope of this study.

Astronauts' tasks for an alternative deployment mode involving man are listed in Table 3-20.

3.2.3.7 Support Research and Technology

Supporting Research and Technology (SRT) requirements associated with the Kilometer Wave Orbiting Telescope (KWOT) (Instrument No. 41) are listed below. Full descriptions of SRT items are shown in Section 4.3.

Research and Advance Technology

Investigate techniques for erection of large structures in space (SRT 53).

Advance Development

Assess materials for internal use to determine whether rapid aging and breakdown are caused by internal atmosphere (SRT 82).

Assess materials for external use to evaluate (1) hard vacuum effects on materials, finishes, et cetera, and (2) development of processing, handling, and assembly techniques (SRT 83).

3.2.3.8 Development Cost and Schedules

The Phase D cost is shown in Table 3-21, which shows both development and operations costs. The development schedule is shown in Figure 3-27. Quantities of equipment required in development are shown in Table 3-22.

Table 3-20

ASTRONAUT TASKS--ALTERNATIVE DEPLOYMENT MODE (MANNED INVOLVEMENT)

Kilometer Wave Orbiting Telescope-KWOT

(OASF Instrument No. 41)

Task	Crew 'A' Time*	Crew 'B' Time*	Equipment Used in Performing Task	Schedule (L = Launch)	Cum. Time (hr = min.)
Verify sunchronous orbit	---	---	Ground tracking station	L + 2 orbits	8:00
Orient launch vehicle with vertical	5 min.	---	---	L + 3	8:05
Open launch vehicle fairings	3 min.	---	Launch vehicle control panel	L + 3	8:08
Check out major KWOT systems	---	30 min.	KWOT C/O console	L + 3	8:38
Separate KWOT from launch vehicle	30 sec	---	Launch vehicle control panel	L + 3	** 8:38
Switch KWOT to external power	---	10 sec	KWOT C/O console	L + 3	8:39
Warm up equipment	---	10 min.	---	L + 3	8:49
Lock-on starfield tracker	---	2 min.	KWOT C/O console	L + 3	8:51
Activate propulsion systems	---	30 sec	KWOT C/O console	L + 3	8:51
Sever KWOT attachment	---	30 sec	---	L + 3	8:52
Monitor cluster assembly	---	2 min.	---	L + 3	8:54
Initiate KWOT deployment	---	10 sec	KWOT C/O console	L + 3	8:54
Monitor deployment	---	4 hr	Optical aids (binoculars)	L + 3	4:54
Calibrate Antenna	---	1 hr	R. A. control console	L + 3	** 5:54
Initiate operational mode	---	5 hr	R. A. control console	L + 3	10:54
Map Celestial sphere	---	---	Ground station	---	†
Recalibrate rhombic and repeat	---	---	Ground station	---	†

*Estimated

**Sequence of operations may be interrupted at this point.

†KWOT operation unattended hereafter; A complete sky mapping operation covering 180° requires 360 hours ($1/2^{\circ}$ per hour) continuous operation.

Table 3-21

TASK COST ESTIMATE--PHASE D
KILOMETER WAVE ORBITING TELESCOPE (KWOT)
(OASF Instrument No. 41)
($ thousands)

Development total	80,950		
Engineering		6,000	
Detectors		*	
Collecting optics		50,000	
Antenna array (1,000 mi)			50,000
Fine Guidance		3,800	
Star trackers (4)			1,200
Gas systems (1 small, 3 large)			2,600
Housing		16,200	
Unmanned satellites (4)			1,200
Deployment Mechanism			5,000
Power Supplies			10,000
Experiment sensors		4,950	
Tape recorders (2)			200
Satellite to grd comm systems (4)			750
Receiver			4,000
Major hardware articles		*	
Mockup			*
Engineering model			*
Project verification model			*
Qualification model			*
Operations total	37,348		
Flight instrument		24,240	
Backup flight instrument		9,710	
Engineering support		3,398	
Phase D total	118,298		

*Cost item not derived where overall estimate for instrument is not significantly affected.

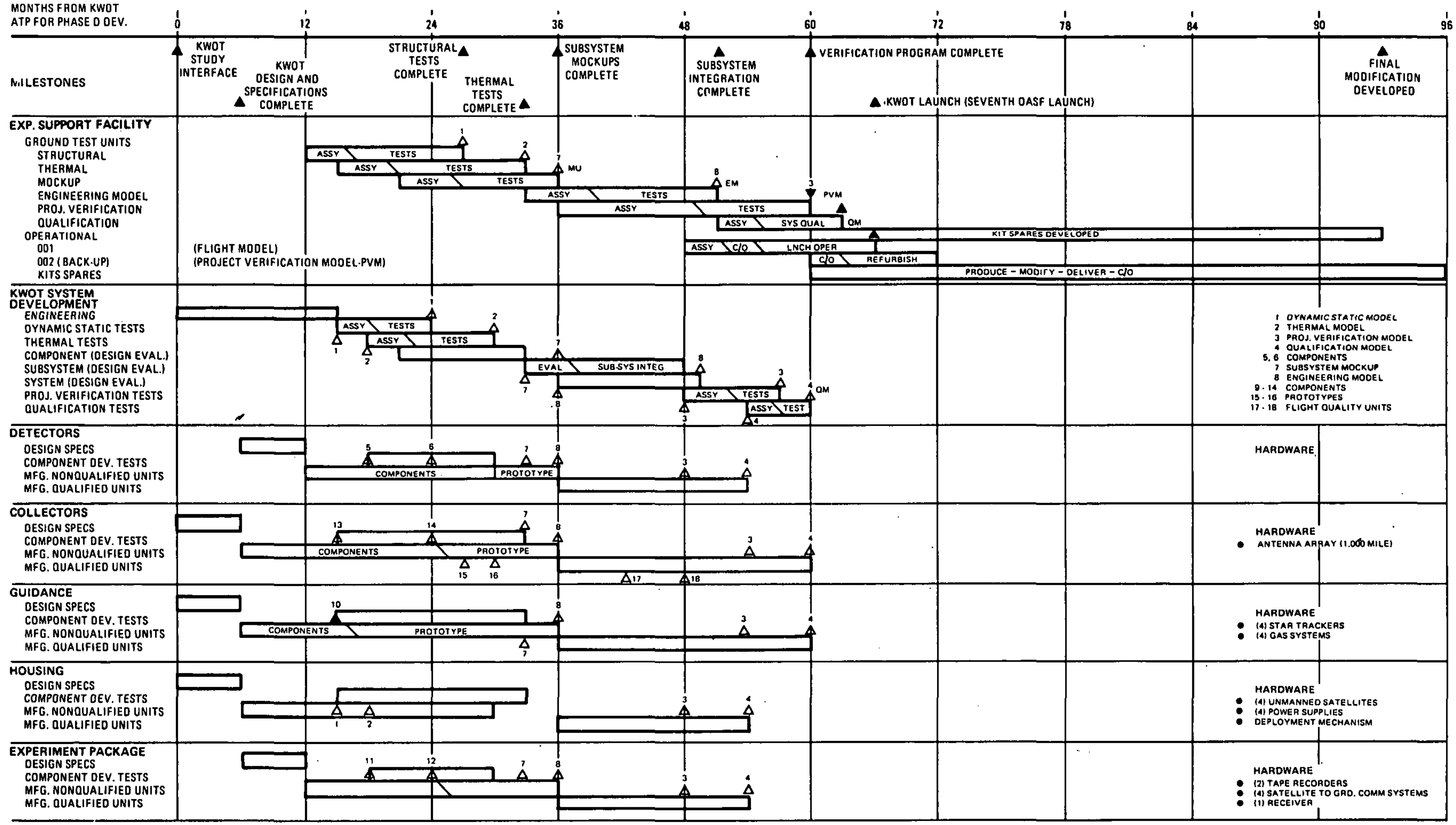

Figure 3-27. Development Schedule, Kilometer Wave Orbiting Telescope (KWOT) (OASF Instrument No. 41)

Table 3-22

PRIMARY INSTRUMENT EQUIPMENT LIST--DEVELOPMENT PHASE D
Kilometer Wave Orbiting Telescope (KWOT) (OASF Instrument No. 41)

Functional System (Major Element)	Subsystem	Assemblies	Quantity		
			Breadboard	Prototype	Flight Quality
Kilometer wave orbiting telescope (KWOT)	Detectors				
	Collecting optics	Antenna array (1,000 mi)	2	4	4
	Fine guidance	Star trackers	1	2	2
		Gas system	1	2	2
	Housing	Unmanned satellites	---	1	2
		Power supplies	---	1	2
		Deployment mechanism	---	1	2
	Experiment sensors	Tape recorders	1	1	1
		Sat. To grd. comm sys	1	1	1
		Receivers	1	1	1
	Major hardware articles	Mockup	1	---	---
		Engineering model	---	1	---
		Project verification model	---	60%*	40%*
		Qualification model	---	---	1

*Obtained from subsystem development quantities.

3.2.3.9 Definitions of KWOT Subsystems

KWOT subsystems perform the following general functions:

1. Attitude Subsystem--Measures attitude, or orientation, of each of the bodies in the KWOT structure, relative to the system frame of reference.
2. Position Subsystem--Measures position of each of the units in the KWOT structure relative to the system frame of reference.
3. Pointing Subsystem--Measures orientation of the system frame of reference with respect to the celestial sphere.
4. Communications Subsystem--Provides all necessary communications between units of the KWOT structure, and between KWOT and ground stations.
5. Command and Control Subsystems--Receives, stores, and interprets commands received from ground control, and generates the necessary thruster command signals to maintain the attitude and position of the structural elements within limits.

6. Data Subsystem--Collects, stores, processes, and prepared for transmission all data gathered in the KWOT system, both scientific and housekeeping.
7. Radio Astronomy Subsystem.
8. Ground Support System--Includes ground portions of the communications, command, and data systems, and perhaps other subystems as well.

3.2.3.10 Dipole Unit Functions

1. Amplify the rf signal appearing at the dipole terminals, modulate a carrier, and transmit it to the central observatory.
2. Receive control signals from central observatory to control its preamp.
3. Generate all primary power needed in the unit.
4. Sense all necessary housekeeping data, and transmit it to the central observatory.

The shape of the antenna, and hence the characteristics of the beam, is controlled by controlling positions of the outer units with respect to the central observatory (Figure 3-28 and 3-29). These positions are sensed from the

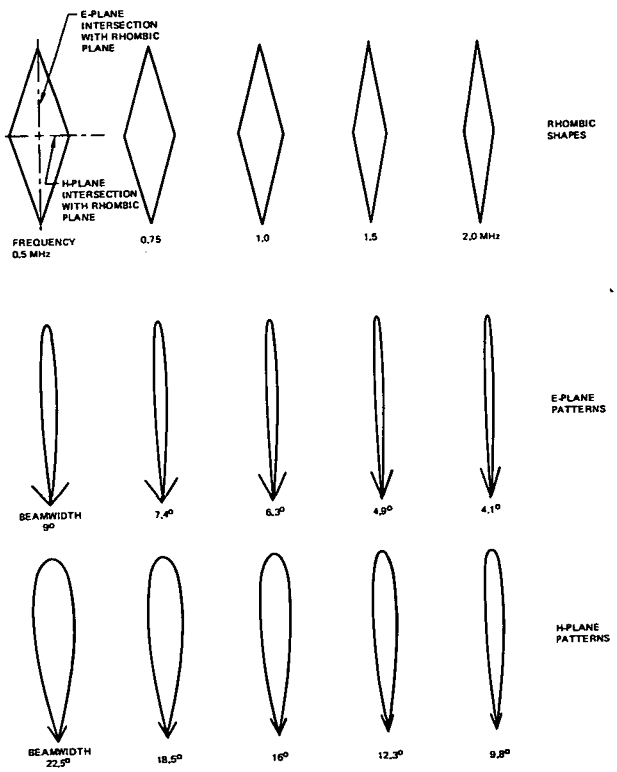

Figure 3-28. Antenna Characteristics of Rhombic Shapes

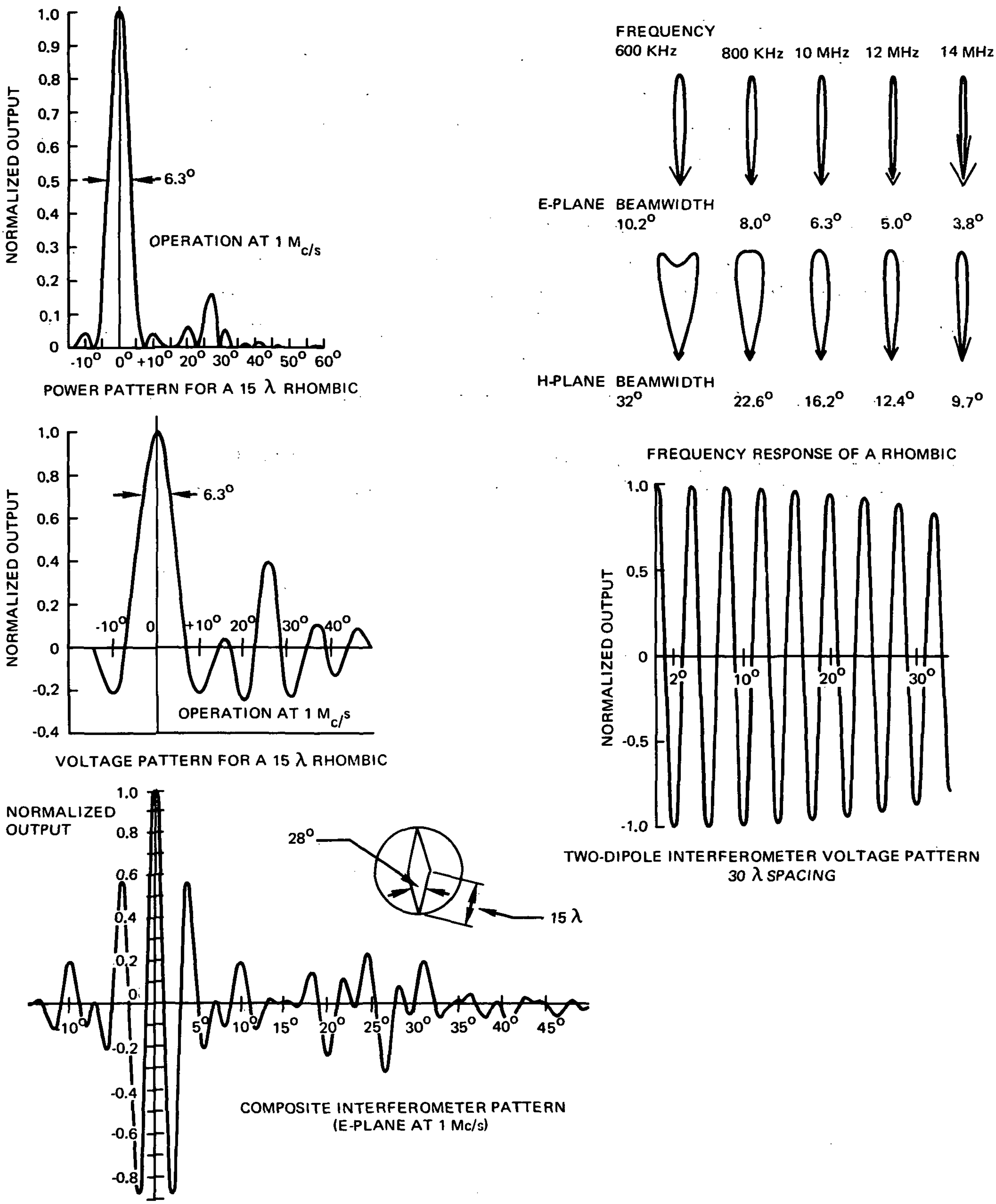

Figure 3-29. Antenna Patterns for a Kilometer Wave Orbiting Telescope

central observatory and corrected by firing appropriate thrustors on the outer units. For the action of the thrustors to be properly directed, the attitude of each subsatellite must also be controlled. This control can best be accomplished through the use of attitude sensors in each subsatellite, and thrustors to correct the attitude.

All subsatellite units generate attitude data and housekeeping data which must be transmitted to the central observatory, and all but the two interferometer subsatellite units generate scientific data as well. Furthermore, all subsatellite units receive thruster control commands, and most of them receive other command signals as well. Therefore, two-way communications is required from each subsatellite to the central observatory.

Each subsatellite and data system will use electric power, and will require some form of long-lived source of primary power, such as solar cells.

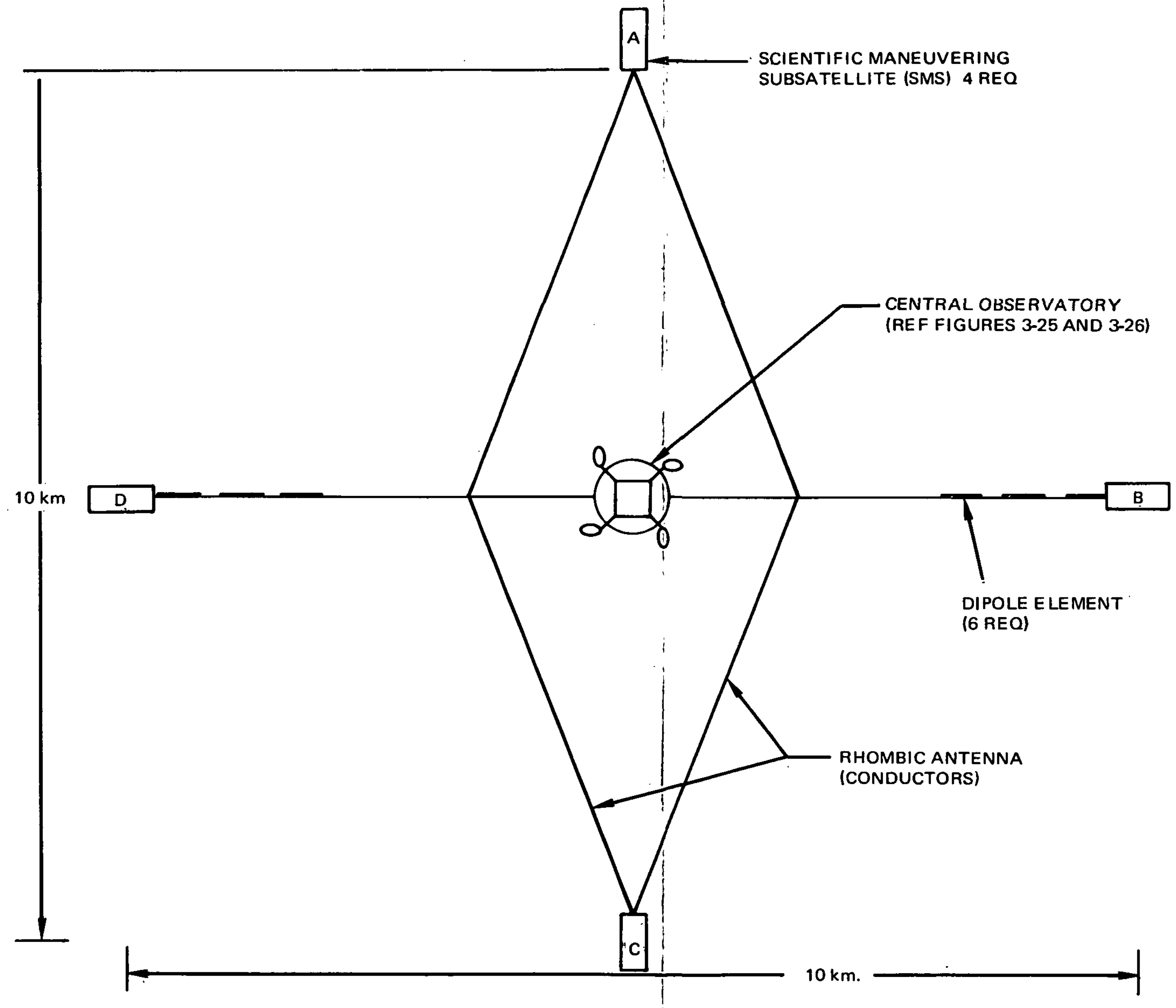

Figure 3-22 KWOT Configuration
OASF Instrument No. 41

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3.2.4 1-Meter Normal-Incidence Telescope, Steller--OASF Instrument No. 14

3.2.4.1 General Characteristics

The IR telescope is unique among the astronomy instruments in that it must be cooled in its entirety to very substantial cryogenic temperatures. This requirement results from the fact that a body will radiate energy in the IR region according to its temperature and its surface emissivity. Thus, if various parts of the optical system, such as the mirrors, the secondary supports, and the baffles, are not sufficiently cooled, they will radiate energy that may be seen as "noise" by the IR detector at the focus of the primary optical path.

A telescope at a temperature of about 77°K (liquid nitrogen temperature) would emit negligible radiation noise in the 1 μ to 25 μ wavelength range, where the greatest interest in IR astronomy is currently centered. In the 25 μ to 100 μ wavelength range, the radiation noise from a 77°K telescope is at its maximum; however, adequate observation should still be possible, based on radiation fluxes observed from known astronomical objects. From 100 μ to up perhaps 1,000 μ, an essentially unexplored IR radiation region, noise from a telescope at this temperature is again negligible.

The detectors in IR telescopes, at the focus of the optical path, must be kept at even lower cryogenic temperatures. To suppress "noise" in the detection and recording system, temperatures as low as 1.5°K are desired in some cases. Note that these extremely low temperatures apply only to the detectors and not to the telescope as a whole.

With regard to the entire telescope, two basic methods of achieving the cryogenic temperatures specified exist: passive cooling and active cooling. Passive cooling is achieved through shielding the telescope from unwanted radiation from the Earth and from the sun to a sufficient extent that the telescope, exposed only to cold space, achieves equilibrium at the desired temperature. Active cooling involves the use of cryogenic refrigeration systems; in these systems, the cryogenic fluids may be used either on an open-cycle, resupplied basis or may be continuously recycled through a closed refrigeration system (which places a power demand on the spacecraft).

For Task B, a passively cooled telescope-shield combination was conceptually designed, becaused (1) this was a basically simple configuration, (2) the same telescope, without the shield, could be inserted in a cryogenically cooled space station environment if advantageous, and (3) the analysis of passive cooling would provide the basis for a comparison of active versus passive cooling techniques, if required. The passive cooling analysis is presented in Appendix A. (As indicated in Task C, the use of the telescope derived here, without the shield, in a cryogenically cooled space station environment, was found to be advantageous, for reasons of packaging for launch and simplicity of orbital operations.)

The IR instrument derived in Task B (Figure 3-30) consists of a straightforward Cassegrainian optical system mounted on a thermal shield that rejects radiation from both the sun and the Earth. It is mounted on a gimbal system, or yolk, that enables the telescope to be pointed as required. The IR instrumentation section (an interferometer, a radiometer, and an IR detector array) is mounted directly behind the primary mirror of the Cassegrainian optics, on the cold side of the shield. An auxiliary optical path, for simultaneous visible-light imaging, is conducted along the arms of the yolk and through the shield at the point where the yolk pivots, to the back side of the shield where the TV viewfinder tracker, the vidicon, and the electronics can be located without the heat that they emit affecting the temperature of the telescope. The shield is attitude-controlled to provide the necessary orientation to the Earth and the sun, and the (heat-emitting) drive motors for positioning the telescope yolk with respect to the shield are behind the shield (hot side) with only a (non-heat-emitting) mechanical drive mechanism going through the shield to the telescope.

The principal difference between the optics of this telescope and the optics of the 1-m non-diffraction-limited UV-visible-IR telescope (OASF Instrument No. 45, Section 3.2.5) is the coating of the mirror surfaces to enhance IR reflectivity.

3.2.4.2 Design Criteria

Collection and detection of photon energy from various astronomical sources in the spectral region of 1 to 1,000 μ requires a special instrument. To operate in this IR region of the spectrum, consideration must be given to the absolute temperatures of various portions of the telescope which are viewed by the detector. When this is done, it is found that it is necessary to consider cooling of the telescope to prevent the telescope's own inherent noise from "masking" the reception of the desired signal. It is also desirable to keep the overall size of all parts of the telescope that must be cooled as small as possible to limit the amound of cooling required. To reduce the amount of cooling to a minimum, all heat-producing elements in the IR instrument system must be thermally isolated from the telescope.

The IR telescope shown in Figure 3-30 should be capable of satisfactory operation in the 1 to 1,000 μ region. To achieve this range of operation, radiative cooling techniques are used to permit the telescope optics to stabilize at a temperature of 77°K or less. The detectors, which view parts of the telescope and deep space may be cooled by radiative or active techniques. These detectors are expected to achieve operational temperatures as low as 1.5°K. To minimize the power being dissipated by the IR instrument, all amplification (other than preamplification) and processing of signals received are accomplished outside (hotside) of the thermal shield. Power required to drive the interferometer is kept to a minimum. Instrumentation change (as indicated by the use of a rotating pallet) is caused to occur at infrequent intervals to prevent indiscriminant heating of the telescope. A pellicle in the f/10 Ritchey-Chretien optical system is utilized to extract a portion of the received energy (over the field of view) and route it into the optical link of the view-finder/tracker system.

The mechanical-drive linkage is arranged as a dual drive to each axis of motion to prevent backlash. The stable reference for the drive system is obtained from CMG's that orient the thermal shield continuously so that the telescope is never irradiated by either the Earth or sun.

3.2.4.3 Detailed Characteristics

The basic characteristics of the 1-m IR normal-incidence stellar telescope have been summarized in Figure 3-2 in Section 3.1. Additional details about the instrument are provided in Tables 3-22, 3-23, and 3-24.

3.2.4.4 Utilization of Man

Setup and maintenance requirements are summarized for this instrument in Table 3-25. Because man's utilization in the operation of the instrument depends on the observational program, operational information is separately summarized in Table 3-26.

Deployment

After protective covers and supports are removed, and the optics and instrumentation have been examined for damage, the radiative heat shield is erected. The CMG's are activated and connected to the analog computer (using sun- and Earth-sensor-data inputs) to ensure the appropriate telescope and shield orientation relative to the sun and Earth. Finally, a cryogenic agent (LH_2) is applied to the instrument for initial cooldown to about $77^{\circ}K$.

Alignment

Optical alignment is checked in the red portion of the visible spectrum; this satisfies longer wavelength system requirements. An IR astronomical source of known size and spectral distribution is used for testing the interferometer portion of the instrumentation.

Calibration

A number of artificial IR sources, supplemented by stars, is used for calibration of the instrumentation. The instrumentation consists of a radiometer, interferometer, and solid-state detector matrix. They are all electro-optical, and the data output is in electronic signal form and is telemetered.

Operation

Temperatures of the various parts of the instrument are monitored during observations, particularly during those in the far IR (100μ to $1,000\mu$).

Table 3-22A

COLLECTOR PARAMETERS
1-Meter IR Normal-Incidence Telescope, Stellar--
OASF Instrument No. 14

Aperture	1 m
Primary focal length	1.5 m
Effective focal length	10 m
Total field of view	5 arc min.
Angular resolution	
On axis	1 arc sec at 4μ
Poorest in field of view	1 arc sec at 4μ
Obscuration of aperture	6.25%
Minimum wavelength	0.7μ
Maximum wavelength	1,000μ
Primary f/No.	1.5
System f/No.	10
Scale at system focal plane	20.6 arc sec/mm
Resolation at system focal plane	20.6 lines/mm
Linear field of view at system focal plane	14.6 mm

The calibration observation for the spectral region of interest is taken, then the actual observations for data, and then the calibration observations are repeated. This procedure ensures that the true conditions under which the data were collected are known, so that any necessary corrections can be applied during data reduction.

Scheduled Maintenance

Inspection of the shield for damage or potential failure is indicated. It is desirable to check the state of the electronics and detectors. It is not expected that damage to the optics will be incurred, but it is of interest to observe changes in the surfaces. It is necessary to resupply cryogenic fluid after any maintenance, for cooldown.

Table 3-23

INTERFACE CHARACTERISTICS
1-Meter IR Normal Incidence Telescope, Stellar--
OASF Instrument No. 14

General	
System weight (less expendables)	1,000 kg
System volume (launch configuration)	50 m^3
System shape (launch configuration)	Open-ended cylinder with central plug
Method of accomplishing...	
Deployment	Extend thermal shield
Alignment	Adjust focus of secondary-TV remote
Calibration	Standard sources
Operation	Automatic
Experiment change	Rotating turrent
Stowage requirements (launch)	
Mechanical	Brace telescope because of cantilever installation
Experiment data handling	
Format	35-mm magnetic-tape data block.
Processing	None
Recording media	Magnetic tape
Mode of data recovery	Exchange tape cartridge in space station
Pointing requirements	
Pointing accuracy (acquisition)	$\pm 1^{\circ}$
Power consumption	
Stowed	None
Standby	200 W
Operate	300 W

Table 3-24

GUIDANCE AND CONTROL CHARACTERISTICS
1-Meter IR Normal-Incidence Telescope, Stellar--
OASF Instrument No. 14

Guidance characteristics	
Coarse	
Initial acquisition field of view	±1°
Resolution	±10 arc sec
Residual error	±60 arc sec
Intermediate	
Field of view	±120 arc sec
Resolution	±1 arc sec
Residual error	±5 arc sec
Fine	
Field of view	±30 arc sec
Resolution	±0.1 arc sec
Residual error	±1 arc sec
Control characteristics	
CMG	
Type: Two degrees of freedom	
Wheel momentum	≈2,000 lb-ft-sec
Gimbal Stops: Outer, none, inner ±60°	
Spin motor power (start)	≈200 W
(run)	≈ 35 W
Servo power (peak)	≈200 W
(average)	≈ 30 W
Max.torque	≈1,000 ft-lb
Weight	≈400 lb
Diameter (wheel housing)	≈ 40 in.
Length (overall)	≈ 50 in.

Table 3-25

SETUP AND MAINTENANCE REQUIREMENTS
1-Meter IR Normal-Incidence Telescope, Stellar--OASF Instrument No. 14

Operation	Average Times/Year	Duration (hours)	No. of Men	Skill Identification*	Hours/Man	Average Power (W)	Special Equip Weight (lb)	Special Equip Volume (ft^3)
Deployment	---	15	1	12	4	20	900	35
			1	14	2			
			1	21	15			
Alignment	---	12	1	14	12	10	---	---
Calibration	---	4	1	21	4	25	---	---
Scheduled maintenance	6	8	1	12	8	25	70	13
Unscheduled maintenance	1	2	1	12	2	25	15	3

*Skills are identified by number in Table 3-3.

Table 3-26

OPERATION SUPPORT AND REQUIREMENTS
1-Meter IR Normal-Incidence Telescope, Stellar--OASF Instrument No. 14

ORDS No.	Time per Observation (hours)	No. of Men	Skill Identification*	Man-hours/ Observation	Start Time (hours from start of observation)	Number of Observations
029	0.33	1	5	0.6	-0.2	800
063S	6 months	1	5	1 day	-1	1
072	5	1	5	1.2	-0.2	100
073	500	1	5	2 days	-0.5	~10
074	300	1	5	2 days	-0.2	5
075	5	1	5	1.2	-0.2	300
076S	6 months	1	5	1 day	-1	1
077	300	1	5	2 days	-0.2	90
078	500	1	5	2 days	-0.5	>10

*Skills are identified by number in Table 3-3.

Unscheduled Maintenance

Unscheduled maintenance will be necessary if (1) the heat shield is severely damaged (meteoroid or other cause), (2) a portion of the detector or transmission systems fails, or (3) the stabilization system fails.

3.2.4.5 Supporting Research and Technology

Supporting Research and Technology (SRT) requirements for the 1-Meter-IR Normal-Incidence Telescope (Instrument No. 14) are listed below. Full descriptions of SRT items are given in Section 4.3.

Research and Advance Technology

Develop methods for rapidly evaluating mirror figure and alignment under 1-3 and zero-g environments (SRT 1).

Conduct experimental studies of precision structural properties of mirror material related to optical performance (SRT 2).

Establish details of thermal fluctuations in secondary shield system as a function of primary shield thermal fluctuations (SRT 41).

Investigate mirror support structures that minimize the mechanical and optical problems of Cassegrainian telescopes (SRT 54).

Investigate techniques for alignment and focusing mechanisms for optical telescopes (SRT 55).

Investigate the dimensional stability of candidate mirror materials (SRT 56).

Evaluate sputtering on mirror surfaces from high-energy particles (SRT 57).

Investigate the adhesion of high-reflectivity low-emissivity IR coatings to structural substrata at cryogenic temperatures (below 100°) (SRT 57A).

Advance Development

Develop defector-mounting techniques and cryogenic equipment for sensor cooling of IR telescope (SRT 64).

Determine the effect of superconductivity on the emissivity of metallic conductors (SRT 66).

Perform a detailed thermal and structural analysis for a cooled IR telescope (SRT 67).

Develop an IR imaging device of adequate resolution for use with a 1-m-aperture IR telescope (SRT 68).

Develop filters for IR spectroscopy (SRT 68A).

Assess materials for internal use to determine if rapid aging and breakdown are caused by internal atmosphere (SRT 82).

Assess materials for external use to evaluate (1) hard-vacuum effects on materials, finishes, etc., and (2) development of processing, handling, and assembly techniques (SRT 83).

3.2.4.6 Instrumentation Section

Interferometer

An interferometer shown schematically in Figure 3-31, is incorporated in the instrumentation section of the IR telescope. The infrared energy collected by the telescope is passed through a hole in the rotating pallet where the interferometer is to be used. The optical arrangement of the interferometer divides the energy to create an interference pattern. The bolometer detects the interference pattern as a function of time and the position of the movable mirror.

Although a Michelson-type of interferometer is depicted in Figures 3-30 and 3-31, other types of interferometers could also be considered. The specific design capabilities of the interferometer shown are listed in Table 3-27.

DC Radiometer

In the spectral region of 5 to 14μ, mercury-doped germanium (Ge:Hg) operating at a temperature of between 4^{o}K and 40^{o}K is normally utilized for detection of radiation. Figure 3-32 shows a radiative-cooled mercury-doped-germanium detector radiometer assembly weighing 3 kg that can be mounted on the rotating pallet in the IR instrumentation section. For the radiometer configuration shown, it is expected that any installed detector will stabilize thermally at some temperature and 35^{o}K. Variations in the radiative aperture will enable different types of radiometer detector materials to be optimized at other temperatures for use in other spectral regions.

IR Detector Array

To accomplish an IR sky survey within a reasonable operating period, a detector array can be incorporated into an assembly similar to that discussed in the preceding paragraph. Scanning of the heavens can then be accomplished by holding the IR telescope at a given angle with respect to the orbit plane and

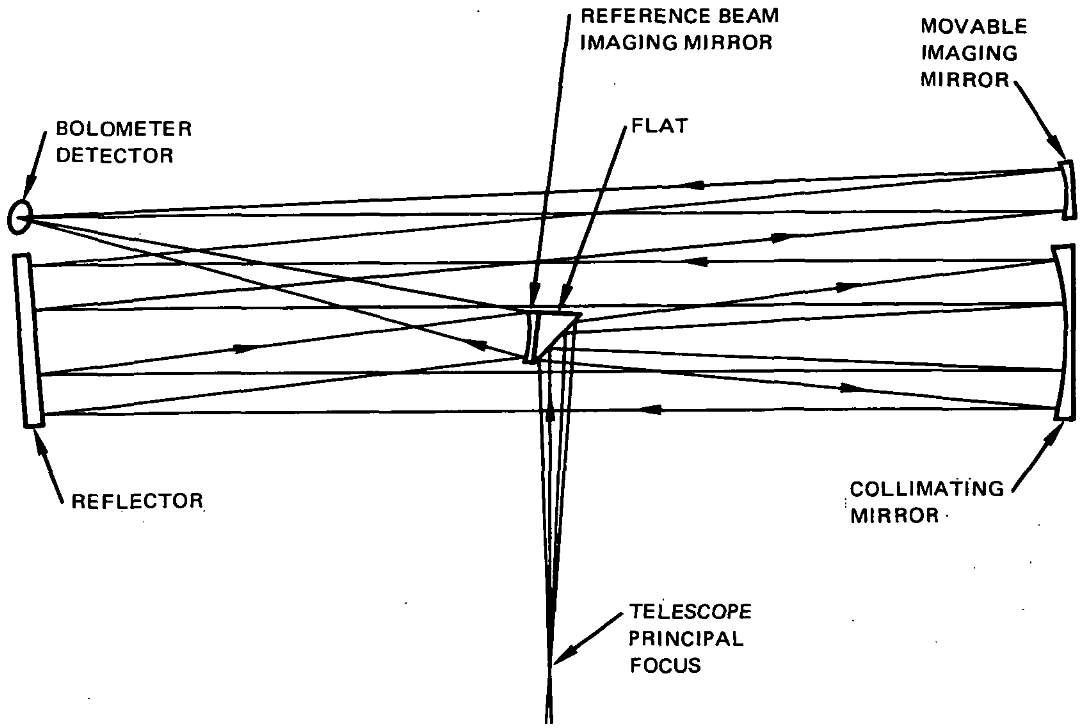
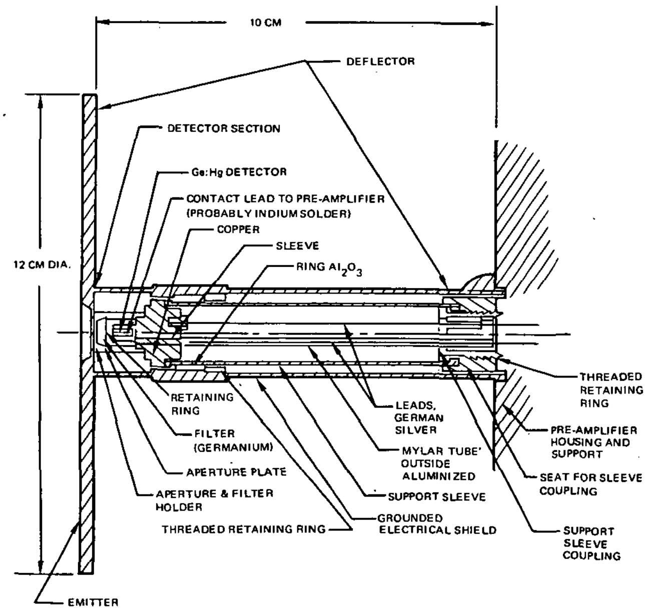


Figure 3-31. Michelson Interferometer



NOTES: MATERIAL THICKNESSES SHOWN ARE SCHEMATIC ONLY
PRE-AMPLIFIER SECTION AT 77°KELVIN

Figure 3-32 DC Radiometer Assembly

Table 3-27

INTERFEROMETER CHARACTERISTICS
1-m IR Normal-Incidence Telescope, Stellar--
OASF Instrument No. 14

Type	Michelson interferometer
Wavelength	
Short	0.7μ
Long	100μ
Resolution	16Å at 4μ
Entrance aperture	
Slit width	50, 250, 1,250μ
Slit height	200, 1,000, 5,000μ
Incident radiation	
f/No. limitation	10
Spatial resolution	1 arc sec at 4μ
Detector type	Bolometer (cooled thermister)
Recorder	Magnetic tape
Weight	20 kg (including 10 kg for tape recorder)

scanning a full circle (generally less than a great circle) on the celestial sphere as the orbit is traversed. The angle measured from the orbit plane is changed for each successive orbit traverse until the entire celestial sphere is scanned. Considering the 5-arc-min. field of the Ritchey-Chretien optics of the telescope, a 100-element array of mercury-doped-germanium detectors, weighing about 4 kg, would enable a 4-arc-min. "slice" of the celestial sphere (2.5 arc-sec/element, at 10 μ wavelength) to be obtained per orbit traverse. At the expected operational altitude (≈500 nmi) only a 3.5-arc-min. field of view is required to produce a complete celestial scan in a half year of continuous scanning.

3.2.4.7 Development Cost and Schedules

The Phase D cost is shown in Table 3-28, which shows both development and operations costs. The development schedule is shown in Figure 3-33. Quantities of equipment required in development are shown in Table 3-29.

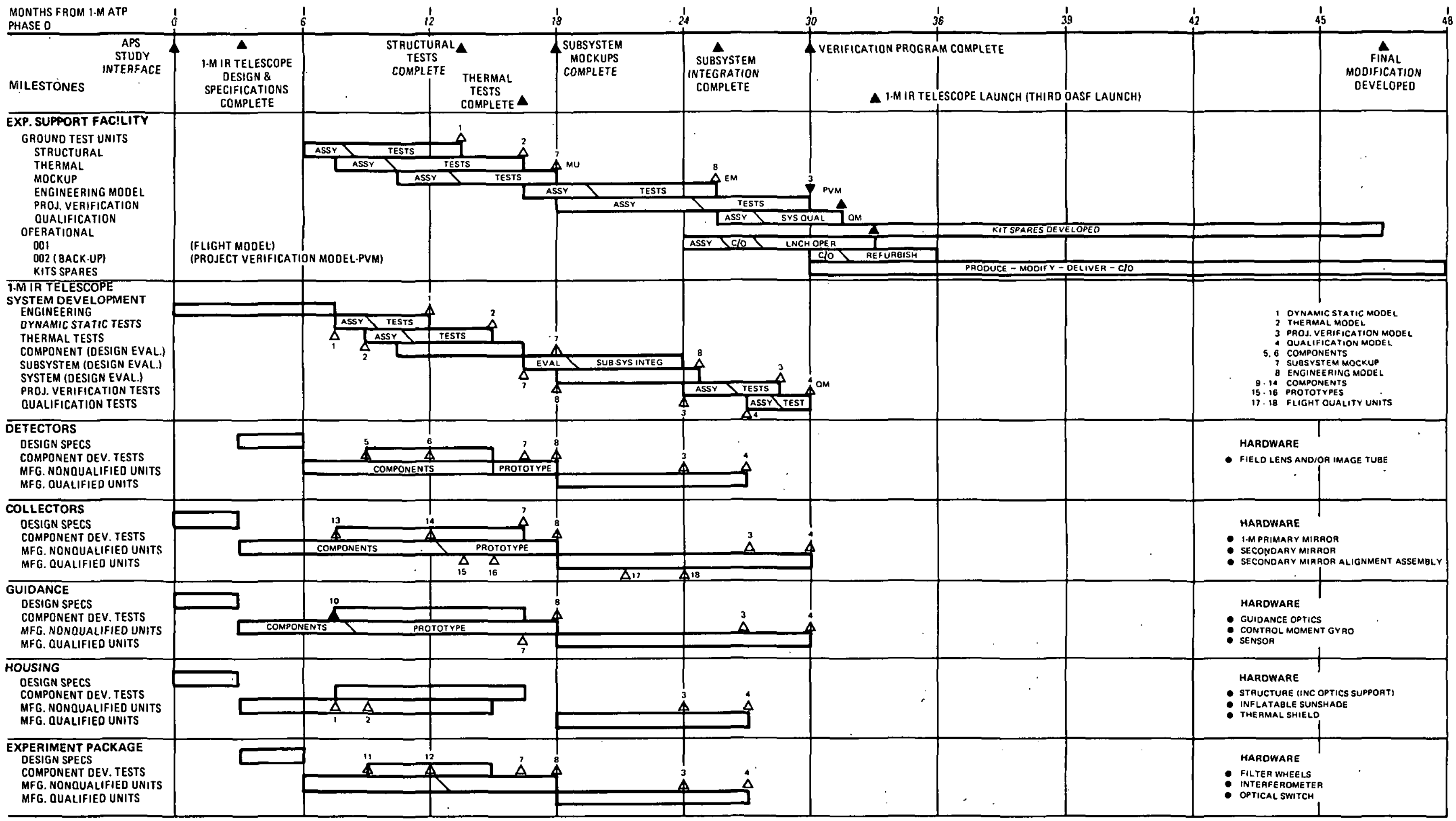


Figure 3-33. Development Schedule, 1-Meter IR Normal Incidence Telescope, Stellar (OASF Instrument No. 14)

Table 3-28

TASK COST ESTIMATE--PHASE D
I-Meter IR Normal-Incidence Telescope, Stellar--OASF Instrument No. 14
($ thousands)

Development total	4,285		
Engineering		360	
Detectors		*	
Field lens and/or image tube			*
Collecting optics		700	
1-m primary mirror			*
Secondary mirror			*
Secondary mirror align. assy			*
Fine guidance		715	
Guidance optics			*
Sensor			*
Control moment gyros			*
Housing (primarily servo aspect and hardware)		610	
Structure (including optics support)			400
Inflatable sunshade			30
Thermal shield			180
Experiment sensors		1,050	
Filter wheels			*
Interferometer			*
Optical switch			*
Major articles		850	
Mockup			*
Engineering model			*
Project verification model			*
Qualification model			*
Operations total	1,980		
Flight instrument		1,285	
Back-up flight instrument		515	
Engineering support		180	
Phase D total	6,265**		

*Cost item not derived where overall estimate for instrument is not significantly affected.

**Assumes previous development of 1-m non-diffraction-limited OASF Instrument No. 45, same optical contractor for both instruments.

Table 3-29

PRIMARY INSTRUMENT EQUIPMENT LIST--DEVELOPMENT PHASE D
1-Meter IR Normal-Incidence Telescope, Stellar--OASF Instrument No. 14

Functional System (Major Element)	Subsystem	Assemblies	Quantity		
			Bread-board	Proto-Type	Flight Quality
1-meter IR telescope	Detectors	Field lens and/or image tube	1	2	1
	Collecting optics	1-m primary mirror	1	2	1
		Secondary mirror	1	2	1
		Secondary mirror align. assy	2	2	1
	Fine guidance	Guidance optics	1	1	2
		Sensor	1	1	2
		Control moment gyro	1	2	1
	Housing	Structure (including optics support)	1	1	2
		Inflatable sunshade			2
		Thermal shield	1	1	2
	Experiment sensors	Filter wheels	1	1	2
		Interferometers	1	1	2
		Optical switch	1	1	2
	Major hardware articles	Mockup	1	---	---
		Engineering model	---	1	---
		Project verification model	---	60%*	40%*
		Qualification model	---	---	1

*Obtained from subsystem development quantities.

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Figure 3-30. 1-Meter Infrared Normal Incidence Telescope, Stellar. OASF Instrument No. 14

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3.2.5 1-Meter Non-Diffraction-Limited UV-VIS-IR Normal Incidence Telescope, Stellar - OASF Instrument No. 45

3.2.5.1 General Characteristics

The 1.0-m f/5 stellar telescope is a general-purpose telescope consisting of a non-diffraction-limited collector and an instrumentation package of varied capabilities (Figure 3-34). Among the functions provided by the telescope are stellar spectrophotometry, stellar and planetary spectrography in a variety of dispersions, and slitless spectrography of extended sources such as planetary nebulae. The principal spectral range to be investigated by this telescope is the UV region from about 1,000 to 4,000 Å, although some visual range measurements are also contemplated.

Guidance and control are accomplished by means of a star tracker mounted both inboard and outboard on the telescope, control moment gyros (CMG's) for pointing control of the telescope, and a beam steering mirror for vernier pointing of the line of sight within the telescope.

The outboard astrotrackers are gimballed, and, by means of calculated offset angles from specified reference stars, can point the telescope adequately to acquire the target star in the field of view of the internal tracker, which in turn centers the target star in its field of view. The CMG's mounted on the telescope provide the necessary torques to steer the telescope in response to nulling error signals from the astrotrackers. Although this guidance is satisfactory for the spectrophotometer, it is submarginal for the spectrographs. Accordingly, a third stage of guidance is added, whereby a tracker, which is incorporated with each instrument package, supplies drive signals to actuate deflectors built into the rotating optical switch mirror.

The telescope is also fitted with a sunshade which extends approximately 2 m beyond the end of the telescope and serves to shorten the dead time on the day side of each orbit.

This instrument is intended as a logical successor to the orbiting astronomical observatory (OAO) series of telescopes, applying to one or more of them the advantages of manned intervention to increase their scope and versatility.

3.2.5.2 Design Criteria

By extracting from the requirements of the overall astronomy program those observations not needing a high degree of angular resolution or pointing precision, a group was assembled which could be performed with a resolution not better than 1 sec. These observations can be performed with instrumentation that is well within the present state of the art and could be flown with the shortest conceivable delay. Hence, a telescope based on a modification of the Goddard Experiment Package is recommended to fill this function.

3.2.5.3 Detailed Characteristics

The basic characteristics of the 1-m nondiffraction-limited UV-VIS-IR normal incidence stellar telescope have been summarized in Figure 3-2 in Section 3.1.

Additional details about the instrument are tabulated in Table 3-30, 3-31, and 3-32.

3.2.5.4 Utilization of Man

Setup and maintenance requirements are summarized for this instrument in Table 3-33. Because man's utilization in the operation of the instrument depends on the observational program, operational information is separately summarized in Table 3-34.

Deployment

The deployment tasks require no unusual mental or manual skills, so that they can be done by automatic mechanisms with EVA backup capability. Deployment includes the erection of star and planet trackers and the sunshade, removal of protective coverings, and the installation of image and photomultiplier tubes and tape recorders. The accomplishment of the deployment,

Table 3-30

COLLECTOR PARAMETERS
1-m Non-Diffraction-Limited UV-Vis-IR
Normal-Incidence Stellar Telescope--
OASF Instrument No. 45

Aperture	1 m
Primary focal length	2 m
Effective focal length	5 m
Total field of view	10 arc min.
Angular resolution	
On axis	0.2 arc sec at 4,000 Å
Poorest in field of view	1 arc sec at 4,000 Å
Obscuration of aperture	~15%
Minimum wavelength	< 900 Å
Maximum wavelength	>12,000 Å
Primary f/No.	2
System f/No.	5
Scale at system focal plane	42 arc sec/mm
Resolution at system focal plane	14 lines/mm
Linear field of view at system focal plane	8.8 mm

Table 3-31

INTERFACE CHARACTERISTICS (page 1 of 2)
1-m Non-Diffraction-Limited UV-Vis-IR
Normal-Incidence Stellar Telescope--
OASF Instrument No. 45

General	
System weight (less expendables)	1,000 kg
System volume (launch configuration)	3.5 m^3
System shape (launch configuration)	Cylindrical
Method of accomplishing. . .	
Deployment	Removal of plastic bags and extension of sunshade.
Alignment	Autocollimation, motor-operated secondary, TV sensor.

Table 3-31 (page 2 of 2)

Calibration	Standard sources using photography.
Operation	Remote control pointing and photography.
Experiment change	Remote control of rotatable mirror, manual change of units.
Stowage requirements (launch)	
Mechanical	Air bag support for optics. Plastic bag covering.
Electrical	None.
Experiment data handling	
Format	35-mm roll film.
Processing	On board.
Recording media	Photographic film and magnetic tape.
Mode of data recovery	Exchange of cartridges for film and tape.
Pointing requirements	
Pointing accuracy (acquisition)	±5 min. -automatic; 1-min. (angle) manual.
Power consumption	
Stowed	None.
Standby	80W
Operate	110W

either automatically or by EVA, is important, because the photocathodes of the UV-sensitive image tubes and photomultipliers, once opened for use, cannot be exposed to any atmosphere. If contaminated accidentally, they have to be replaced and the instrumentation recalibrated.

Alignment

An optical technician (No. 14) observes a TV screen to interpret a display of star images. The TV camera takes the place of the eyepiece of an autocollimator which is rigidly attached to the instrumentation pallet. The autocollimator is used in two modes. In the first mode, it projects an

Table 3-32

GUIDANCE AND CONTROL CHARACTERISTICS
1-m Non-Diffraction-Limited UV-Vis-IR
Normal-Incidence Stellar Telescope--
OASF Instrument No. 45

Guidance Characteristics	
Coarse	
Initial acquisition field of view	±5°
Resolution	±2 arc sec
Residual error	±5 arc min.
Intermediate	
Field of view	±5 arc min.
Resolution	±0.5 arc sec
Residual error	±2 arc sec
Fine	
Field of view	±2 arc min.
Resolution	±0.05 arc sec
Residual error	±0.1 arc sec
Control characteristics	
CMG	
Type: Single degree of freedom, viscous damped	
Wheel momentum:	≈640 oz.-in.-sec.
Gimbal stops	±60°
Spin motor power (start):	≈40 W
(run):	≈6 W
Servo power (peak):	≈10 W
(average):	≈1.5 W
Max. torque:	≈3.8 oz.-in.
Weight:	≈16 lb
Diameter:	≈5 in.
Length:	≈8-1/2 in.

Table 3-33

SETUP AND MAINTENANCE REQUIREMENTS
1-m Non-Diffraction-Limited UV-Vis-IR
Normal-Incidence Stellar Telescope--
OASF Instrument No. 45

Operation	Average Times Per Year	Duration (hours)	No. of Men	Skill* Identi-fication	Hours Per Man	Average Power (W)	Special Equip. Weight (lb)	Special Equip. Volume (ft^3)
Deployment	---	2	1	21	2	---	---	---
Alignment	---	12	1	14	12	15	---	---
Calibration	---	24	1	21	24	5	---	---
			1	12	4	---	---	---
Scheduled maintenance	6	4	1	14	1	---	--	--
			1	12	4	15	15	2
Unscheduled maintenance	1/2	5	1	12	5	---	---	---
			1	14	2	15	30	3

*Skills are identified by number in Table 3-3.

image which is reflected off the rotatable mirror (optical switch) and then off an optically flat area ground and polished on the center of the secondary mirror and then reflected back through the system. If the projected and reflected images are in coincidence (in the manner of a range-finder) then the secondary mirror is centered and normal to the telescope optical axis. (The technician manipulates servo-motor controls to achieve this alignment.) In the second mode, the autocollimator (with its image projector off) is used as an alignment telescope. The technician views the star image (on the TV monitor) and further adjusts the controls until he obtains the best possible star image shape on the TV monitor.

Table 3-34

OPERATION SUPPORT AND REQUIREMENTS
1-m Non-Diffraction-Limited UV-Vis-IR
Normal-Incidence Stellar Telescope--
OASF Instrument No. 45

ORDS No.	Time per Observation (hours)	No. of Men	Skill* Identification	Man-hours/ Observation	Start Time (hours from start of observation)	No. of Observations
002	0.03	1	5	0.1	-0.05	2,000
027	0.13	1	5	0.5	-0.25	500
028	0.33	1	5	0.6	-0.25	500
		1	8	0.05	+48	
030	0.33	1	5	0.6	-0.25	250
031	1	1	5	1.25	-0.25	50
		1	8	0.05	+48	
032	0.5	1	5	0.75	-0.25	300
		1	8	0.05	+48	
033	0.25	1	5	0.5	-0.25	100
		1	8	0.05	+48	
034	0.5	1	5	0.5	-0.25	300
		1	8	0.05	+48	
037	0.33	1	5	0.6	-0.25	150
		1	8	0.05	+48	
113	0.25	1	5	0.5	-0.25	300
		1	8	0.05	+48	

*Skills are identified by number in Table 3-3.

The scheme described above has been derived from Kollsman experience on the Goddard Experiment Package. In the light of this experience, 12 hours appears to be a reasonable time allotment for the alignment procedure (Table 3-33). This time may be reduced, depending on the skill of the operator, the design of the servomechanisms, and a number of partially controllable parameters such as machined tolerances, temperature variations, and structural hysterisis.

Other alignment tasks include checking and adjusting of the rotational axis of the rotatable mirror, and ensuring that the star trackers are boresighted with the telescope axis.

Calibration

The two spectrophotometers, the slitless spectrograph, the concave grating spectrograph, and the echelle spectrograph are calibrated separately for each observation requirement. Photography and spectrography of MK-UBV standards as well as the use of a calibrated standard lamp are used in the procedure. A phototechnician or observer loads the film strip and plate camera magazines and reduces the developed photographs with a densitometer. The densitometry could be done in the spacecraft to which the telescope is attached.

The calibration time indicated on Table 3-33 is based on an estimate of the number of photographs needed for calibration sequences, the use time of standard sources and the time needed to obtain the observations. The allotment of 24 hours is subject to some uncertainty, depending on unknowns such as the specific observing program and the reflection efficiency of UV mirror coatings.

Operation

Each of the spectrographic experiments requires a technician to load the film or plate magazine, and an observer to check the field of view to which the instrument is pointed, to initiate the exposure timing mechanism, and to remove the contents of the camera magazine and develop the photographic material after the exposure. It may be necessary for the observer to change gratings (servomechanism) or filters during the course of an exposure sequence.

Scheduled Maintenance

An optical technician examines the telescope and instrument optics for damage or deterioration.

An electromechanical technician checks the TV cameras and monitors and other electronics for deterioration and replaces degraded or unreliable components. A modular replacement technique is indicated.

Unscheduled Maintenance

The major portion of the electromechanical technician's time (Table 3-33) is for unusual electronic failures in the photomultipliers, TV cathode ray tubes or image intensifiers, because the large number of such components implies a significant failure problem.

The time allotment for an optical technician in Table 3-33 for failures in which the optical alignment could have been disturbed and needs to be checked.

3.2.5.5 Supporting Research and Technology

Supporting Research and Technology (SRT) requirements for the 1-m non-diffraction limited UV-Visible-IR telescope (Instrument No. 45) are listed below. Full descriptions of SRT items are given in Section 4.3.

Research and Advanced Technology

Conduct experimental studies of precision structural properties of mirror material related to optical performance (SRT 2).

Develop mirror surfaces to provide high UV reflectivity, precision of figure, and freedom from scattering (SRT 4).

Develop XUV-sensitive imaging tubes for use below 1,050 Å (SRT 11).

Develop techniques to overcome electrostatic charge build-up and fog-producing spark discharge on roll film in hard vacuum (SRT 17).

Develop criteria for film-transport mechanisms suitable for roll film in hard vacuum to avoid emulsion cracking and flaking (SRT 39).

Investigate degradation of telescope detector and reflective surfaces resulting from O_2 exposure (SRT 42).

Investigate mirror support structures that minimize the mechanical and optical problems of Cassegrainian telescopes (SRT 54).

Investigate techniques for alignment and focusing mechanisms for optical telescopes (SRT 55).

Investigate the dimensional stability of candidate mirror materials (SRT 56).

Evaluate sputtering on mirror surfaces from high-energy particles (SRT 57).

Advance Development

Assess materials for internal use to determine whether rapid aging and breakdown are caused by internal atmosphere (SRT 82).

Assess materials for external use to evaluate (A) hard vacuum effects on materials, finishes, etc.; and (B) development of processing, handling, and assembly techniques (SRT 83).

Supporting Development

Develop image tubes with greater spacial resolution than now currently obtainable (SRT 84).

3.2.5.6 Development Cost and Schedules

The Phase D cost is shown in Table 3-35, which shows both development and operations costs. The development schedule is shown in Figure 3-35. Quantities of equipment required in development are shown in Table 3-36.

3.2.5.7 Instrumentation Section

Photoelectric Spectrophometer (See Figure 3-36)

The two photoelectric spectrophometers are identical except for the wavelength range involved. One unit covers the UV spectral range while the other is principally designed for the visible range with the near-UV and IR

Table 3-35 (page 1 of 2)

TASK COST ESTIMATE - PHASE D
1-METER NON-DIFFRACTION-LIMITED UV-VISIBLE-IR-NORMAL INCIDENCE TELESCOPE, STELLAR (OASF INSTRUMENT NO. 45)--
($ Thousands)

Development total	10,729		
Engineering		1,010	
Detectors		*	
35-mm digital magnetic tape recorder			*
35-mm strip film			*
Spectrograph film			*
Field lens and/or image tube			*
Collecting optics		353	
1.0-m primary mirror			97
Secondary mirror			30
Secondary mirror alignment assembly			226
Fine guidance		664	
Guidance optics			*
Sensor			*
Control moment gyro			*
Housing		350	
Structure (including optics support)			238
Thermal shield			92
Sunshade			20
Experiment sensors		7,238	
35-mm plate camera			699
Filter wheels			150
35-mm strip camera			500
Concave grating spectrograph			600

*Cost item not derived where overall estimate for instrument is not significantly affected.

Table 3-35 (page 2 of 2)

Photopolarimeter			500
Spectrophotometer			800
Echelle spectrograph			714
Interferometer			1,000
Radiometer (cryo)			1,300
Solid-state detector matrix (cryo)			700
Optical switch			275
Major hardware articles		1,114	
Mockup			*
Engineering model			*
Project verification model			*
Qualification model			*
Operations total	4,961		
Flight instrument		3,221	
Back up flight instrument		1,289	
Engineering support		451	
Phase D total	15,690**		

*Cost item not derived where overall estimate for instrument is not significantly affected.
**Assumes previous development of Stellar ATM (GEP) optics.

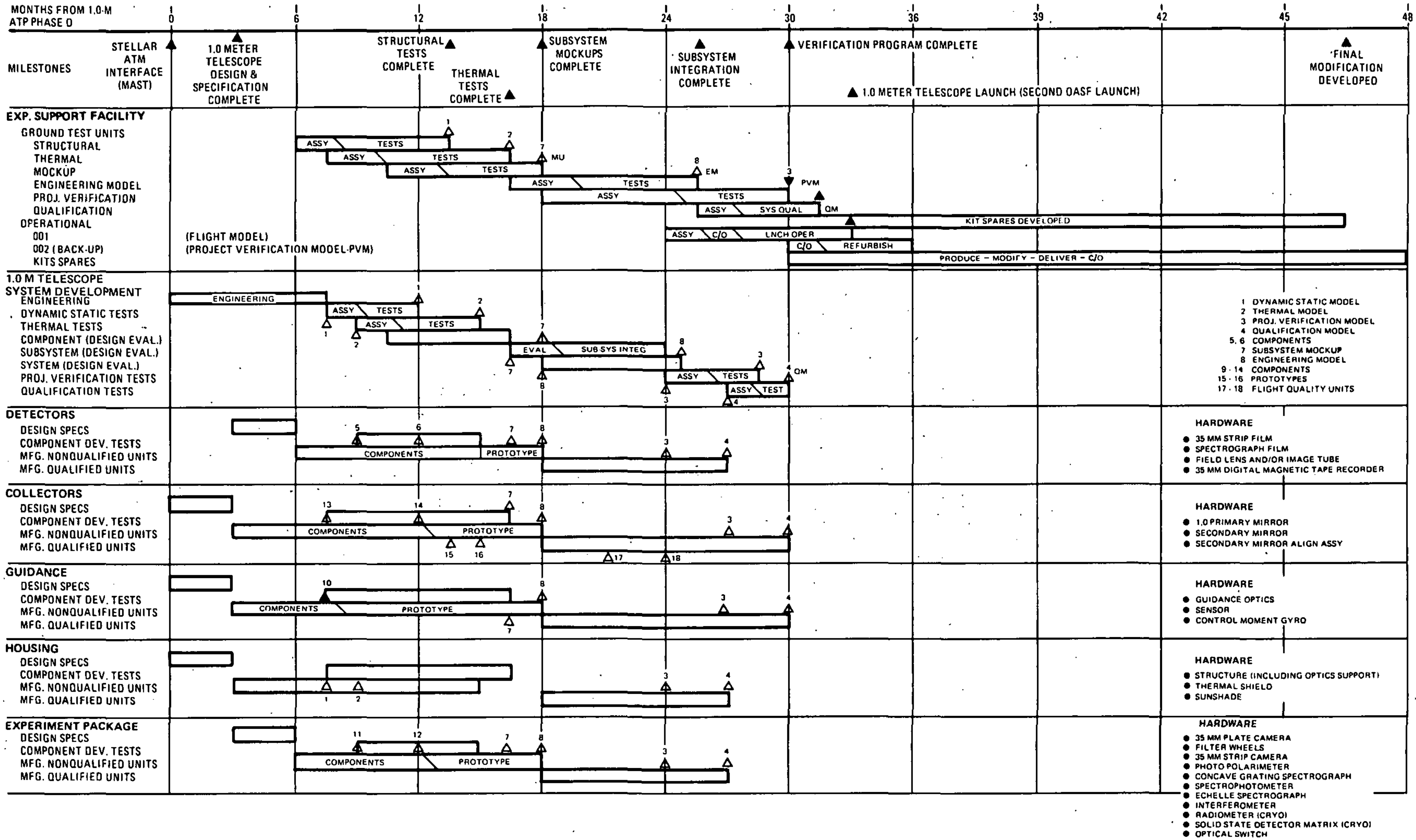

Figure 3-35. Development Schedule, 1.0 Meter Non-Diffraction-Limited UV-Visible-IR Normal Incidence Telescope, Stellar (OASF Instrument No. 45)

Table 3-36

PRIMARY INSTRUMENT EQUIPMENT LIST--DEVELOPMENT PHASE D
1-m Non-Diffraction-Limited UV-Visible-IR
Normal-Incidence Stellar Telescope
(OASF Instrument No. 45)

Functional system (major element)	Subsystem	Assemblies	Quantity		
			Bread-board	Proto-type	Flight Quality
1.0-m nondiffraction-limited UV-visible-IR telescope	Detectors	35-mm strip film	2	1	2
		Spectrograph film	2	1	2
		Field lens and/or image tube	1	2	1
		35-mm digital magnetic tape recorder	1	2	1
	Collecting optics	1.0-m primary mirror	1	2	1
		Secondary mirror	1	2	1
		Secondary mirror alignment assy	2	2	1
	Fine guidance	Guidance optics	1	1	2
		Sensor	1	1	2
		Control moment gyro	1	2	1
	Housing	Structure (including optics support)	1	1	2
		Thermal shield	1	1	2
		Sunshade			2
	Experiment sensors	35-mm plate camera	1	1	2
		Filter wheels	1	1	2
		35-mm strip camera	1	1	2
		Concave grating spectrograph	1	1	2
		Photo polarimeter	1	1	2
		Spectrophotometer	1	1	2
		Echelle spectrograph	1	1	2
		Interferometer	1	1	2
		Radiometer (cryo)	1	2	1
		Solid state detector matrix (cryo)	1	2	1
		Optical switch	1	1	2
	Major hardware articles	Mockup	1	---	---
		Engineering model	---	1	---
		Project verification model	---	60%*	40%*
		Qualification model	---	---	1

*Obtained from subsystem development quantities

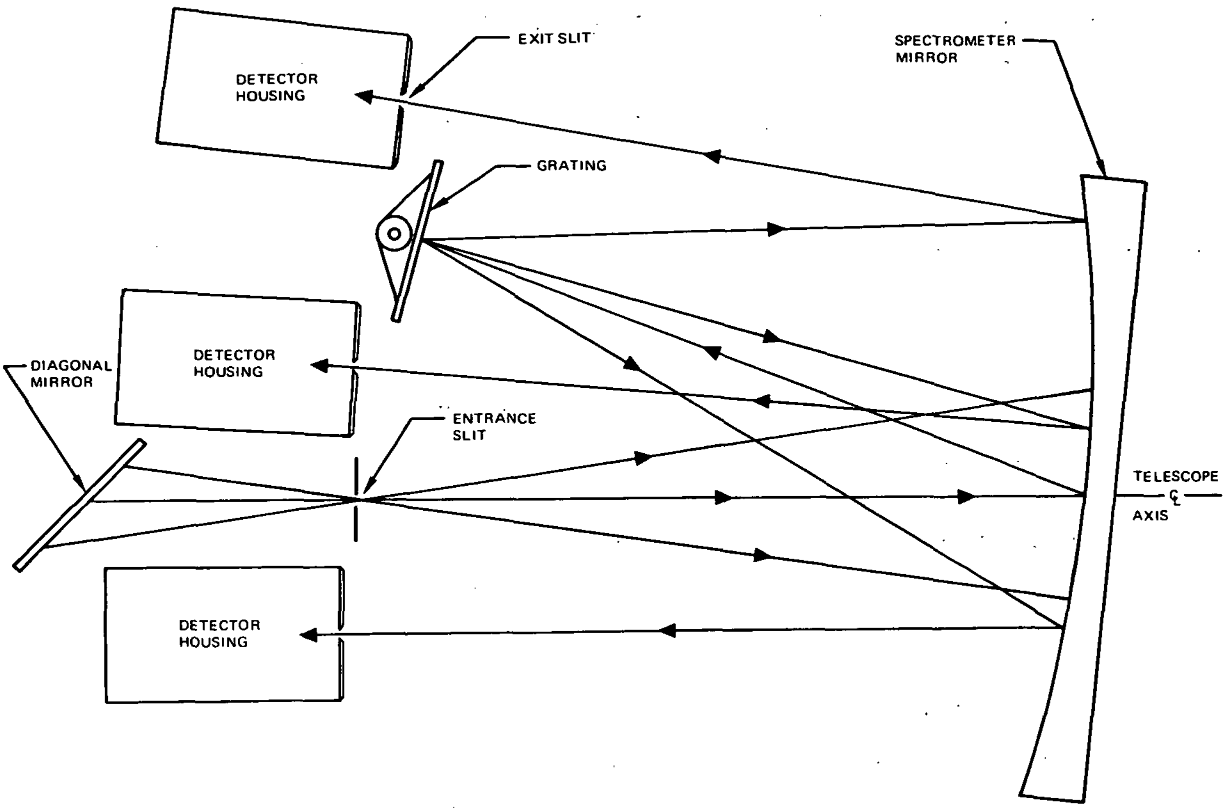

Figure 3-36. Photoelectric Spectrophotometer

included. Both are Ebert spectrometers based in general design on the Goddard Experiment Package spectrometer, but reduced in size. Each consists of an entrance slit, a concave spectrometer mirror, a slightly aspherized plane grating which is capable of scanning through a restricted angle, and three exit slots, each backed up by a photomultiplier tube selected for best response in the wavelength band to be covered.

The spectrophotometers were designed to cover the range from 800 to 4, 000 Å and 2, 500 to 12, 000 Å respectively (see Table 3-37) with a wavelength resolution ranging from 10 to 100 Å, depending on the magnitude of the observed star. A threshold of 15th magnitude is anticipated. To standardize readings, a tethered reference light source is used for calibration.

Normal-Incidence Concave-Grating Spectrograph (Figure 3-37)

The normal-incidence concave-grating spectrograph consists of a slit, a concave grating, and a camera magazine. Associated with it is a reference

Table 3-37

PHOTOELECTRIC SPECTROPHOTOMETER CHARACTERISTICS
1-Meter Non-Diffraction-Limited UV-Visible-IR
Normal-Incidence Telescope, Stellar --
(OASF Instrument No. 45)

Wavelength	
Short:	800 and 3, 200 Å
Long:	3, 200 and 12, 000 Å
Resolution:	10 Å
Entrance aperture	
Slit width:	120μ
Slit height:	120μ
Incident radiation	
f/No. limitation:	5
Spatial resolution	1 arc sec
Main grating	
Type:	Plane (Schmidt)
Size:	32 x 32 mm
Ruling frequency:	~2, 400 and ~800 lines/mm
Dispersion:	16 Å/mm at 2, 000 Å
Angle of diffraction range:	~0 to 36°
Spectral order:	1
Recorder characteristics	
Type:	Multiplier phototubes
Aperture:	6 mm
Weight	10 kg

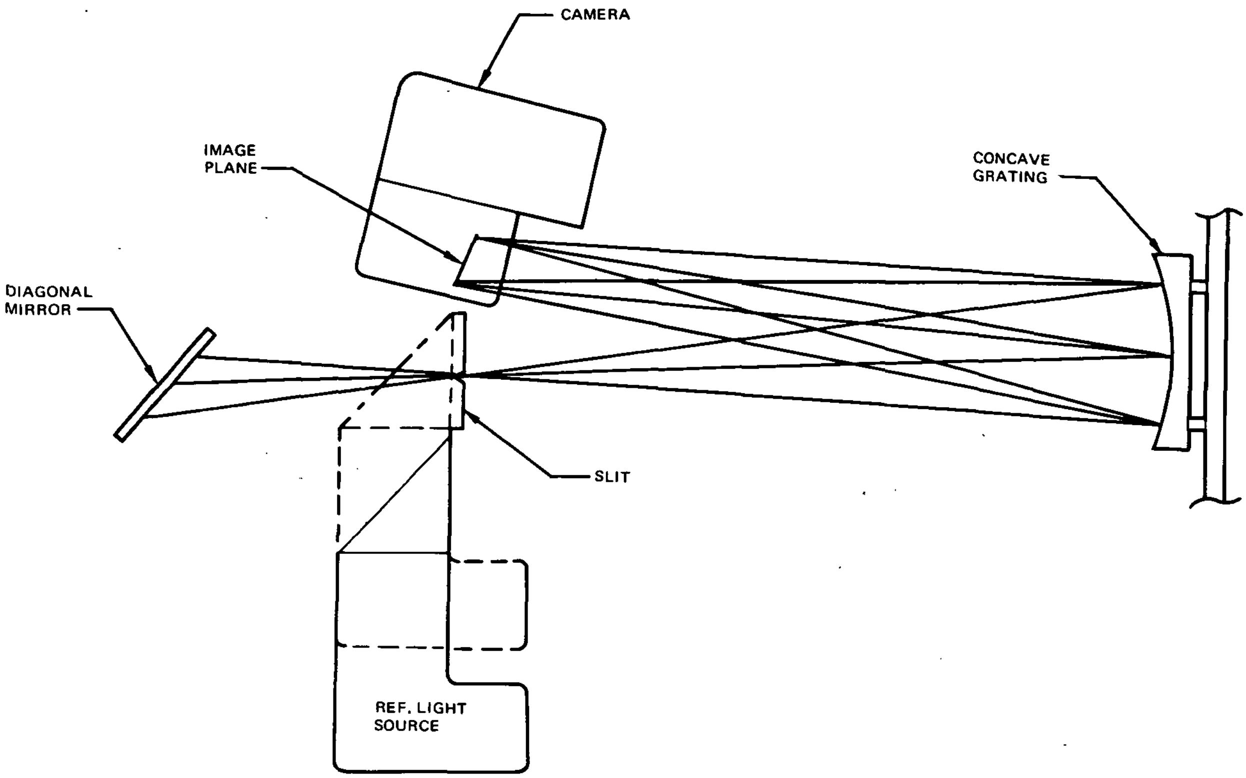

Figure 3-37. Normal Incidence Concave Grating Spectrograph

light source which introduces the energy for a comparison spectrum on the extreme ends of the slit. It was designed to cover the range from 1,000 to 3,000 Å, with a dispersion of 100 Å/mm (see Table 3-38). An interchangeable grating is provided to double the dispersion to 50 Å/mm for a more detailed examination of the details of the shortwave-end of the spectrum. An Eagle mount spectrograph with virtually normal incidence and based on a Rowland circle of 25-cm diam meets all requirements if the grating is ruled with 400 lines/mm, and alternate grating with 800 lines/mm.

Echelle Spectrograph (Figure 3-38)

Where higher dispersion requires a film format that is larger than a double frame, it is possible to generate a compact format by the use of a crossed grating technique. Schroeder has described the technique as applied to an echelle grating spectrograph (Reference 3-4).

Table 3-38

CONCAVE GRATING SPECTROGRAPH CHARACTERISTICS
1-Meter Non-Diffraction-Limited UV-Visible-IR
Normal-Incidence Telescope, Stellar
(OASF Instrument No. 45)

Type:	Normal incidence (Eagle mount)
Wavelength	
Short:	1,000 Å
Long:	3,000 Å
Resolution:	2 Å at 1,500 Å
Entrance aperture	
Slit width:	20 μ
Slit height:	300 μ
Incident radiation	
f/No. limitation:	15
Spatial resolution:	1.4 sec
Main grating	
Type:	Concave
Size:	33.3 wide x 36.6, 52 mm
Ruling frequency:	200 and 400 lines/mm
Dispersion:	100 Å/mm at 1,500 Å
Angle of diffraction range:	$0.29^{\circ} - 2.58^{\circ}$, $2.3^{\circ} - 6.9^{\circ}$
Spectral order:	1
Recorder characteristics	
Type:	Film
Aperture:	25 x 15 (wide) mm
Remote change cycle time:	15 sec
Film type limitations:	Schumann type
Exposure per magazine load:	150
Power consumption during cycle change:	2 W
Weight	12.5 kg (including 10 kg for plate camera)

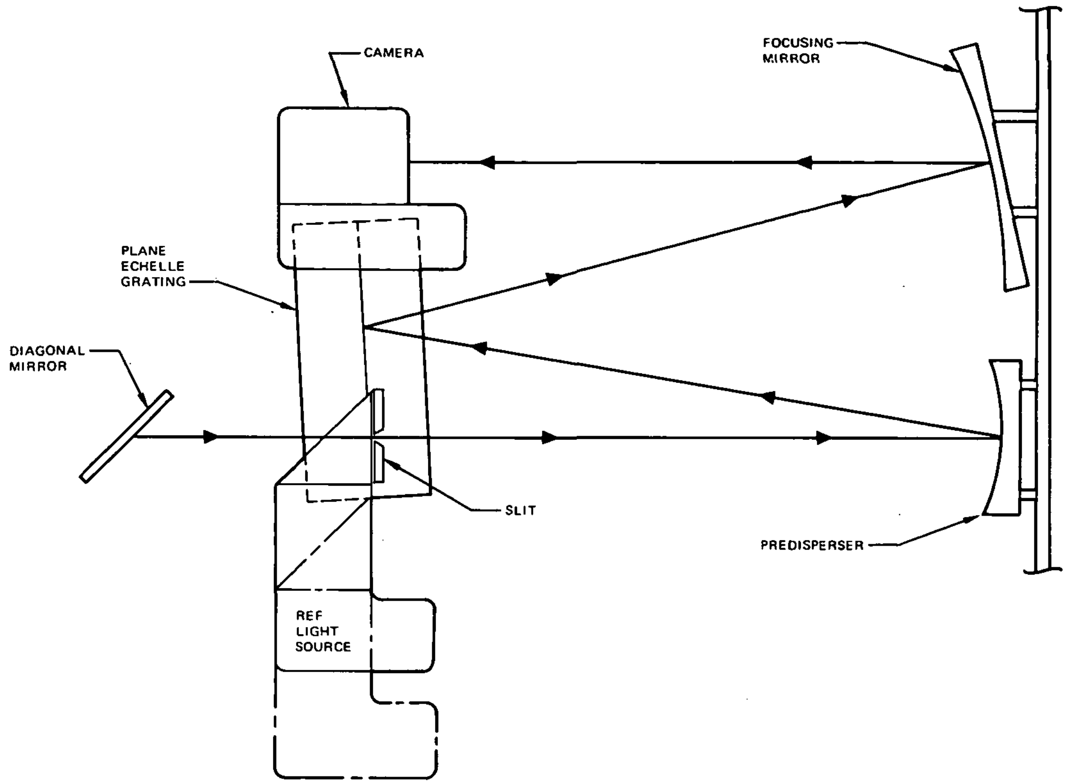

Figure 3-38. Echelle Spectrograph

The spectrograph was designed to provide a dispersion of 10 Å/mm and to cover the range of 800 to 3,000 Å (see Table 3-39). It consists of a slit, a concave predisperser grating, a plane echelle main grating, a concave focusing mirror, and a camera magazine. A reference light source provides comparison spectrum capability. Interchangeable gratings, both predisperser and main can be provided to alter the parameters of the instrument to suit a specific observation. The 20-cm focal length of the spectrograph allows compact packaging.

<u>Slitless Spectrograph</u> (See Figure 3-39)

The slitless spectrograph is designed to make photographic records of extended celestial sources, such as diffuse and planetary nebulae in the light of any one of a series bright spectral lines. To this end, the slit of the spectrograph is replaced by a field stop designed to include the desired field and exclude all else. Because of the diffuse nature of the object being

Table 3-39

ECHELLE SPECTROGRAPH CHARACTERISTICS
1-Meter Non-Diffraction-Limited UV-Visible-IR
Normal-Incidence Telescope, Stellar
(OASF Instrument No. 45)

Wavelength	
Short:	800 Å
Long:	3,000 Å
Resolution:	0.2 Å at 2,000 Å
Entrance aperture	
Slit width:	20μ
Slit height:	300μ
Incident radiation	
f/No. limitation:	5
Spatial resolution:	0.24 sec
Predisperser grating	
Type:	Concave
Size:	42 x 42 mm
Ruling frequency:	500 lines/mm
Dispersion:	100 Å/mm
Angle of diffraction range:	2.3° - 8.6° dispenser
Spectral order:	1
Main grating	
Type:	Echelle
Size:	35 x 60 mm
Ruling frequency:	490 lines/mm
Dispersion:	10 Å/mm at 2,000 Å
Angle of diffraction range:	23.3° - 33.3°
Spectral order:	7-24
Recorder characteristics	
Type:	Film
Aperture:	25 x 35 mm wide
Remote change cycle time:	15 sec
Film type limitations:	Schumann type
Exposure per magazine load:	50
Power consumption during cycle change:	2 W
Weight	16 kg (including 10 kg for plate camera)

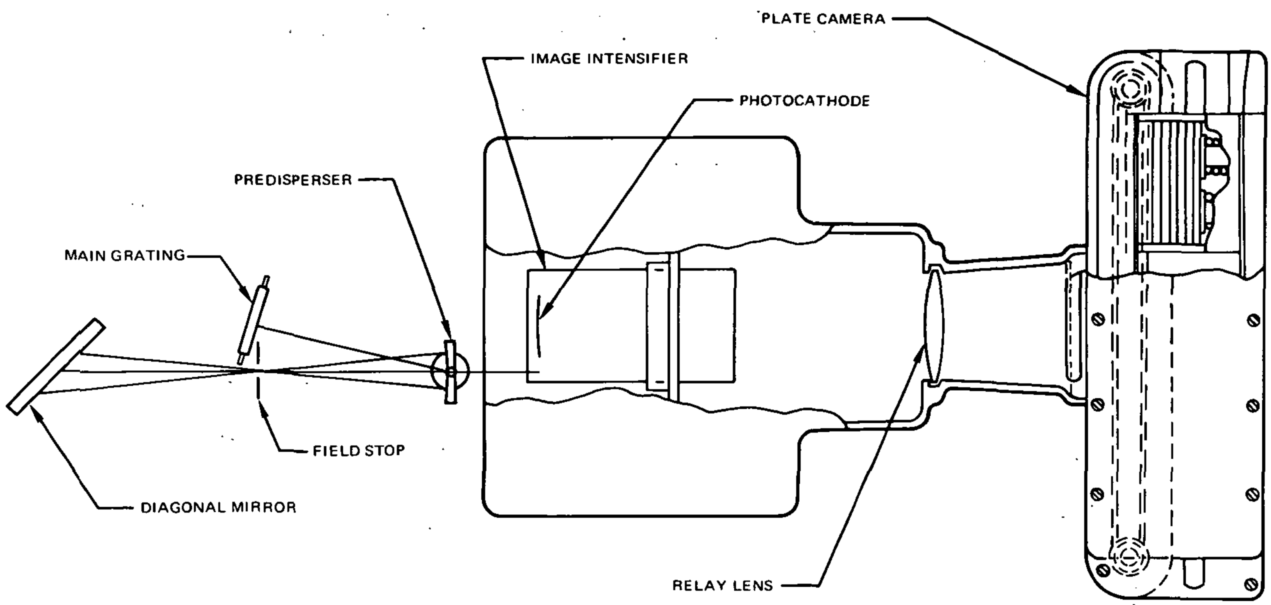

Figure 3-39. Image-Intensifier Slitless Spectrograph

recorded, an image intensifier is placed at the spectrograph focus. A conventional intensifier with a semitransparent cathode is shown in Figure 3-39 but current progress in the application of open tubes could result in an extension of the spectral range below the 1,050 Å cutoff (see Table 3-40). The instrument shown uses a predisperser in preference to filters for order separation in the interest of increased efficiency.

The instrument is composed of the field stop, the two gratings, predisperser and main, an image intensifier, an optical relay, and a camera magazine. Although a plate camera is shown in the drawing, a roll-film camera could also be employed.

Table 3-40

SLITLESS SPECTROGRAPH CHARACTERISTICS
1-Meter Non-Diffraction-Limited UV-Visible-IR
Normal-Incidence Telescope, Stellar
(OASF Instrument No. 45)

Type:	Echelle - scanning - image intensifier
Wavelength	
Short:	800 Å
Long:	4, 000 Å
Resolution:	2. 5 Å at 2, 000 Å (second order)
Entrance aperture	14, 600μ x 14, 600μ slitless
Incident radiation	
f/No. limitation:	5
Spatial resolution:	1. 5 sec
Predisperser grating--scanning	
Type:	Concave
Size:	36 x 36 mm
Ruling frequency:	572 lines/mm
Dispersion:	80 Å/mm
Angle of diffraction range and incidence range:	1. 31° disperser
Spectral order:	1 and 6. 57°
Main grating	
Type:	Concave
Size:	36 x 36 mm
Ruling frequency:	499 lines/mm
Dispersion:	50 Å/mm at 2, 000 Å
Angle of diffraction range and incidence:	2. 29° - 5. 73°
Recorder characteristics	
Type:	Film and image intensifier photo tube
Aperture:	25 mm
Remote change cycle time:	15 sec
Film type limitations:	Matched to phosphor
Exposure per magazine load:	150
Power consumption during cycle change:	2 W
Weight	14 kg (including 12 kg for plate camera)

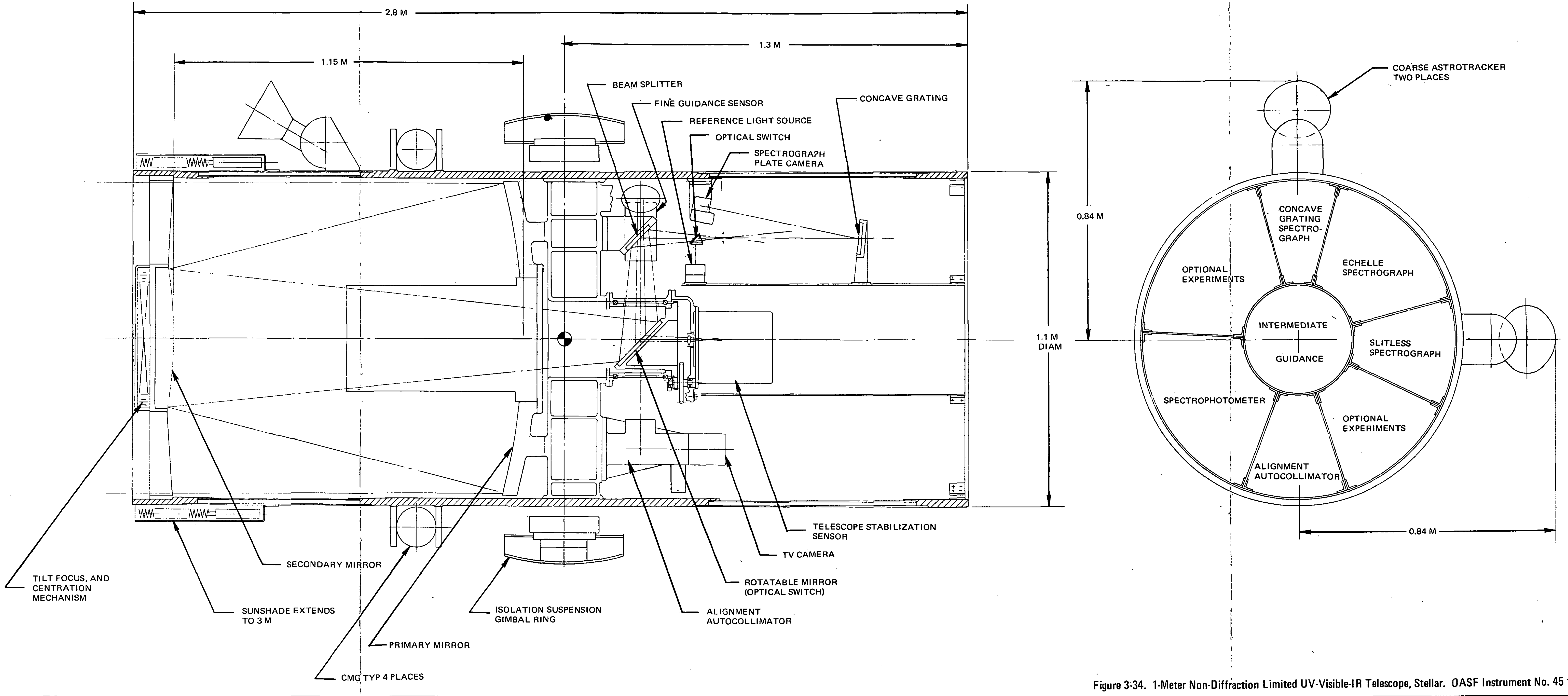

Figure 3-34. 1-Meter Non-Diffraction Limited UV-Visible-IR Telescope, Stellar. OASF Instrument No. 45

3.2.6 1-Meter Diffraction-Limited UV-Visible-IR Normal-Incidence Telescope, Stellar-OASF Instrument No. 34

3.2.6.1 General Characteristics

To perform the tasks of high-resolution planetary photography and high-dispersion stellar spectrography, a 1-m-aperture telescope, diffraction-limited at 4,000 Å, is recommended (Figure 3-40). This instrument provides an angular resolution of 0.1 arc sec in the UV region, and a resolution almost that fine in the blue region of the spectrum.

The telescope presented here was derived from the Princeton Experiment Package of the OAO series. It anticipates a partially manned mission, with some of the observations being remotely performed. Therefore, the use of film as a detector is limited, and video detectors, specifically SEC vidicons, provide the bulk of the recording.

This Cassegrainian-configuration telescope has a 1-m-aperture, a 2-m-focal-length primary mirror, and a secondary mirror that provides a five-power magnification, giving an effective focal length of 10 m. The image is brought to an "optical switch" (Figure 3-41) behind the primary mirror. The optical switch is a rotatable mirror (for choosing between the two imagery optical paths) with a slit (for the spectrograph). Each of the imagery optical paths includes a relay lens of special design to give an additional magnification of 20 power, thus making the effective focal length of the cameras 200 m. The spectrograph is of the echelle type, covering the spectral range in a number of diffraction-pattern orders. To match the resolution of the spectrograph to that of the vidicon camera, the format is large, requiring about seven successive exposures and a scanning sequence to record the spectrum.

In the converging beam of light before the Cassegrain focus is a set of three corrector lenses to provide an extended field for guidance. The central portion of each of these correctors is removed to leave the on-axis light rays unaffected. The image formed by the corrector lenses is interrupted by two articulated prism-and-lens assemblies called "image movers" (Figure 3-42), which relay the intercepted portion of the image to the image plane of a pair of star trackers. The articulation permits the trackers to see two stars

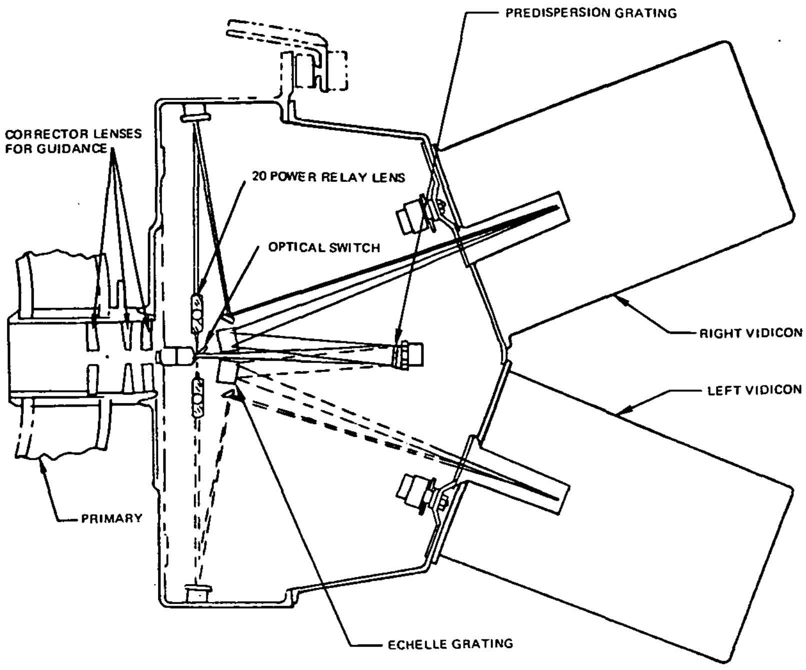

Figure 3-41. Echelle Spectrograph and Photographic Optical Layouts

selected from the annulus surrounding the observed star. Thus, a variable offset to two stars can be used providing guidance information in three axes.

The telescope was originally designed chiefly as a stellar spectrograph instrument and high-resolution star field recorder. While it meets the requirements for the 1.0-m diffraction-limited stellar telescope whose function is to perform planetary photography and stellar spectrography, the guidance technique employed in the original telescope design is suitable for the spectrographic function only. For present purposes, the guidance is modified to provide on-axis tracking for planetary photography so that the telescope is guided by the planet being recorded rather than by nearby stars. This is done by inserting a beam splitter and mirror to tap off some of the main-optical-path energy and transfer it to the guidance optical path as illustrated in Figure 3-42. A supplementary lens corrects for the shift in focus caused by change in path length.

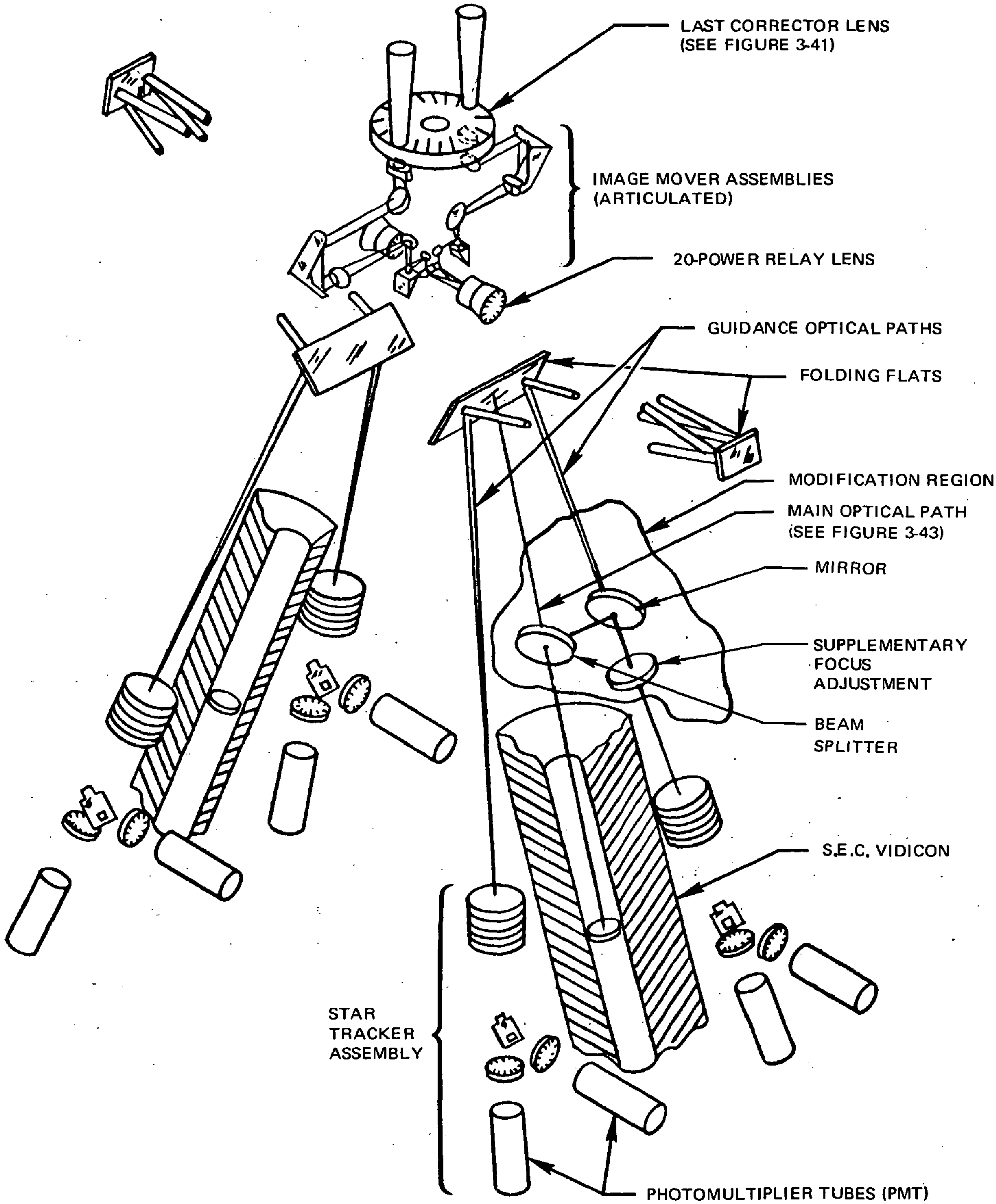

Figure 3-42. Fine Guidance System, Showing Modification for Planet Tracking

External modifications to the telescope include the installation of a 4-m-long sunshade, removal of the magnetic pusher suspension and replacement by isolation gimbals suitable for the OASF orbital facilities, and the addition of outboard star trackers for acquisition and roll reference when photographing planets.

3.2.6.2 Design Criteria

Among the observations indicated by the scientific community as a part of the space astronomy program are high-resolution photography of the nearby planets, namely Mercury, Venus and Mars, and high-resolution spectrography of stars to determine the composition of the stars and intervening matter. A resolution improvement of half an order of magnitude over the best ground-based telescopes can be achieved by a diffraction-limited telescope of 1-m aperture. This same telescope, operating above the UV absorbing layers of the atmosphere, can focus the radiation down to a short wavelength limit of about 900 Å for spectroscopic analysis.

The principal requirement in the achievement of "diffraction-limited" optics is to provide optical elements that are extremely accurate both in their configuration and alignment, so as to approach closely the theoretical diffraction pattern that would be produced by "perfect" optics. The theoretical image of a distant point source (based on analysis of diffraction effects) is a central (Airy) disc surrounded by a series of concentric rings, with about 84% of the focused radiation impinging in the central disc and the remaining 16% in the rings. From this knowledge, the ability to distinguish between two point sources may be equated to the ability to distinguish between the diffraction images of those sources. When the center of the diffraction pattern for one point source lies on the "dark ring" between the central disc and the first bright ring for another point source (assumed to be of equal intensity), which gives a separation angle between the sources of

$$\theta = 1.22 \lambda / D$$

where

θ = separation angle between point sources

λ = wavelength

D = telescope aperture

the energy-intensity minimum at the midpoint between the centers of the two diffraction images is about 80% of the intensity at the centers. The separation-angle relationship in the above equation, known as "Rayleigh's criterion," is most frequently used as the criterion for the ability to distinguish between two point sources.

Any imperfection that may exist in the optical system causes some of the energy from the central disc to be redistributed into the ring system, without actually changing the diameters of the central disc or the rings. In terms of the image formed on a recording medium (film or image tube), this phenomeon can have the same effect as simply enlarging the central disc. For example, if deviations in the optical path lengths through the system are on the order of $\frac{\lambda}{4}$ (a value investigated by Rayleigh and known as "Rayleigh's limit"), the brightness in the inner two or three rings is approximately doubled at the expense of some of the brightness in the central disc. In effect, the image of a distant point source is more than doubled in size, with a corresponding loss in ability to distinguish between closely spaced sources, ability to see detail, and ability to distinguish faint sources close to bright ones. To approach closely the theoretical performance attainable by "perfect" optics, it is desirable to achieve tolerance limits much more stringent than the Rayleigh limit. Current standards for "diffraction-limited" optics for reflective systems (note that any deviation of a reflective surface produces twice that deviation in the optics path length) limit the root-mean-square (rms) value of the surface deviation to $\frac{\lambda}{50}$. This deviation limit, in turn, limits the energy intensity impinging in the ring pattern to less than a 5% increase over the intensity in the rings experienced with "perfect" optics (References 3-5, page 413 and 3-6, page 444).

3.2.6.3 Detailed Characteristics

The basic characteristics of the 1-m diffraction-limited UV-visible-IR normal-incidence stellar telescope have been summarized in Figure 3-2 in Section 3.1.

Additional details about the instrument are tabulated in Table 3-41, 3-42, and 3-43.

3.2.6.4 Utilization of Man

Setup and maintenance requirements are summarized for this instrument in Table 3-44. Because man's utilization in the operation of the instrument depends on the observational program, operational information is separately summarized in Table 3-45.

Deployment

Erecting the star trackers, uncovering mirrors, gratings, and cameras, and erecting the magnetic suspension and gimbals can be done automatically with man as backup. The optical surfaces (telescope and instrumentation) are inspected so that their initial condition is known for comparison at a later time.

Outgassing after exposure to atmospheric contaminants is a problem for this telescope. Because it has a number of TV vidicons, photomultiplier tubes (PMT), and other electronic components that have high voltages, high-voltage arc-over and consequent deterioration of optical surfaces can become important considerations during later phases of operation. Therefore, the telescope surfaces must be given sufficient opportunity to outgas in vacuum before the electrical components are energized.

Alignment

An optical technician observing a TV monitor screen (projected image from an autocollimator) and using remote controls checks and adjusts the optical alignment (tilt, centration, and focus). The procedure is similar in that described for the 1-m non-diffraction-limited UV-visible-IR telescope (OASF Instrument No. 45) in the corresponding paragraph of Section 3.2.5.4.

Calibration

Because all the data sensors in this instrument are electro-optical, the calibration procedure is typified by that of the guidance PMT's. Selected

Table 3-41

COLLECTOR PARAMETERS
1-M Diffraction-Limited UV-VIS-IR
Normal-Incidence Stellar Telescope--OASF Instrument No. 34

Aperture	1.017 m
Primary focal length	2.034 m
Effective focal length	10.17 m
Total field of view	2 arc min.
Angular resolution	
On axis	0.1 arc sec at 4,000 Å
Poorest in field of view	0.15 arc sec at 4,000 Å
Obscuration of aperture	5%
Minimum wavelength	900 Å
Maximum wavelength	6,000 Å
Primary/No.	2
System/No.	10
Scale at system focal plane	20.3 arc sec/mm
Resolution at system focal plane	203 lines/mm
Linear field of view at system focal plane	5.9 mm

astronomical objects (for example, luminosity-standard MKK stars) are observed and the sensitivity of the PMT's determined from a comparison of the observed to the standard values. This procedure should apply equally well to both the imaging and the spectrographic sections of the instrument.

Operation

After the target object has been located on the TV monitor connected to the telescope viewfinder, the SEC vidicon scans the image (bit by bit, because the

Table 3-42

INTERFACE CHARACTERISTICS
1-M Diffraction-Limited UV-VIS-IR
Normal-Incidence Stellar Telescope--OASF Instrument No. 34

General	
System weight (less expendables)	≈240 kg
System volume (launch configuration)	≈4.1 m^3
System shape (launch configuration)	Cylindrical
Method of accomplishing...	
Deployment	Remove plastic air bags, uncap, and magnetic suspension
Alignment	Motor-driven, using TV and autocollimator
Calibration	Standard source
Operation	Remote viewing and telemetry
Stowage requirements (launch)	
Mechanical	Inflatable plastic bags and plastic bag covering
Experiment data handling	
Format	1-in. SEC vidicon
Recording media	Real-time telemetry
Mode of data recovery	Telemetry
Power consumption	
Stowed	None
Standby	≈90 W
Operate	≈150 W

Table 3-43

GUIDANCE AND CONTROL CHARACTERISTICS
1-M Diffraction-Limited UV-VIS-IR
Normal-Incidence Stellar Telescope--OASF Instrument No. 34

Guidance characteristics	
Coarse	
Initial acquisition field of view	$\pm 5^o$
Resolution	±15 arc sec
Residual error	±1 arc min.
Intermediate	
Field of view	±3 arc min.
Fine	
Field of view	±1 arc min.
Resolution	±0.01 arc sec
Residual error	±1 arc sec
Control characteristics	
CMG	
Type:	Single degree of freedom, viscous damped
Wheel momentum:	≈640 oz-in-sec
Gimbal stops:	$\pm 60^o$
Spin motor power (start):	40 W
(run):	6 W
Servo power (peak):	10 W
(average):	1.5 W
Max. torque:	3.8 oz-in.
Weight:	16 lb
Diameter:	5 in.
Length:	8-1/2 in.
Suspension characteristics	
Type:	Two axis bearing supported gimbals
Bearing breakaway torque:	≈0.005 oz-in.

20-power relay lens looks at only a small portion of the field of view at any time) in the focal plane until the entire field of view has been recorded. This may take several orbits, which would require halting the scan and repositioning of the telescope in the middle of an exposure after each interruption.

Table 3-44

SETUP AND MAINTENANCE REQUIREMENTS
1-M Diffraction-Limited UV-VIS-IR
Normal-Incidence Stellar Telescope--OASF Instrument No. 34

Operation	Average Times per Year	Duration (hours)	No. of Men	Skill Identification*	Hours per Man	Average Power (W)	Special Equip Weight (lb)	Special Equip Volume (ft^3)
Deployment	---	2	1	21	2	---	---	---
Alignment	---	12	1	14	12	15	---	---
Calibration	---	9	1	21	9	5	---	---
			1	12	1			
Scheduled maintenance	6	4	1	14	1	15	15	2
Unscheduled maintenance	1/2	3	1	12	2	15	30	3
			1	14	1			

*Skills are identified by number in Table 3-3.

Table 3-45

OPERATION SUPPORT AND REQUIREMENTS
1-M Diffraction-Limited UV-VIS-IR
Normal-Incidence Stellar Telescope--OASF Instrument No. 34

ORDS No.	Time per Observation (hours)	No. of Men	Skill Identification*	Manhours/ Observation	Start Time (hours from start of observation)	Number of Observations
020	0.16	1	5	0.5	-0.25	350/year
021, 022	0.67	1	5	1.0	-0.25	1,000
035, 036	1.0	1	5	1.25	-0.25	300
040	0.01	1	5	0.3	-0.25	500

*Skills are identified by number in Table 3-3.

Scheduled Maintenance

The optical technician checks the mirrors (and other optics) for alignment and reflective efficiency. The electromechanical technician inspects the electronics components (TV cameras and PMT's) including voltage checks for evidence of deterioration.

Unscheduled Maintenance

Failed electronic components (particularly the PMT's which are vacuum tubes and thus inherently less reliable than solid-state circuitry) are replaced. PMT failure may occur almost immediately after onset of initial signs (voltage changes, cathode efficiency change); therefore, the regular maintenance checks may not reveal a potential failure unless it is immediately imminent.

3.2.6.5 Supporting Research and Technology

Supporting Research and Technology (SRT) requirements for the 1-Meter Diffraction Limited UV-VIS-IR Normal Incidence Telescope (Instrument No. 34) are listed below. Full descriptions of SRT items are given in Section 4.3.

Research and Advance Technology

Develop methods for rapidly evaluating mirror figure and alignment under one-gravity and zero-gravity environments (SRT 1).

Conduct experimental studies of precision structural properties of mirror material related to optical performance (SRT 2).

Develop methods for generating and maintaining diffraction-limited (5,000 Å) mirror quality in orbital environments (SRT 3).

Develop mirror surfaces to provide high UV reflectivity, precision of figure, and freedom from scattering (SRT 4).

Develop cantilevered mirror as a reflective beam deflector (SRT 5)

Develop XUV-sensitive imaging tubes for use below 1,050 Å (SRT 11).

Investigate degradation of telescope detector and reflective surfaces resulting from 0_2 exposure (SRT 42).

Investigate mirror support structures that minimize the mechanical and optical problems of Cassegrainian telescopes (SRT 54).

Investigate techniques for alignment and focusing mechanisms for optical telescopes (SRT 55).

Investigate the dimensional stability of candidate mirror materials (SRT 56).

Evaluate sputtering on mirror surfaces from high-energy particles (SRT 57).

Advanced Development

Assess materials for internal use to determine whether rapid aging and breakdown are caused by internal atmosphere (SRT 82).

Assess materials for external use to evaluate (a) hard vacuum effects on materials, finishes, etc.; and (b) development of processing, handling, and assembly techniques (SRT 83).

Supporting Development

Develop image tubes with greater spatial resolution than currently obtainable (SRT 84).

Develop photographic emulsions with improved spatial resolution (SRT 84A).

3.2.6.6 Phase D Cost

The Phase D cost is shown in Table 3-46 which shows both development and operation costs. The development schedule is shown in Figure 3-43. Quantities of equipment required in development are shown in Table 3-47.

3.2.6.7 Instrumentation Section

Large-Scale Image Recorder (See Figure 3-44)

The large-scale image recorder consists of an SEC-vidicon television camera, a 20-power microscope objective relay lens, and a pair of folding mirrors. For reliability, complete redundancy is provided so that the failure of one video tube will not negate the entire program. A photographic camera magazine could replace one of the video cameras. The relay lens is a triplet consisting of fused silica and LiF elements to permit transmission down to 2,000 Å. The field of view on the vidicon format with the 200-m effective focal length is approximately 22 sec, which is sufficiently large to record

Table 3-46 (page 1 of 2)

TASK COST ESTIMATE - PHASE D
1-Meter Diffraction Limited UV-Visible-IR Normal-Incidence Telescope, Stellar (OASF Instrument No. 34)--

($ thousands)

Development total	6,719		
Engineering		550	
Detectors		*	
35-mm digital magnetic tape recorder			*
35-mm strip film			*
Spectrograph film			*
Field lens and/or image tube			*
70-mm plates			*
Collecting optics		421	
1.0-m primary mirror			125
Secondary mirror			45
Secondary mirror alignment assembly			251
Fine guidance		490	
Guidance optics			*
Sensor			*
Control moment gyros			*
Housing (primarily servo aspect and hardware)		258	
Structure (including optics support)			238
Inflatable sunshade			20
Experiment sensors		3,900	
Filter wheels			150

*Cost item not derived where overall estimate for instrument is not significantly affected.

Table 3-46 (page 2 of 2)

Interferometer			800
35-mm plate camera			550
70-mm plate camera			650
35-mm cine camera			775
Echelle spectrograph			750
Optical switch			275
Major hardware articles		1,100	
Mockup			*
Engineering model			*
Project verification model			*
Qualification model			*
Operations total	3,104		
Flight instrument		2,016	
Backup flight instrument		806	
Engineering support		282	
Phase D total	9,823**		

*Cost item not derived where overall estimate for instrument is not significantly affected.

**Assumes previous development of 1-m non-diffraction-limited OASF Instrument No. 45.

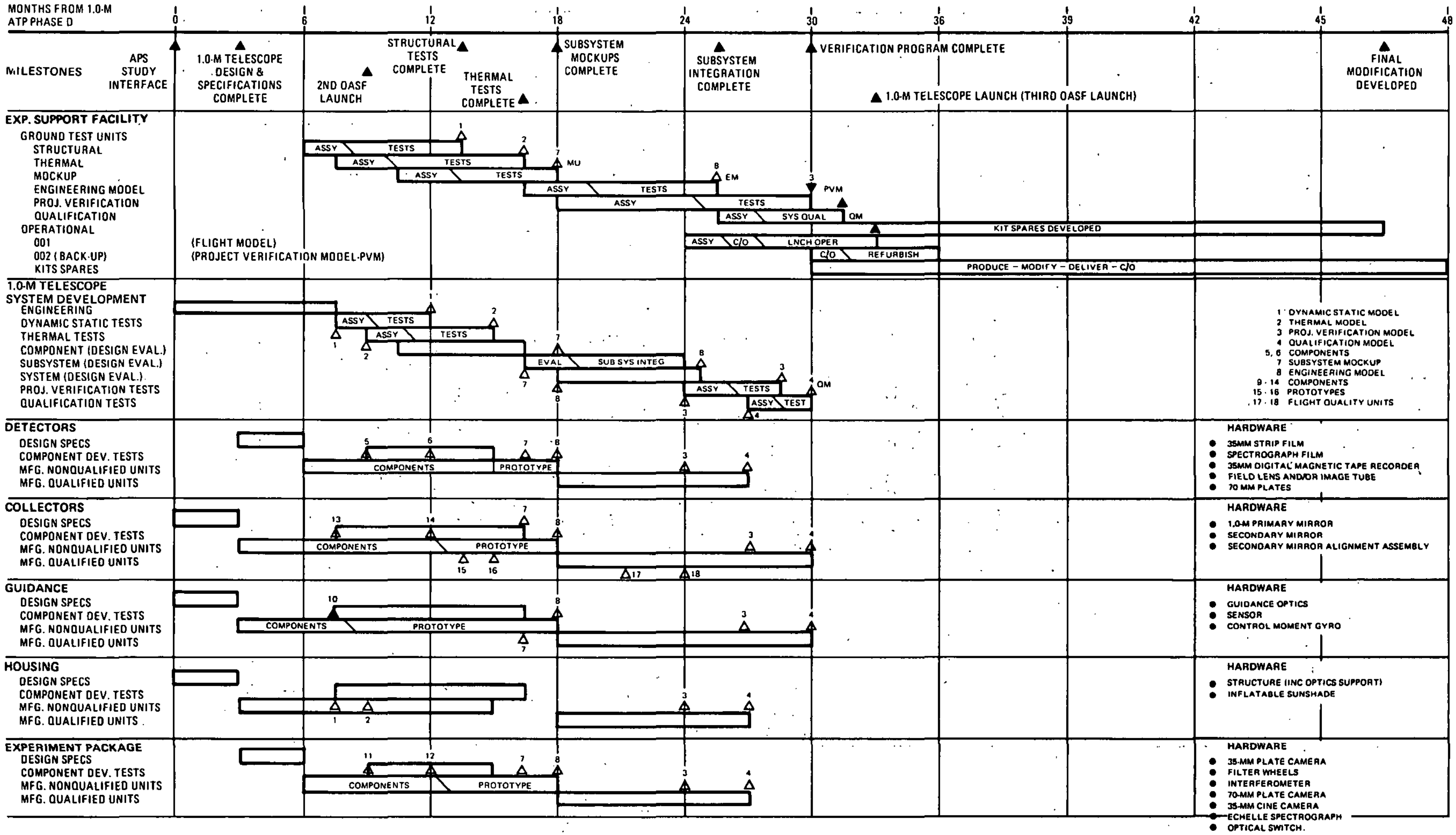

Figure 3-43. Development Schedule, 1-Meter Diffraction-Limited UV-Visible-IR Normal Incidence Telescope, Stellar (OASF Instrument No. 34)

Table 3-47

PRIMARY INSTRUMENT EQUIPMENT LIST--DEVELOPMENT PHASE D--(MID-LATE) (APS)

1.0-Meter Diffraction-Limited UV-Visible-IR Normal-Incidence Stellar Telescope (OASF Instrument No. 34)

Functional System (Major Element)	Subsystem	Assemblies	Quantity		
			Bread-board	Proto-type	Flight Quality
1.0-m diffraction-limited UV-visible-IR telescope	Detectors	35-mm strip film	2	1	2
		Spectrograph film	2	1	2
		Field lens and/or image tube	1	2	1
		70-mm plates	1	2	1
		35-mm digital magnetic tape recorder	1	2	1
	Collecting optics	1.0-m primary mirror	1	2	1
		Secondary mirror	1	2	1
		Secondary mirror alignment assy	2	2	1
	Fine guidance	Guidance optics	1	1	2
		Sensor	1	1	2
		Control moment gyro	1	2	1
	Housing	Structure (including optics support)	1	1	2
		Inflatable sunshade	---	---	2
	Experiment sensors	35-mm plate camera	1	1	2
		Filter wheels	1	1	2
		70-mm plate camera	1	1	2
		35-mm cine camera	1	1	2
		Echelle spectrograph interferometer	1	1	2
		Optical switch	1	1	2
	Major hardware articles	Mockup	1	---	---
		Engineering model	---	1	---
		Project verification model	---	60%	40%*
		Qualification model	---	---	1

*Obtained from subsystem development quantities.

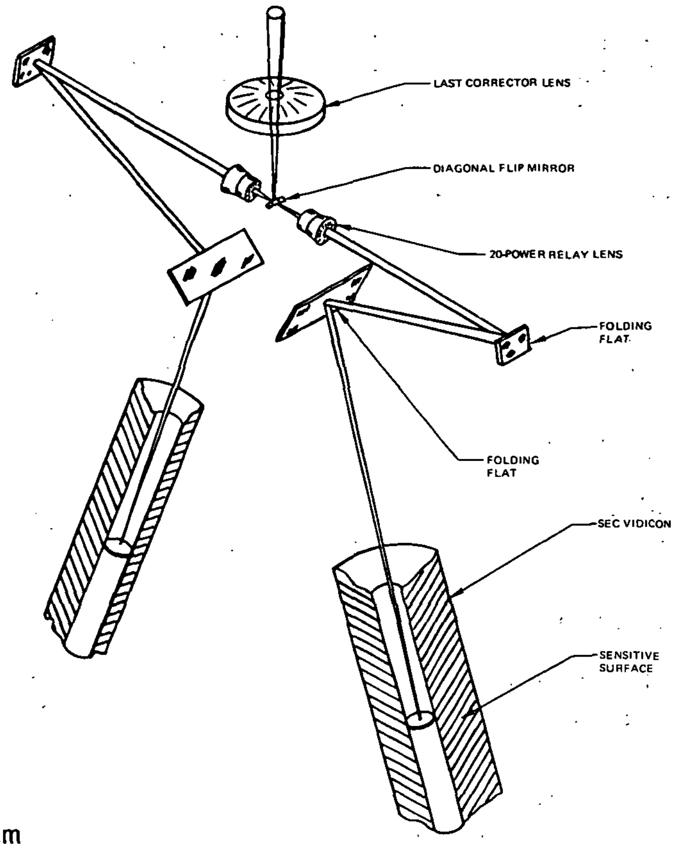

Figure 3-44. F/200 Imaging System

the entire crescent of Mercury, approximately 90% of the Martian diameter at opposition, and about two-thirds of Venus's crescent at its closest observable range. A minor adjustment in the magnification of one of the relay lenses could well be made to permit the inclusion of the entire image on a single exposure.

Echelle Spectrograph (See Figure 3-41)

The other principal function of this telescope is to record spectrograms of stars and planetary atmospheres for determining their chemical constituents. To this end, as echelle spectrograph is included, it serves the purpose well by folding the desired range of spectrum (from 800 to 3,000 Å) (see Table 3-48) into a compact format.

The spectrograph consists of a slit, a concave predisperser grating, a pair of flat echelle gratings and the same image tubes that are used to record the image field. The slit is a part of the rotatable mirror (optical switch) that

Table 3-48

ECHELLE SPECTROGRAPH CHARACTERISTICS
1-M Diffraction-Limited UV-Visible-IR Normal-Incidence
Stellar Telescope--OASF Instrument No. 34

Wavelength	
Short:	800 Å
Long:	3,000 Å
Resolution:	0.1 Å at 1,000 Å
Entrance aperture	
Slit width:	25-100μ
Slit weight:	700μ
Incident radiation	
f/No. limitation:	10
Spatial resolution:	0.1 arc sec
Predisperser grating	
Type:	concave
Size:	25 x 25 mm
Ruling frequency:	720 line/mm
Dispersion:	25 Å/mm at 1,000 Å
Spectral order	1
Main grating	
Type:	Plane echelle
Size:	32 x 32 mm
Ruling frequency:	360 lines/mm
Dispersion:	1 Å/mm at 1,000 Å
Spectral order:	13-40
Recorder characteristics	
Type:	SEC vidicon
Aperture:	25.4 x 22 mm
Remote change cycle time:	Variable
Limitations:	20 lines/mm
Power consumption	10 W
Window material:	LiF
Weight	5 kg

directs the optical path to either of the vidicons cameras. The predisperser grating can be tilted to direct the return beam to either of the two echelle gratings, depending on which camera tube is to be employed. The gratings are capable of limited scanning to select the portion of the format to be recorded, as it takes seven exposures to cover the entire format. The echelle gratings are immediately adjacent to the second of the folding flats in each line of sight to keep the rays arriving at the vidicon virtually normal to the face plate in either case.

Provision for recording a comparison spectrum is considered a comparatively straightforward engineering task.

As in the case of the image field recorder, the addition of versatility to the spectrograph, by establishing different parameters for each of the echelle gratings, is anticipated. By this means, it is possible to increase the overall coverage, yet retain the capability of deriving the critical information in the event of the failure of either camera tube.

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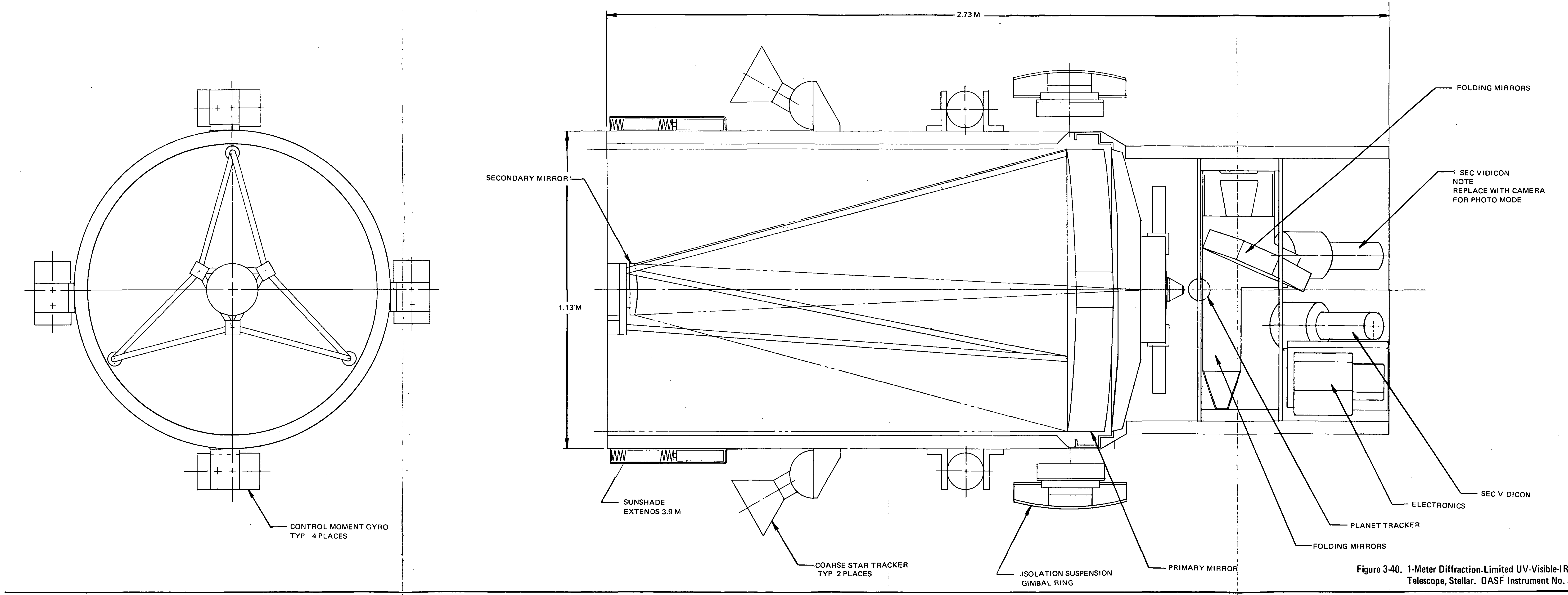

Figure 3-40. 1-Meter Diffraction-Limited UV-Visible-IR Telescope, Stellar. OASF Instrument No. 34

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3.2.7 0.3-Meter UV Schmidt Normal-Incidence Telescope, Stellar-OASF Instrument No. 33

3.2.7.1 General Characteristics

The 0.3-m all-reflective Schmidt Camera (Figure 3-45) described in this section is a modification of the all-reflective Schmidt Camera built for Northwestern University and described in References 2-5 and 3-7.

The following description of the Schmidt Camera is given in Reference 3-8.

> The basic principle of (the "Schmidt) Camera" is that a single concave spherical mirror with a stop at its center of curvature has no unique axis and therefore yields equally good images at all points of its field. The field is curved, with a radius equal to the focal length. If small focal ratios are used, spherical aberration may become appreciable, although it should be noted that the spherical aberration of a single concave spherical mirror is smaller than that of the three- and four-lens anastigmats such as the triplet or Tessar types of the same focal ratio. To correct this residual spherical aberration, Schmidt introduced, in the stop at the center of curvature of the mirror, a thin, non-spherical corrector plate of glass. Even though this plate is non-achromatic it reduces the already very small spherical aberration to 2 or 3 percent of its original value over the range of wave lengths normally photographed. This permits critical definition over a large field with a focal ratio that is an order of magnitude smaller than is possible with lens systems.

Space operation permits the reception of UV energy, and to capitalize on this capability it becomes necessary to re-examine the design of the Schmidt Camera as a UV collector. Conventional glass-corrector plates absorb the UV. The use of quartz permits the extension of the spectrum somewhat further into the ultraviolet but does not come near to passing the critical Lyman-alpha wavelength. Some of the fluoride crystals pass this wavelength, but they are not available in sizes suitable for manufacturing a corrector plate. Therefore, it becomes necessary to use a corrector plate that is reflective rather than refractive. The instrument shown here substitutes a reflective aspheric mirror for the classical design's thin refractive correcting plate at the center of curvature of its spherical collecting mirror.

The instrument has an aperture of 0.3, a focal length of 0.9, a 150-mm film format with a phosphor-coated-fiber optic-field flattener and image converter permitting the use of a conventional roll-film camera. The field of view thus provided approaches 10°. The compact camera, in turn, permits an on-axis location with obscuration held to a reasonable amount thus simplifying the optical design of the telescope. The reflective corrector plate is mounted back to back with another corrector plate on which a diffraction grating is ruled. Because of the size of this corrector plate, it is composed of a mosaic of four pieces aligned precisely to act as a single grating and corrector. These two mirrors are turret mounted to permit rapid selection of mode of operation.

The telescope housing is mounted by means of three-axis gimbals to the spacecraft. Guidance is provided by means of gimbaled star trackers for acquisition and roll reference and a boresighted telescope with a fine guidance sensor to maintain precise pointing during exposure. CMG's receive the signals from the trackers and provide the torques necessary to control the attitude of the telescope in yaw, pitch, and roll.

A sunshade extendable after deployment permits the telescope line of sight to be directed closer to the sun than would otherwise be possible.

For stellar surveys, Schmidt cameras are unsurpassed, providing as they do both a reasonably wide field with good definition and a large aperture to permit photographing of faint starts with relatively short exposures. In space, from a point of vantage above the nightglow, it will be possible to reach a fainter magnitude limit because the lower background level will permit longer exposures than are profitable on the ground.

3. 2. 7. 2 Design Criteria

The instrument is to have a camera which can use standard panchromatic film in place of special UV films or plates. It must be capable of photographing the entire sky in the range 900 to 4, 000 Å. All stars brighter than apparent visual magnitude, m_v, = +8. 0 will be recorded on a single exposure of 2-hours duration. Both photographs and spectra of the stars in the UV spectral sky survey will be needed. To be efficient, about 50 spectra per exposure must be obtained, an instrument field of view at least 8^o in diameter is needed to satisfy the above. A spectral resolution of 1 Å will be adequate for many applications, including the following:

1. Identification of UV objects for subsequent observation using conventional spectroscopy with finer wavelength resolution.

2. Identification of the most conspicuous luminosity sensitive lines by comparing spectra of stars having MK classifications.
3. Detection of shifted spectral lines and of strong interstellar absorption lines.

3.2.7.3 Detailed Characteristics

The basic characteristics of the 0.3-m UV Schmidt normal-incidence stellar telescope, have been summarized in Figure 3-2 in Section 3.1. Additional details about the instrument are provided in Tables 3-49, 3-50, and 3-51.

3.2.7.4 Utilization of Man

Setup and maintenance requirements are summarized for this instrument in Table 3-52. Since man's utilization in the operation of the instrument is dependent upon the observational program, operational information is separately summarized in Table 3-53.

Table 3-49

COLLECTOR PARAMETERS
0.3-Meter UV Schmidt Normal-Incidence Stellar-Telescope
(OASF Instrument No. 33)

Aperture	0.3 m
Primary focal length	0.91 m
Effective focal length	0.91 m
Total field of view	10°
Angular resolution	
On axis	0.25 arc sec at 1,200 Å
Poorest in field of view	0.5 arc sec at 1,200 Å
Obscuration of aperture	27%
Minimum wavelength	1,000 Å
Maximum wavelength	2,000 Å
Primary f/No.	1.46
System f/No.	3
Scale at system focal plane	226 arc sec/mm
Resolution at system focal plane	45 lines/mm
Linear field of view at system focal plane	152.4 mm

Table 3-50

INTERFACE CHARACTERISTICS
0.3-Meter UV Schmidt Normal-Incidence Stellar-Telescope
OASF Instrument No. 33

General	
System weight (less expendables)	430 kg
System volume (launch configuration)	2.5m^3
System shape (launch configuration)	Rectangular prism w/off-axis cylinder
Method of accomplishing	
Deployment	Automatic sunshade extension
Alignment	None
Calibration	Photography of standard source
Operation	Automatic
Experiment change	Flip mirror-remotely controlled
Stowage requirements (launch)	
Mechanical	Inflated air bags to protect optics, plastic protective bags
Electrical	None
Experiment data handling	
Format	150-mm roll film
Processing	On board
Recording media	Photographic emulsion
Mode of data recovery	Film magazine replacement
Pointing requirements	
Pointing accuracy (acquisition) ±	external acquisition (manual)(angle)
Power consumption	
Stowed	0
Standby	120 W
Operate	120 W, peak 125 W

Table 3-51

GUIDANCE AND CONTROL CHARACTERISTICS
0.3-Meter UV Schmidt Normal-Incidence Stellar-Telescope
OASF Instrument No. 33

Guidance characteristics	
Coarse	
Initial acquisition filed of view	Manual external
Intermediate	
Field of view	Manual external
Fine	
Field of view	±3 min
Resolution	±0.5 arc-sec
Residual error	5 arc-sec
Control characteristics	
Control Moment gyro	
Type	Two degrees of freedom
Wheel momentum	15 lb-ft-sec
Gimbal stops	Outer none - inner ±70°
Spin motor power (start)	40 W
(run)	6 W
Servo power (peak)	40 W
(average)	5 W
Max. torque	15 oz-in.
Weight	30 lb
Diameter of wheel housing	≈8 in.
Length of wheel housing	5 in.
Suspension characteristics	
Type	3 degree of freedom, bearing-supported gimbals

Table 3-52

SETUP AND MAINTENANCE REQUIREMENTS
0.3-Meter UV Schmidt Normal-Incidence Stellar-Telescope
OASF Instrument No. 33

Operation	Average Times/ Year	Duration (hours)	No. of Men	Skill Identification*	Hours/ Man	Average Power (W)	Special Equip Weight (lb)	Special Equip Volume (ft^3)
Deployment	---	1	1	21	1	---	---	---
Alignment	---	1	1	14	1	3	3	1
Calibration	---	3	1	21	3	---	3	1
Scheduled maintenance	6	1-1/2	1	14	1-1/2	5	5	1
		---	1	12	1	5	5	1
Unscheduled maintenance	1/3	1	1	12	1	5	10	2

*Skills are identified B-1 number in Table 3-3.

Table 3-53

OPERATION SUPPORT AND REQUIREMENTS
0.3-Meter UV Schmidt Normal-Incidence Stellar-Telescope
OASF Instrument No. 33

ORDS No.	Time per Observation (hours)	No. of Men	Skill Identification*	Man hours/ Observation	Start Time (hours from start of observation)	Number of Observations
101	2	1	5	2.25	-0.25	50
		1	8	0.05	+48	
107	0.2	1	5	0.5	-0.25	800
		1	8	0.05	+48	

*Skills are identified by number in Table 3-3.

Deployment

The sunshade is extended, the two mirrors and star trackers uncovered, the gimbal erected, and the phosphor-coated fiber-optic face-plate camera removed from its protective packaging.

Alignment

The telescope has two corrector elements so that it can be used both as a wide-field UV camera with broadband filters, and as an objective grating spectrograph. After changing from grating to correcting plate by rotating the corrector assembly 180°, refocusing the camera will suffice if the supporting structure of the optical system is stiffened enough. The focusing scheme that Northwestern University describes for their 0.3-m Schmidt telescope appears to be a good method and it has been retained here (as well as for the late-time-period 1-m UV Schmidt, OASF Instrument No. 13). In this scheme, an optical technician observes a star image on a TV monitor. If two images are present, he moves a one-dimensional control which moves the camera along the optical axis until he sees a single star, indicating that proper focus has been achieved.

Calibration

Calibration is done from densitometry of a sequence of photographs taken and processed by the observer. The primary reason for the calibration plates is to determine appropriate exposure times for the combination of telescope and narrow-band filter. The calibration plates also serve as standards by which to measure the deterioration of the UV-reflective coatings over long periods of time. The number of plates taken depends on the range of brightness of the galactic objects in the observation program.

Operation

Exposure time for a single frame is estamated to be about 2 hours. The telescope may, upon completing an exposure, be programmed to move automatically to another preplanned location and to initiate another exposure. Alternatively, an observer points the telescope to the proper star field, loads the plate or film magazine, and initiates the exposure. The plates are developed in orbit to minimize radiation fogging.

The changeover from direct plates to the objective prism grating is done remotely from the spacecraft. A series of test plates is taken to achieve good focus.

Scheduled Maintenance

An electromechanical technician checks the camera-sequence mechanism at regular intervals. An optical technician checks the condition of the optical surfaces. The narrow-band filters may be replaced and the previously used ones tested for changes in transmission properties.

Unscheduled Maintenance

Electromechanical failure is considered very unusual and will probably call for the use of electromechanical technicians for trouble shooting and modular replacement.

3.2.7.5 Supporting Research and Technology

Supporting Research and Technology (SRT) requirements for the 0.3-Meter UV Schmidt normal-incidence telescope (instrument No. 33) are listed below. Full descriptions of SRT items are given in Section 4.3.

Research and Advance Technology

Develop mirror coatings with higher reflectivity shortward of 1,200 Å (SRT 4).

Develop fabrication techniques for noncircular aspherics (SRT 6).

Develop ruling techniques for ruling gratings on aspherics (SRT 9).

Develop techniques to overcome electrostatic charge buildup and fog-producing spark discharge on roll film in hard vacuum (SRT 17).

Develop improved grating ruling techniques and equipment to provide closer ruling spacing and greater uniformity of ruling spacing, blaze angle, and surface finish (SRT 38).

Develop criteria for film-transport mechanism suitable for roll film in hard vacuum to avoid emulsion cracking and flaking (SRT 39).

Investigate degradation of telescope detector and reflective surfaces resulting from O_2 exposure (SRT 42).

Investigate techniques for alignment and focusing mechanisms for optical telescopes (SRT 55).

Investigate the dimensional stability of candidate mirror materials (SRT 56).

Evaluate sputtering on mirror surfaces from high-energy particles (SRT 57).

Advance Development

Assess materials for internal use to determine if rapid aging and breakdown are caused by internal atmosphere (SRT 82).

Assess materials for external use to evaluate (1) hard-vacuum effects on materials, finishes, etc., and (2) development of processing, handling, and assembly techniques (SRT 83).

Supporting Development

Develop image tubes with greater spatial resolution than currently obtainable (SRT 84).

3.2.7.6 Development Cost and Schedules

The Phase D cost is shown in Table 3-54 which shows both development and operations costs. The development schedule is shown in Figure 3-46. Quantities of equipment required in development are shown in Table 3-55.

3.2.7.7 Instrumentation Section

Fiber-Optic Face-Plate Camera

The fiber-optic camera (Figure 3-47) is composed of three sections. The first contains the face plate and consists of a phosphor-coated fiber-optic bundle, the shutter, and the fiber-optic mount; the second includes the film-magazine assembly, which includes the film and film-transport mechanism. Finarlly, the third section is the camera-housing section, which serves as a radiation shield and environmental (temperature-humidity) chamber. The camera weights about 10 kg. The phosphor camera has several potential advantages in that the phosphor transforms UV light to blue-violet light, thereby admitting the use of normal roll film rather than abrasion, pressure-sensitive Schumann-type film; the face plate flattens the field, thus eliminating the mechanical problems associated with shaping sheets of film to a spherical surface; the film magazine may be pressurized, thereby avoiding the deleterious effects of a vacuum environment on photographic film.

Table 3-54

TASK COST ESTIMATE--PHASE D
0.3-Meter UV Schmidt Normal-Incidence Stellar-Telescope
(OASF Instrument No. 33)
($thousands)

Development total	3,265		
Engineering		240	
Detectors		*	
70-mm plates			*
Collecting optics		715	
0.3-m primary mirror			15
Corrector mirror			250
Alignment assy			450
Manual guidance		300	
TV camera			*
Control moment gyro			*
Housing		195	
Structure (including optics support)			175
Inflatable sunshade			20
Experiment sensors		950	
Filter wheels			150
70-mm plate camera			800
Major hardware articles		865	
Mockup			*
Engineering model			*
Project verification model			*
Qualification model			*
Operations total	1,677		
Flight instrument		1,089	
Backup flight instrument		436	
Engineering support		152	
Phase D total	4,942		

*Cost item not derived where overall estimate for instrument is not significantly affected.

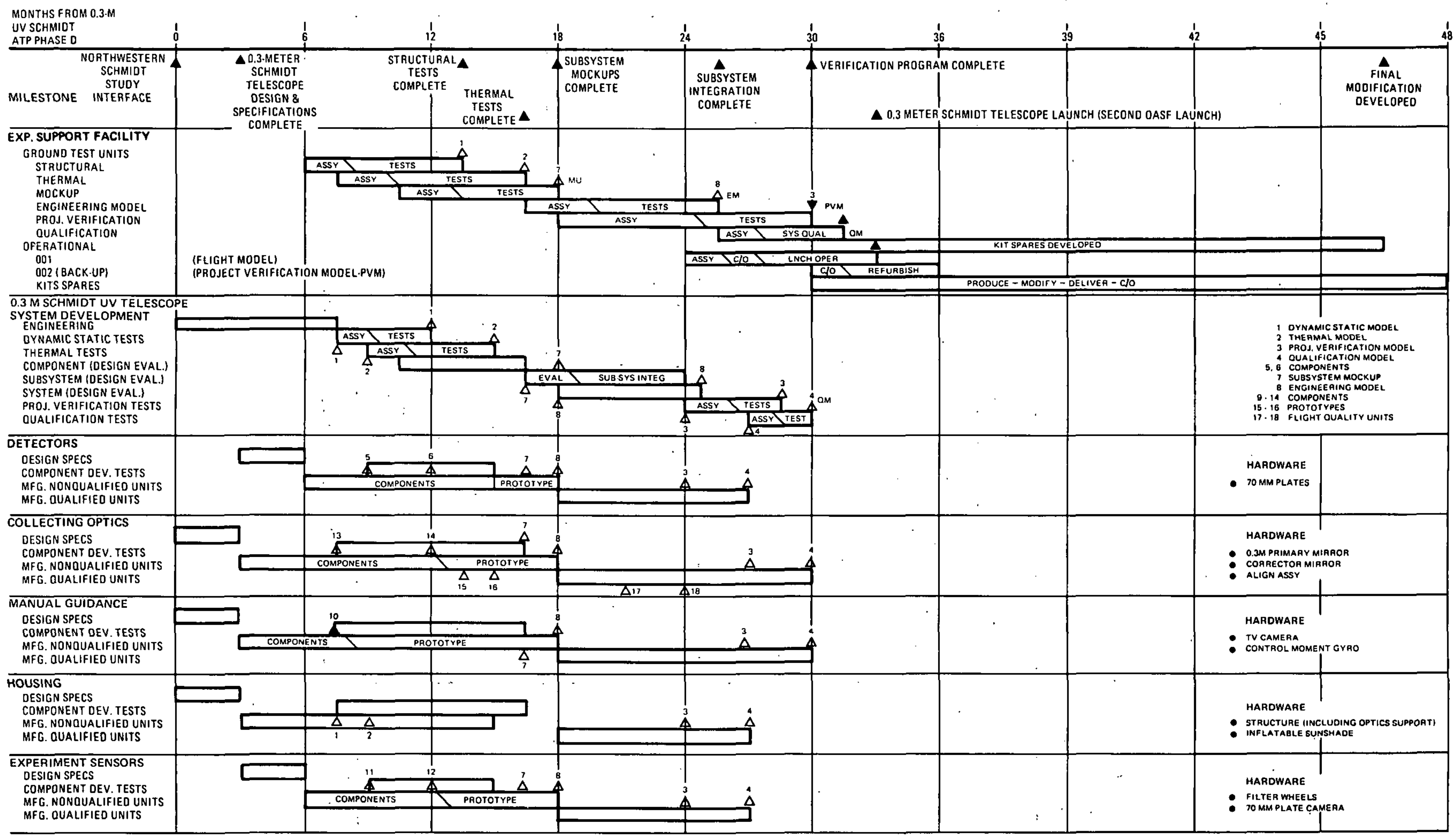

Figure 3-46. Development Schedule, 0.3-Meter UV Schmidt Normal Incidence Telescope, Stellar (OASF Instrument No. 33)

Table 3-55

PRIMARY INSTRUMENT EQUIPMENT LIST--DEVELOPMENT PHASE D
0.3-Meter UV Schmidt Normal-Incidence Stellar-Telescope
(OASF Instrument No. 33)

Functional System (Major Element)	Subsystem	Assemblies	Quantity		
			Bread-Board	Proto-Type	Flight Quality
0.3-Meter UV Schmidt telescope	Detectors	70-mm plates	2	2	2
	Collecting optics	0.3-m primary mirror	---	--- 2	2
		Corrector mirror	---	2	2
		Alignment assy	2	4	4
	Manual guidance	TV camera	1	2	2
		Control moment gyro	1	2	2
	Housing	Structure (Including Optics Support)	---	1	2
		Inflatable Sunshade	---	1	2
	Experiment Sensors	Filter wheels	1	1	1
		70-mm plate camera	1	1	1
	Major hardware articles.	Mockup	1	---	---
		Engineering model	---	1	---
		Project verification model	---	60%*	40%*
		Qualification model	---	---	1

*Obtained from subsystem development quantities.

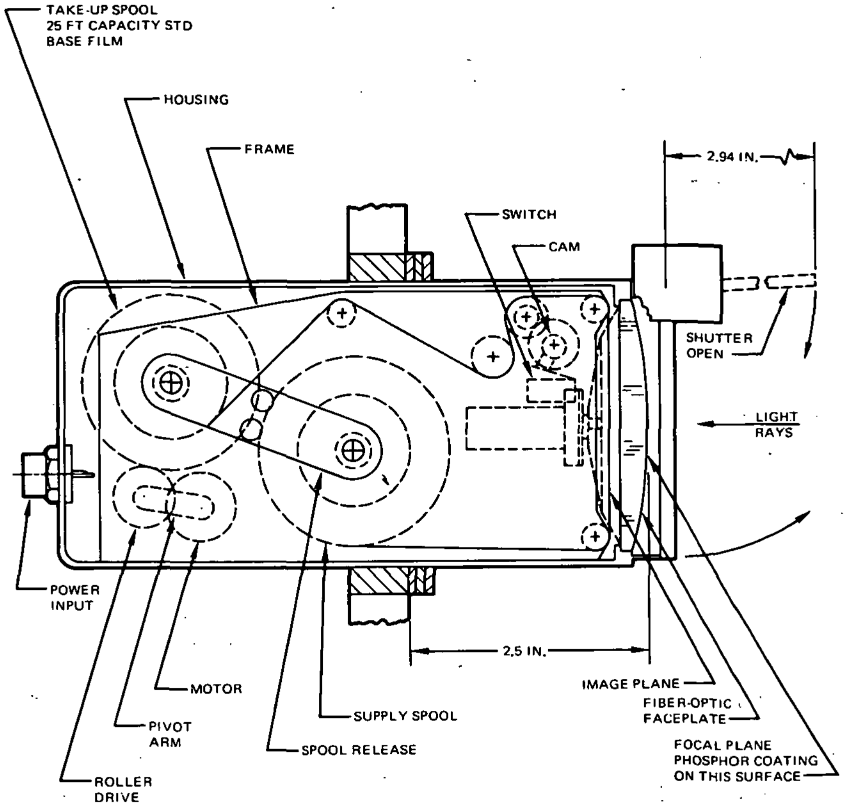

Figure 3-47. Phosphor-Coated Fiber-Optic-Faceplate Camera

Objective Grating

The UV grating which is ruled on the aspheric correcting plate has a grating frequency of 110 lines/mm, resulting in a 2 Å resolution and 100 Å/mm dispersion (see Table 3-56). A grating of such coarseness will be wasteful of light in the UV unless the greatest care is exercised in ruling control. The demand for UV gratings is improving the above situation. A further problem is that this grating is larger than any now being made, so that either larger ruling engines will be needed, or the ruled corrector will have to be made in segments.

Table 3-56

OBJECTIVE GRATING CHARACTERISTICS
0. 3-Meter UV Schmidt Normal-Incidence Stellar-Telescope
(OASF Instrument No. 33)

Wavelength	
Short	900 Å
Long	4,300 Å
Resolution	2 Å at 1,200 Å
Incident radiation	
f/No. limitation	5
Spatial resolution	5 arc sec
Main grating	
Type	Aspheric
Size	300 mm
Ruling frequency	110 lines/mm
Dispersion	100 Å/mm at 1,200 Å
Angle of diffraction range	-11.4 to -13.5°
Spectral order	1
Recorder characteristics	
Type	Phosphor-augmented camera
Aperture	150 mm
Remote change cycle time	1 sec
Film type limitations	Roll film
Exposure per magazine load	144
Power consumption during cycle change	5 W
Power consumption during calibration	10 W
Weight	15 kg

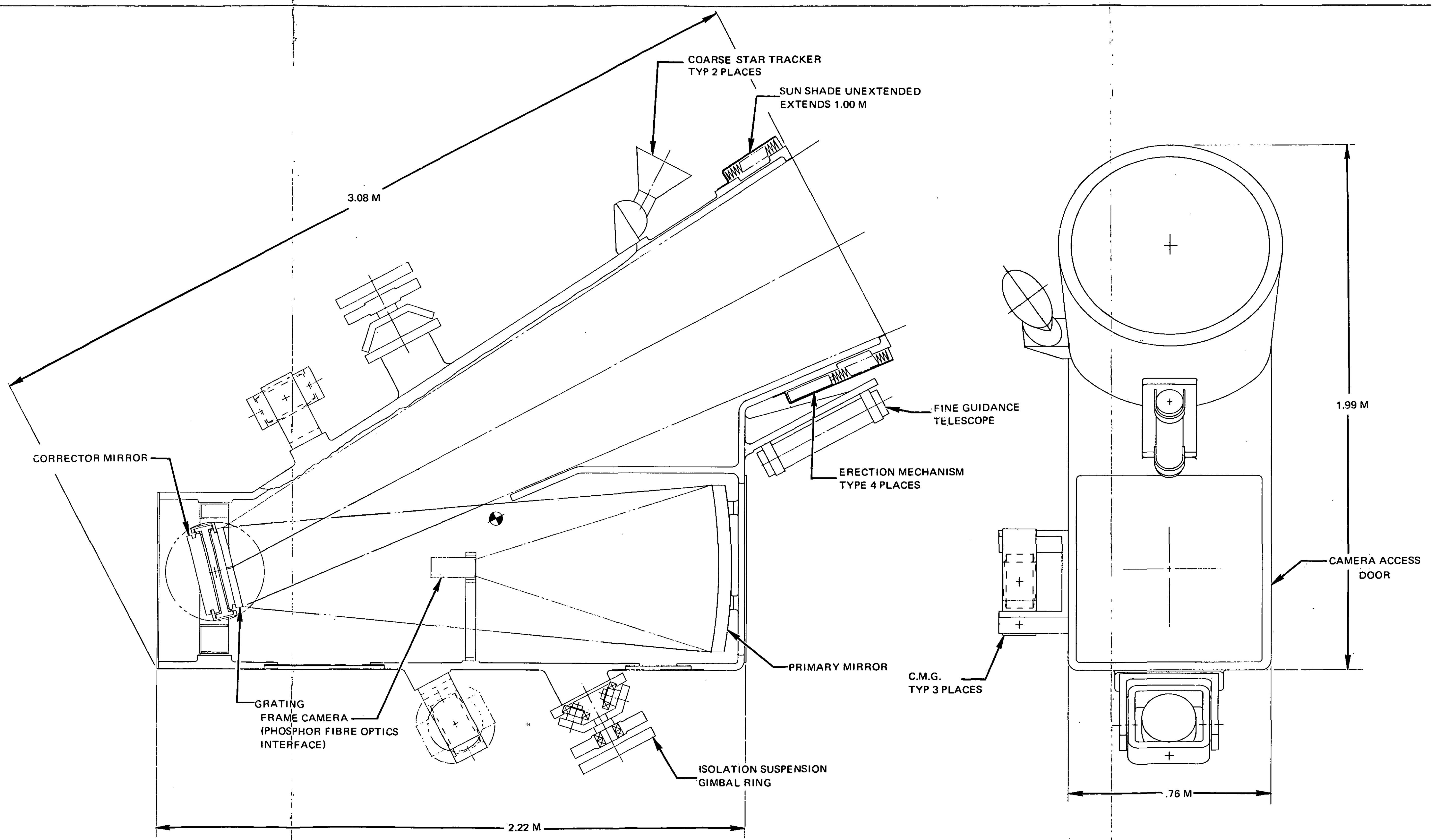

Figure 3-45. 0.3-Meter UV Schmidt, Normal Incidence Telescope, Stellar. OASF Instrument No. 33

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3.2.8 1- to 6- Solar Radii Coronagraph Normal-Incidence Telescope, Solar - OASF Instrument No. 36

3.2.8.1 General Characteristics

The 1- to 6-solar-radii coronagraph combines with the 5- to 30-solar-radii coronagraph (Section 3.2.29) to observe white-light emission of outward-moving plasma clouds from the solar limb to a distance of 30 solar radii from the center of the sun. Coverage of this considerable region is divided into two instruments for the following reasons: (1) the two instruments are each relatively small in size as contrasted with one instrument of unwieldy proportions; (2) the inner coronagraph, which requires a much smaller field of view, provides higher resolution for a given image size, in the region where the coronal phenomena are expected to be much more interesting; (3) the range-of-response requirement for the recording medium (film) is considerably relaxed by splitting into two parts the six- to eight-order-of-magnitude difference in radiation flux levels between the solar limb and 30 solar radii.

The 1- to 6-solar radii coronagraph (Figure 3-48) is a motion-picture camera with a telephoto lens to restrict the field of view to three degrees on a 35-mm format. It is fitted out with occulting disks, both internal and external to block out the direct rays of the sun so that the picture obtained contains the image of the inner corona without the glare of the direct sun. It is composed of four parts: an optical bench, which ties everything together; an optics housing, which provides a support for the objective lens, field lines, relay lens, folding mirrors, elements of the calibration chain, and thermal mirrors; a light tube, which serves as a baffle, a support for the instrument cover, and protection for the external occulting disks; and a 35-mm cine camera, which records the corona pictures on film.

Optically the coronagraph consists of an objective lens and relay system which form an image of the corona at the camera focal plane. On the field lens, which is at the focus of the objective lens, is an internal occulting disk. This disk occupies the place where the solar image would be were it not for the external occulters. It blocks the last remnant of direct solar light. In front of the objective lens by somewhat over two meters is an external occulting disk, supported by the optical bench and so designed as to shield the internal optics completely from direct sunlight, yet offer minimum vignetting to light from the corona. Backing up this occulting disk are two more disks, placed so as to cut off any diffraction effects that would permit sunlight to pass. A thermal mirror (f/100) surrounding the objective lens redirects unused solar radiation out into space again, protecting the instrument from undue heating.

The instrument is an outgrowth of the coronagraphs that have been operating for many years in the mountain observatories in Colorado and Southern France. It is anticipated that by going into space higher contrast and correspondingly higher definition can be achieved.

3.2.8.2 Design Criteria

The coronagraph suggested by the scientific community was required to have a field capable of viewing the outer corona, and minimal vignetting of the inner corona. While ideally this makes an interesting goal, achievement of it is encumbered with practical difficulties. In the first place, a detector capable of recording the outer corona would be exposed beyond saturation by the inner corona. Secondly, it is not at all evident that scattering due to unocculted light from the inner corona will not cause excessive fogging of the outer corona image. Therefore, the original requirement was divided into two parts, providing separate instruments for viewing the inner and outer portions of the corona. These instruments are to be co-mounted and operated as a unit.

The inner coronagraph was intended to cover the portion of the corona out to 6 solar radii and requires a design that will ensure that no direct sunlight strikes the optics and that scattering is kept to a minimum.

3.2.8.3 Detailed Characteristics

The basic characteristics of the 1- to 6-solar radii coronagraph normal-incidence telescope, solar, have been summarized in Figure 3-3, Section 3.1. Additional details about the instrument are tabulated in Tables 3-57, 3-58, 3-59, and 3-60.

3.2.8.4 Utilization of Man

Setup and maintenance requirements are summarized for this instrument in Table 3-61. Since man's utilization in the operation of the instrument is dependent upon the observational program, operational information is separately summarized in Table 3-62.

Deployment

The two coronagraphs will be mounted on a common support track (optical bench) at launch. Covers and lens caps will be removed, and the sun sensor will be erected.

Table 3-57

COLLECTOR PARAMETERS

1- to 6-Solar Radii Coronagraph Normal-Incidence Telescope, Solar OASF Instrument No. 36

Aperture	0.0245 m
Primary focal length	0.315 m
Effective focal length	0.315 m
Total field of view	3.25°
Angular resolution	
On axis	10 arc-sec. at 5,000 Å
Poorest in field of view	45 arc-sec. at 5,000 Å
Occulted area in focal plane	3.4 (%)
Minimum wavelength	4,000 Å
Maximum wavelength	10,000 Å
Primary f/No.	12.9
System f/No.	12.9
Scale at system focal plane	690 arc sec/mm
Resolution at system focal plane	69 lines/mm
Linear field of view system focal plane	17.9 mm

Table 3-58

INTERFACE CHARACTERISTICS
1- to 6-Solar Radii Coronagraph Normal-Incidence Solar Telescope--
OASF Instrument No. 36

General (Includes 5- to 30-solar radii coronagraph)	
System weight (less expendables)	≈400 kg
System volume (launch configuration)	≈2.3 m^3
System shape (launch configuration)	2 cylinders on beam
Method of accomplishing	
Deployment	Uncap aperture and remove plastic bag
Alignment	Remote adjustment of internal occulting disk position
Calibration	Use of intensity calibration wedge on photograph
Operation	Remove photograph
Experiment change	---
Stowage requirements (launch)	
Mechanical	Plastic-bag packaging
Electrical	None
Experiment data handling	
Format	35-mm strip film, 18 x 24 mm
Processing	On-board
Recording media	Panchromatic photographic film
Mode of data recovery	Exchange of film magazine
Pointing requirements	
Pointing accuracy (acquisition)	Manual (angle)
Power consumption	
Stowed	None
Standby	≈35 W
Operate	≈60 W

Table 3-59

GUIDANCE AND CONTROL CHARACTERISTICS
1- to 6-Solar Radii Coronagraph Normal-Incidence Solar Telescope--
OASF Instrument No. 36

Guidance characteristics	
Coarse	
Initial acquisition field of view	Manual
Intermediate	
Field of view	±40 arc-min
Resolution	± 5 arc sec
Residual error	±15 arc sec
Control characteristics	
CMG	
Type	Single degree of freedom, viscous damped
Wheel momentum	640 oz-in.-sec
Gimbal stops	±60°
Spin motor power (start)	40 W
(run)	6 W
Servo power (peak)	10 W
(average)	1.5 W
Max. torque	3.8 oz-in.
Weight	16 lb
Diameter	5 in.
Length	8-1/2 in.

Table 3-60

FIELD IMAGE INSTRUMENTATION CHARACTERISTICS
1- to 6-Solar Radii Coronagraph Normal-Incidence Solar Telescope--
OASF Instrument No. 36

Film camera characteristics	
Type	Cine roll film
Aperture	18 x 24 mm
Remote change cycle time	5 sec
Power consumption during change	2 W
Film type limitations	Panchromatic
Exposures per magazine load	3,600
Weight	10 kg
Filter characteristics	Polarizers
Remote change cycle time	1 sec
Power consumption during change	2 W

Table 3-61

SETUP AND MAINTENANCE REQUIREMENTS
1- to 6-Solar Radii Coronagraph Normal-Incidence Solar Telescope--
OASF Instrument No. 36

Operation	Average Times/ Year	Duration (hours)	No. of Men	Skill Identification*	Hours/ Man	Average Power (W)	Special Equip Weight (lb)	Special Equip Volume (ft^3)
Deployment	---	1	1	21	1	---	5	1
Alignment	---	2	1	14	5	5	10	2
Calibration	---	3	1	21	3	1	3	1
Scheduled maintenance	6	2	1	12	2	3	5	1
Unscheduled maintenance	1/5	1	1	12	1	5	5	1

*Skills are identified by number in Table 3-3.

Table 3-62

OPERATION SUPPORT AND REQUIREMENTS
1- to 6-Solar Radii Coronagraph Normal-Incidence Solar Telescope--
OASF Instrument No. 36

ORDS No.	Time per Observation	No. of Men	Skill Identification*	Man-hours/ Observation	Start Time (hours from start of observation)	Number of Observations
062	1 year (continuous)	1	5	2/day in 10-min. periods	-0.25	1
		1	8	2/day (1 period)	+24	

*Skills are identified by number in Table 3-3.

Alignment

The optics of each coronagraph is an independent sealed unit requiring no further adjustment. The positions of the external occulting disks are adjusted in orbit to obtain maximum suppression of diffraction effects. Adjustment of the internal occulting disk will be infrequent. Sample photographic exposures will serve as a record of alignment. The use of a common optical bench assures the boresight alignment of the two coronagraph optics systems to each other.

Calibration

Intensity calibration wedges on the photographs are utilized. Depending on the frequency of photographs and the type of phenomenon being observed, it may be convenient to omit the wedges from many of the photographs during operation and only take intensity test plates at intervals.

Operation

Remote-controlled simultaneous photography through both coronagraph cameras is typical of the operational use. The sun sensor will keep the system centered on the solar image. The cine camera magazines are changed and the film developed at frequent intervals.

Scheduled Maintenance

Requirements are examination of the camera optics and mechanisms for deterioration and a check on the accuracy of the sun-sensor pointing.

Unscheduled Maintenance

Requirements arise only from unusual failures of electrical components, cameras, or supporting structures, or from damage to camera optics, as from sudden shock causing misalignment.

3.2.8.5 Supporting Research and Technology

Supporting Research and Technology (SRT) requirements for the 1 to 6 Solar Radii Coronagraph (Instrument No. 36) are listed below. Full descriptions of SRT Items are given in Section 4.3.

Research and Advanced Technology

Develop techniques to overcome electrostatic charge build-up and fog producing spark discharge on roll film in hard vacuum (SRT 17).

Develop criteria for film transport mechanisms suitable for roll film in hard vacuum to avoid emulsion cracking and flaking (SRT 39).

Advance Development

Assess materials for internal use to determine if rapid aging and breakdown are caused by internal atmosphere (SRT 82).

Assess materials for external use to evaluate (A) hard vacuum effects on materials, finishes, etc.; and (B) development of processing, handling, and assembly techniques (SRT 83).

3.2.8.6 Development Cost and Schedules

The Phase D cost is shown in Table 3-63, which shows both development and operations costs. The development schedule is shown in Figure 3-49. Quantities of equipment required in development are shown in Table 3-64.

Table 3-63

TASK COST ESTIMATE--PHASE D
1- to 6-Solar Radii Coronagraph Normal-Incidence Telescope, Solar
(OASF Instrument No. 36)

Development total	1,285		
Engineering		95	
Detectors		*	
Collecting optics		12	
0.025-m objective lens			*
Field lens			*
Fine guidance		400	
Optics			*
Control moment gyros			*
Sensor			*
Housing		250	
Structure (including optics support)			*
Solar thermal shield (dumping mirror)			*
Experiment sensors		875	
35-mm cine frame camera			875
Major hardware articles		653	
Mockup			*
Engineering model			*
Project verification model			*
Qualification model			*
Operations total	593		
Flight instrument		385	
Back-up flight instrument		154	
Engineering support		54	
Phase D total	1,878**		

*Cost item not derived where overall estimate for instrument is not significantly affected.

**Assumes previous development of ATM Experiment S052 (Reference 2-6).

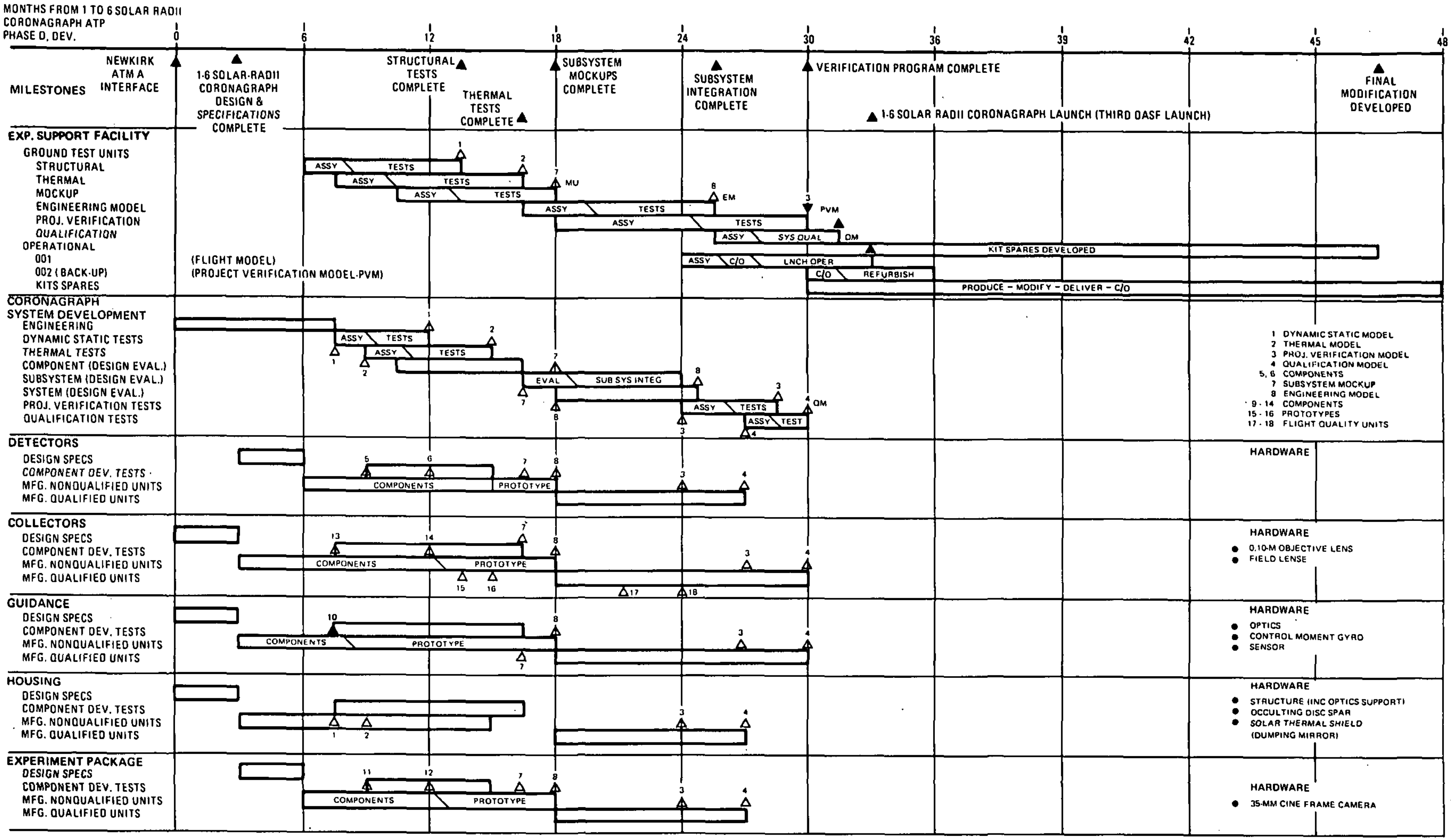

Figure 3-49. Development Schedule, 1- to 6-Solar-Radii Coronagraph Normal Incidence Telescope, Solar (OASF Instrument No. 36)

Table 3-64

PRIMARY INSTRUMENT EQUIPMENT LIST--DEVELOPMENT PHASE D
1- to 6-Solar Radii Coronagraph Normal-Incidence Solar Telescope--
OASF Instrument No. 36

Functional System (Major Element)	Subsystem	Assemblies	Quantity		
			Bread-Board	Proto-Type	Flight Quality
1-6 solar-radii coronagraph (solar)	Detectors				
	Collecting optics	0.025-m objective lens	1	2	1
		Field lens	1	2	1
	Fine guidance	Optics	1	2	2
		Control moment gyro	1	2	2
		Sensor	1	2	2
	Housing	Structure (including optics support)	---	1	2
		Solar thermal shield (dumping mirror)	---	1	2
	Experiment sensors	35-mm cine frame camera	1	1	1
	Major hardware	Mockup	1	---	---
		Engineering model	---	1	---
		Project verification model	---	60%*	40%*
		Qualification model	---	---	1

*Obtained from subsystem development quantities.

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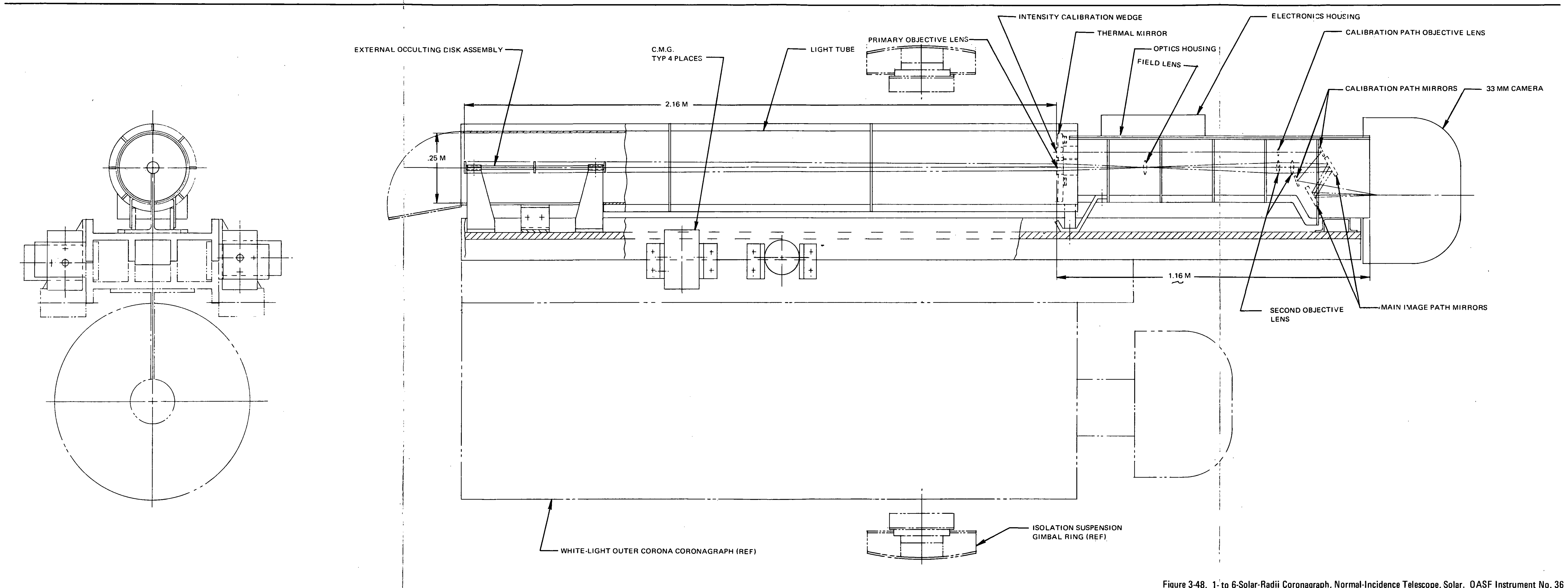

Figure 3-48. 1- to 6-Solar-Radii Coronagraph, Normal-Incidence Telescope, Solar. OASF Instrument No. 36

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3.2.9 5- to 30-Solar Radii Coronagraph Normal Incidence Telescope, Solar-OASF Instrument No. 37

3.2.9.1 General Characteristics

Instrument No. 37 is shown in Figure 3-50. A modification of the inner coronagraph of Section 3.2.8 is recommended for the photographing of the outer corona. If the diameter of the light tube is increased from 0.25 m to 0.65 m the objective lens will have an unobscured view out to a full field of 16° or a view of the corona out to 30 solar radii. An external occulting disk was sized to provide full occulation of the inner corona to 3 solar radii and no vignetting beyond 5 radii. The length of the light tube was retained at 2.16 m and the effective focal length of the optics was set at 90 mm to provide for a plate scale including 30° in a 24-mm format. With these design criteria, a layout was prepared for a camera to record the outer corona. The camera consists of a 35-mm cine magazine with 90-mm EFL optics and an aperture of 40 mm. The focal ratio of 2.5 compared with 12.9 on the inner corona camera reduces the discrepancy in required exposure time. The camera optics include an objective lens, a field lens with an occulting disk, and a relay lens pair. The external occulter, 160 mm in diameter, is placed about 2.16 m in front of the objective lens, with the additional occulting disks placed at strategic points in between.

The combination of the two coronagraphs permits simultaneous recording of both inner and outer coronas. It permits each part of the corona to be recorded at an appropriate scale factor, thus taking advantage of a larger effective format to show the inner corona in more detail.

3.2.9.2 Design Criteria

The goal in designing the outer coronagraph is to permit the recording of the corona out to 30-solar radii, a feat which is not possible on the ground because of atmospheric scattering, and therefore even more critical in space, than the inner coronagraph. Particular attention must be paid to the design of baffles for the suppression of scattering and the optimization of the external occulter spacing.

3.2.9.3 Detailed Characteristics

The basic characteristics of the 5- to 30-solar radii coronagraph normal-incidence telescope, solar, have been summarized in Figure 3-3, Section 3.1.

Additional details about the instrument are tabulated in Tables 3-65, 3-66, 3-67, and 3-68.

3.2.9.4 Utilization of Man for OASF Instruments

The material in Section 3.2.8.4 is applicable here, including the tables presented.

3.2.9.5 Supporting Research and Technology

Supporting Research and Technology (SRT) requirements for the 5- to 30-solar-radii coronagraph (Instrument No. 37) are the same as for the 1- to 6-solar radii coronagraph (Instrument No. 36) and are listed in Section 3.2.8.5.

3.2.9.6 Development Cost and Schedules

The Phase D cost is shown in Table 3-69, which shows both development and operations costs. The development schedule is shown in Figure 3-51. Quantities of equipment required in development are shown in Table 3-70.

Table 3-65

COLLECTOR PARAMETERS
5- to 30-Solar Radii Coronagraph Normal-Incidence
Telescope, Solar OASF Instrument No. 37

Aperture	0.04 m
Primary focal length	0.09 m
Effective focal length	0.09 m
Total field of view	15°
Angular resolution	
On axis	30 arc-sec at 5,000 Å
Poorest in field of view	60 arc-sec at 5,000 Å
Occulted area in focal plane	6.5%
Minimum wavelength	4,000 Å
Maximum wavelength	10,000 Å
Primary f/No.	1.85
System f/No.	1.85
Scale at system focal plane	2,700 arc sec/mm
Resolution at system focal plane	90 lines/mm
Linear field of view at system focal plane	24 mm

Table 3-66

INTERFACE CHARACTERISTICS
5- to 30-Solar Radii Coronagraph Normal-Incidence
Telescope, Solar OASF Instrument No. 37

General (included with 1- to 6-solar radii coronagraph)	
System weight (less expendables)	See Section 3. 2. 8
System volume (launch configuration)	See Section 3. 2. 8
System shape (launch configuration)	See Section 3. 2. 8
Method of accomplishing	
Deployment	See Section 3. 2. 8
Alignment	See Section 3. 2. 8
Calibration	See Section 3. 2. 8
Operation	See Section 3. 2. 8
Experiment change	See Section 3. 2. 8
Stowage requirements (launch)	
Mechanical	Plastic bag packaging
Electrical	None
Experiment data handling	
Format	35-mm strip film, 20 x 24 mm
Processing	On board
Recording media	Panchromatic photographic film
Mode of data recovery	Exchange of film magazine
Pointing requirements	
Pointing accuracy (acquisition)	Manual
Power consumption	
Stowed	Combined with Instrument No. 36
Standby	Combined with Instrument No. 36
Operate	Combined with Instrument No. 36

Table 3-67

GUIDANCE AND CONTROL CHARACTERISTICS
5- to 30-Solar Radii Coronagraph Normal-Incidence
Telescope, Solar OASF Instrument No. 37

Guidance characteristics	
Coarse	
Initial acquisition field of view	Manual
Intermediate	
Field of view	±40 arc min.
Resolution	±5 arc sec
Residual error	±15 arc sec
Fine	
Field of view	Not required
Control characteristics	
Control moment gyro	
Type	Single degree of freedom viscous damped
Wheel momentum	640 oz-in.-sec
Gimbal stops	$\pm 60^{o}$
Spin motor power (start)	40 W
(run)	60 W
Servo power (peak)	10 W
(average)	1.5 W
Max. torque	3.8 oz-in.
Weight	16 lb
Diameter	5 in.
Length	8-1/2 in.

Table 3-68

FIELD IMAGE INSTRUMENTATION CHARACTERISTICS FOR USE ON
5- to 30-Solar Radii Coronagraph Normal-Incidence
Telescope, Solar OASF Instrument No. 37

Film camera characteristics	
Type	Cine roll film
Aperture	18 x 24 mm
Remote change cycle time	5 sec
Power consumption during change	2 W
Film type limitations	Panchromatic
Exposures per magazine load	3,600
Weight	10 kg
Filter Characteristics	
Remote change cycle time	1 sec
Power consumption during change	2 W

Table 3-69

TASK COST ESTIMATE - PHASE D
5- to 30-Solar Radii Coronagraph Normal Incidence Solar Telescope
(OASF Instrument No. 37)
($ thousands)

Development total	2,715		
Engineering		250	
Detectors		*	
Collecting optics		15	
0.04-m objective lens			
Field lens			
Fine guidance		500	
Optics			*
Control moment gyros			*
Sensor			*
Housing		195	
Structure (including optics support)			175
Solar shield (dumping mirror)			20
Experiment sensors		875	
35-mm cine frame camera			875
Major hardware articles		900	
Mockup			*
Engineering model			*
Project verification model			*
Qualification model			*
Operations total	1,577		
Flight instrument		1,024	
Backup flight instrument		410	
Engineering support		143	
Phase D total	4,292**		

*Cost item not derived where overall estimate for instrument is not significantly affected.

**Assumes previous development of ATM Experiment S052 (Reference 2-6).

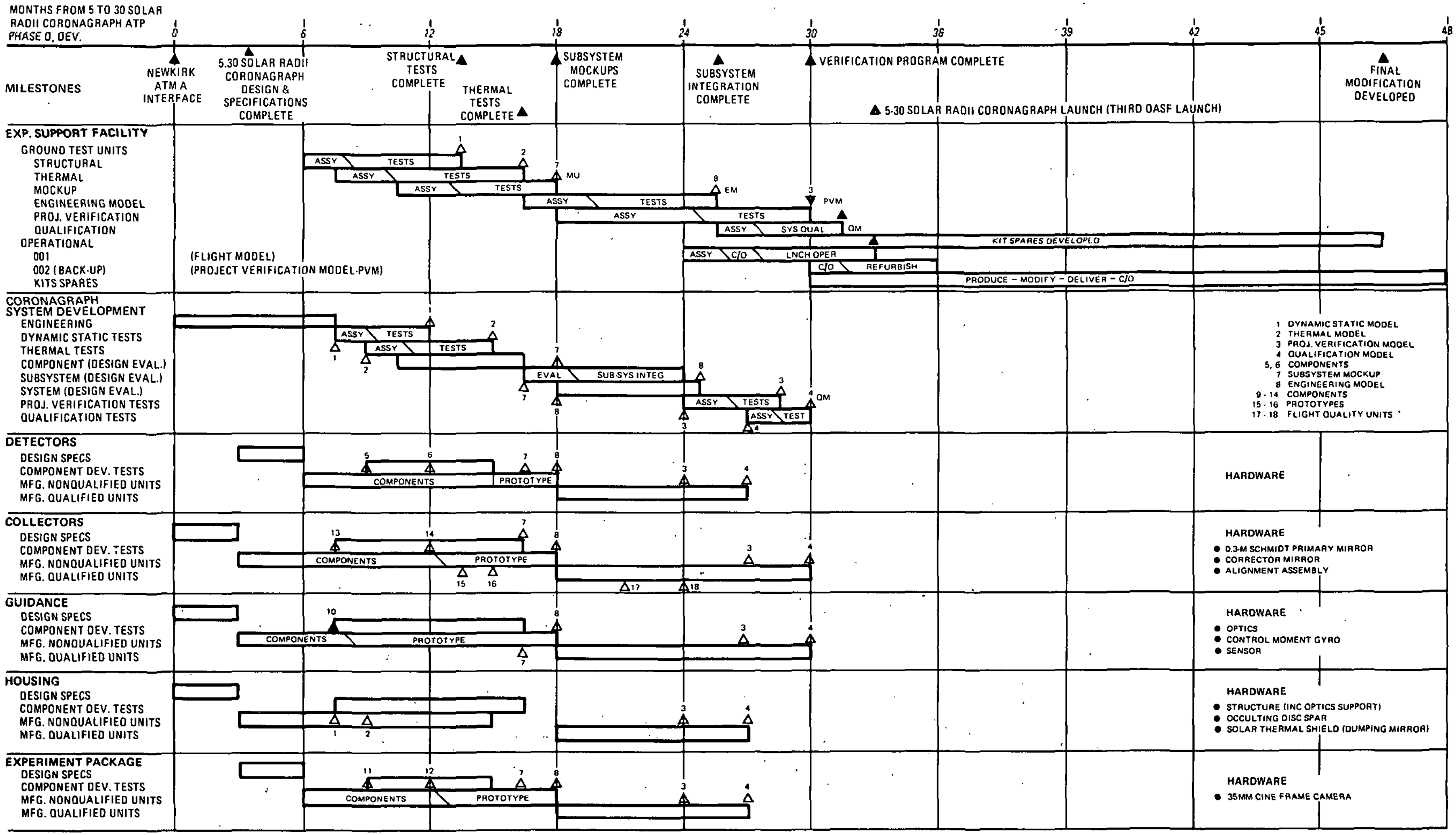

Figure 3-51. Development Schedule, 5-to-30 Solar Radii Coronagraph Normal Incidence Telescope, Solar (OASF instrument No. 37)

Table 3-70

PRIMARY INSTRUMENT EQUIPMENT LIST--DEVELOPMENT PHASE D
5- to 30-Solar Radii Coronagraph Normal Incidence
Solar Telescope (OASF Instrument No. 37)

Functional System (Major Element)	Subsystem	Assemblies	Quantity		
			Bread-board	Proto-type	Flight Quality
5- to 30-solar-radii coronagraph	Detectors	---	---	---	---
	Collecting optics	0. 04-m objective lens	1	2	1
		Field lens	1	2	1
	Fine guidance	Optics			
		Control moment gyro	1	2	2
		Sensor	1	2	2
	Housing	Structure (including optics support)	---	1	2
		Solar thermal shield (dumping mirror)	---	1	2
	Experiment sensors	35-mm cine frame camera	1	1	1
	Major hardware articles	Mockup	1	---	---
		Engineering model	---	1	---
		Project verification model	---	60%*	40%*
		Qualification model	---	---	1

*Obtained from subsystem development quantities.

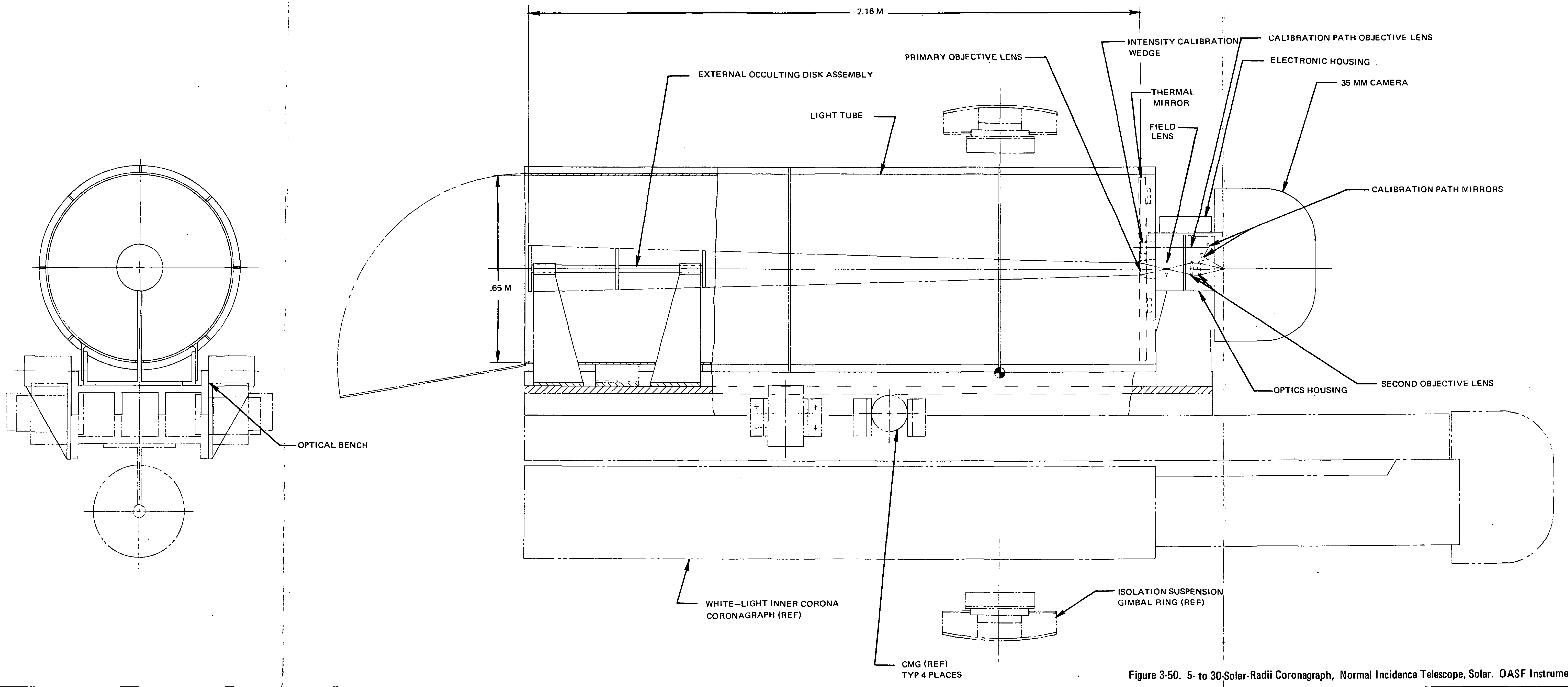

Figure 3-50. 5- to 30-Solar-Radii Coronagraph, Normal Incidence Telescope, Solar. OASF Instrument No. 37

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3.2.10 0.8 Meter UV-Visible Normal-Incidence Telescope; Solar-OASF Instrument No. 44

3.2.10.1 General Characteristics

This telescope has an aperture of 0.8 m, and an effective focal length of 39.2 m (Figure 3-52). The primary mirror is f/3.5; the secondary mirror magnification of 14 produces an f/49 telescope. The Gregorian arrangement of the optical system, as suggested by Zirin (Reference 3-9) was chosen because it provides a solution to the problems of heat rejection and reduction of thermal gradients that are present in solar telescopes. A heat dump mirror placed between the primary and secondary mirrors insures that light scattered off the primary does not contribute to heating of the secondary mirror. At the same time, the heat dump mirror also eliminates the thermal distortion of the primary caused by the infrared image of the heated secondary on the primary, thus permitting the full optical capabilities of the telescope to be exploited. The Cassegrain arrangement cannot eliminate an incident energy variation of from one to six suns over portions of the primary reflective surface.

3.2.10.2 Design Criteria

The telescope was designed for continuous observation of solar plages, sunspots, ultraviolet flares and other features of astronomical interest. It can be used with a high dispersion echelle spectrograph or with a set of cine cameras for taking simultaneous photographic sequences in three spectral regions; it also has two Lyot filters that can be used with the cine cameras or with the slit-jaw camera of the echelle spectrograph.

3.2.10.3 Detailed Characteristics

The basic characteristics of the 0.8 m UV-visible normal-incidence solar telescope have been summarized in Figure 3-3 in Section 3.1.

Additional details about the instrument are tabulated in Table 3-71, 3-72, and 3-73.

Table 3-71

COLLECTOR PARAMETERS
0.8 Meter UV-Visible Normal-Incidence Solar Telescope--
OASF Instrument No. 44

Aperture	0.80 m
Primary focal length	2.8 m
Effective focal length	39.2 m
Total field of view	2.6 arc min.
Angular resolution	
On axis	0.156 arc sec at 5,000 Å
Poorest in field of view	0.196 arc sec at 5,000 Å
Obscuration of aperture	15% total
Minimum wavelength	1,200 Å
Maximum wavelength	10,000 Å
Primary f/No.	3.5
System f/No.	49
Scale at system focal plane	4.43 arc sec/mm
Resolution at system focal plane	33.5 lines/mm
Linear field of view at system focal plane	33.5 mm

3.2.10.4 Utilization of Man

Setup and maintenance requirements are summarized for this instrument in Table 3-74. Because man's utilization in the operation of the instrument depends on the observational program, operational information is summarized separately in Table 3-75.

Table 3-72

INTERFACE CHARACTERISTICS
0.8 Meter UV-Visible Normal-Incidence Solar Telescope--
OASF Instrument No. 44

General	
System weight (less expendables)	800 kg
System volume (launch configuration)	3.25 m^3
System shape (launch configuration)	Cylinder w/flanges and tubular appendages
Method of accomplishing	
Deployment	Activate cooling system remove plastic bags
Alignment	Man-aided electromechanical autocollimation
Calibration	Photography of quiet sun and standard sources
Operation	TV vidicons, cine sequence cameras
Experiment change	Replaceable cameras and optics
Stowage requirements (launch)	
Mechanical	Inflatable bags and supports
Electrical	None
Experiment data handling	
Format	35-mm x 35-mm imaging, 35-mm x 100-mm spectrograph
Processing	On board
Recording media	Photographic emulsions, TV vidicons
Mode of data recovery	Replaceable film magazines
Pointing requirements	
Pointing accuracy (acquisition)	Manual
Power consumption	
Stowed	None
Standby	≈40W
Operate	≈70W

Table 3-73

GUIDANCE AND CONTROL CHARACTERISTICS
0.8 Meter UV Visible Normal-Incidence Solar Telescope--
OASF Instrument No. 44

Guidance characteristics	
Coarse	
Initial acquisition field of view	±5°
Resolution	±10 arc sec
Residual error	±30 arc sec
Fine	
Field of view	±40 arc min.
Resolution	±0.02 arc sec
Residual error	±1 arc sec
Control characteristics	
Control moment gyro	
Type	Single degree of freedom, viscous damped
Wheel momentum	640 oz-in.-sec
Gimbal stops	±60°
Spin motor power (start) (run)	40 W 6 W
Servo power (peak) (average)	10 W 1.5 W
Max. torque	3.8 oz-in.
Weight	16 lb
Diameter	5 in.
Length	8.5 in.

Table 3-74

SETUP AND MAINTENANCE REQUIREMENTS
0.8 Meter UV-Visible Incidence Solar Telescope--
OASF Instrument No. 44

Operation	Average Times/ Year	Duration (hours)	No. of Men	Skill Identification*	Hours/ Man	Average Power (W)	Special Equip Weight (lb)	Special Equip Volume (ft^3)
Deployment	---	2	1	11	1-1/4	---	---	---
	---	---	1	14	3/4	---	---	---
	---	---	1	21	2	---	---	---
Alignment	---	12	1	14	12	15	---	---
Calibration	---	2	1	14	2	5	---	---
Scheduled maintenance	6	4	1	12	1-1/2	15	25	3
	---	---	1	14	1-1/2	---	---	---
	---	---	1	21	1	---	---	---
Unscheduled maintenance	2/3	3	1	12	3	25	30	3

*Skills are identified by number in Table 3-3.

Deployment

The telescope is mounted with a number of other solar instruments. Protective caps and structural supports are removed. Any cameras and gratings not mounted before launch because of lack of structural strength or available supports, are mounted during setup.

Alignment

Alignment is accomplished remotely with the aid of a photodetector and specially designed test mechanisms. Man is in the "loop" to reduce the complexity of the procedure.

Calibration

Monochromatic and bright-line test sources are used, as well as the sun and other stellar sources with known spectral distributions. Test exposures are made at regular intervals to ensure that the Lyot filters, dichroic mirrors, and other parts of the optical system are in proper working order. Intensity calibration is made from exposures of standard star sequences and artificial standards.

Operation

The telescope instrumentation includes a set of remotely controlled cine movie cameras to take solar photographs in the 1,500-Å to 1-μ (10,000-Å) spectral range. There is also an echelle spectrograph of very high dispersion and a slit-jaw viewing system which has a Lyot filter in series with a TV vidicon.

The observer will change film, locate solar features of interest, and make judgments such as exposure time and choice of instrumentation device to use.

Scheduled Maintenance

All optical surfaces, (mirrors, lenses, gratings, slits, and filters) are examined for damage or deterioration at regular intervals. Calibration tests of some elements are made less frequently to determine whether changes in reflectivity or transmittance have occurred. The dichroic mirrors and

Table 3-75

OPERATION SUPPORT AND REQUIREMENTS
0.8 Meter UV-Visible Incidence Solar Telescope--
OASF Instrument No. 44

ORDS No.	Time per Observation	No. of Men	Skill Identification*	Man-hours/ Observation	Start Time (hours from start of observation)	Number of Observations
050	24 hours followed by 0.5 hour/day for 13 days	1	5	3	-0.25	1
				0.75	-0.25	
		1	8	10	+24	
				0.5	+48	
064	30 days continuous	1	5	2/day	-0.25	1
		1	8	4/day	+24	
069	0.5 hour	1	5	0.75	-0.25	3
		1	8	0.2	+48	

*Skills are identified by number in Table 3-3.

Lyot filters are of particular interest in this regard. The cine-camera and échelle-camera transport mechanisms are examined and overhauled at regular intervals, as are other electromechanical equipment units.

Unscheduled Maintenance

Replacement cameras, guidance equipment, filters and motors are available for maintenance. Replacement optics (gratings, mirrors, or lenses) may be available in some cases.

3.2.10.5 Supporting Research and Technology

Supporting Research and Technology (SRT) requirements for the 0.8-m UV-visible-IR diffraction-limited telescopic (Instrument No. 44) are listed below. Full descriptions of SRT items are given in Section 4.3.

Research and Advance Technology

Develop methods for rapidly evaluating mirror figure and alignment under one and zero-g environments (SRT 1).

Conduct experimental studies of precision structural properties of mirror (SRT 2).

Develop methods for generating and maintaining diffraction limited (5,000 Å) mirror quality in orbital environments (SRT 3).

Develop mirror surfaces to provide high ultraviolet reflectivity, precision of figure and freedom from scattering (SRT 4).

Develop cantilevered mirror as a reflective beam deflector (SRT 5).

Develop techniques to overcome electrostatic charge build-up and fog producing spark discharge on roll film in hard vacuum (SRT 17).

Develop flexible film substrata of higher dimensional stability than now available (SRT 18).

Develop improved grating ruling techniques and equipment to provide closer ruling spacing and greater uniformity of ruling spacing, blaze angle and surface finish (SRT 38).

Develop criteria for film transport mechanisms suitable for roll film in hard vacuum to avoid emulsion cracking and flaking (SRT 39).

Investigate degradation of telescope detector and reflective surfaces resulting from 0_2 exposure (SRT 42).

Investigate techniques for alignment and focusing mechanisms for optical telescopes (SRT 55).

Investigate the dimensional stability of candidate mirror materials (SRT 56).

Evaluate sputtering on mirror surfaces from high-energy particles (SRT 57).

Advance Development

Assess materials for internal use to determine if rapid aging and breakdown are caused by internal atmosphere (SRT 82).

Assess materials for external use to evaluate (A) hard vacuum effects on materials, finishes, etc.; and (B) development of processing, handling, and assembly techniques (SRT 83).

Supporting Development

Develop image tubes with greater spatial resolution than are available (SRT 84).

3.2.10.6 Development Cost and Schedules

The Phase D cost is shown in Table 3-76, which shows both development and operations costs. The development schedule is shown in Figure 3-53. Quantities of equipment required in development are shown in Table 3-77.

3.2.10.7 Instrumentation Section

Slit-Jaw Camera

The slit-jaw camera assembly consists of a field lens adjacent to the back of a diagonally mounted slivered slit subassembly, a relay lens that refocuses the light into an f/40 or higher beam just before it goes into the Lyot-Ohman Hα extremely narrow bandpass filter, and relay lens following the filter assembly that focuses the nearly parallel beam of 6,563 Å light onto the TV camera focal plane (Table 3-78). A permanent record of the slit position on the sun is made from the TV camera output, or an observer can view the same output on a TV monitor so that he can select targets of interest and ensure that the spectrograph is accurately positioned on its target feature.

Table 3-76

TASK COST ESTIMATE - PHASE D (page 1 of 2)
0.8-Meter UV-Visible-IR Normal Incidence Solar Telescope--
(OASF Instrument No. 44)
($ thousands)

Development total	6,824		
Engineering		500	
Detectors		*	
Spectrograph film			*
Collecting optics		471	
0.8-m primary mirror			150
Secondary mirror			45
Secondary mirror alignment Assy			276
Manual guidance		300	
TV camera			*
Control moment gyros			*
Housing		288	
Structure			288
Experiment sensors		3,465	
Lyot filter			450
Mod dispersion spectrograph			600
Echelle spectrograph			915
35-mm plate camera			700
Solar magnetograph			800

*Cost item not derived where overall estimate for instrument is not significantly affected.

Table 3-76 (page 2 of 2)

Major hardware articles		1,800	
Mockup			*
Engineering model			*
Project verification model			*
Qualification model			*
Operations total	3,128		
Flight instrument		2,023	
Backup flight instrument		819	
Engineering support		286	
Phase D total	9,952**		

*Cost item not derived where overall estimate for instrument is not significantly affected.
**Assumes previous development of ATM Solar Telescope (JPL) (Reference 2-7)

Echelle Spectrograph

The echelle spectrograph assembly follows the silvered slit (Figure 3-52). The light passing through the slit reflects off a plane mirror (which allows the spectrograph optics to be kept within the projected area of the telescope tube) and then falls onto the predisperser grating (275.5 or 128 lines/mm grating frequency (see Table 3-79) which disperses the beam into the plane of the spectrograph's light path. The predisperser is tilted so that the desired region of the first order spectrum falls onto the echelle grating, the resulting beam contains the dispersing colors, but the light of each wavelength remains collimated. The echelle grating disperses the spectrum presented to it in the plane perpendicular to that of the predisperser grating; the light from the echelle is focused by an imaging mirror onto the focal plane of the spectrograph sequence camera (35 mm x 10 mm).

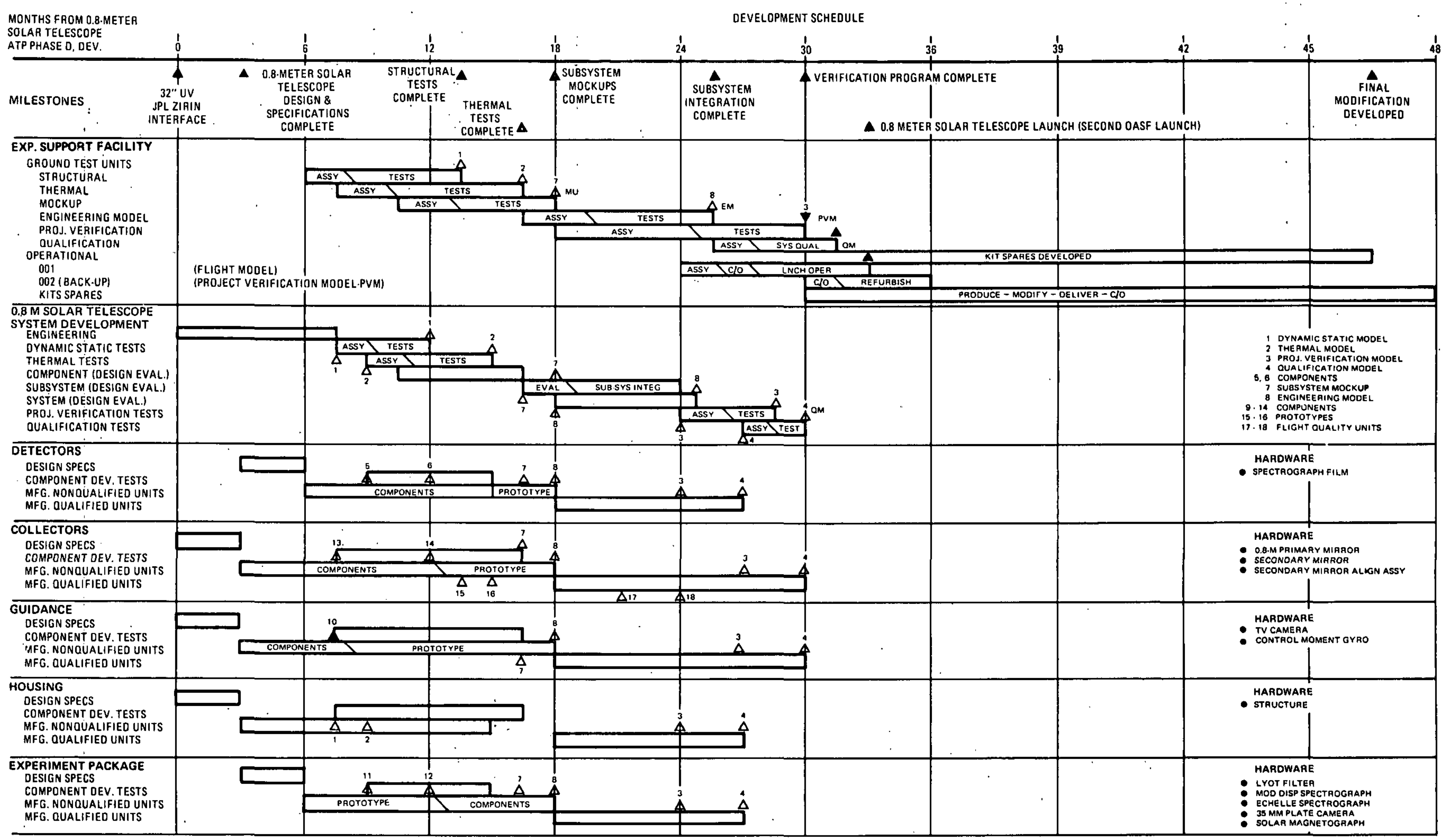

Figure 3-53. Development Schedule, 0.8-Meter UV-Visible Normal Incidence Telescope, Solar (OASF Instrument No. 44)

Table 3-77

PRIMARY INSTRUMENT EQUIPMENT LIST--DEVELOPMENT PHASE D
0.8-m UV-Visible-IR Normal-Incidence Solar Telescope--
(OASF Instrument No. 44)

Functional System (Major Element)	Subsystem	Assemblies	Quantity		
			Bread-Board	Proto-Type	Flight Quality
0.8-m UV-visible-IR telescope	Detectors	Spectrograph film	2	2	2
	Collecting optics	0.8-m primary mirror	1	2	1
		Secondary mirror	1	2	1
		Secondary mirror alignment assembly	2	2	1
	Manual guidance	TV camera	1	1	2
		Control moment gyro	1	1	2
	Housing	Structure		1	2
	Experiment sensors	Lyot filter	1	1	2
		Mod. disp. spectrograph	1	1	2
		Echelle spectrograph	1	1	2
		35-mm plate camera	1	1	2
		Solar magnetograph	1	1	2
	Major hardware articles	Mockup	1	---	---
		Engineering model	---	1	---
		Project verification model	---	60%*	40%*
		Qualification model	---	---	---

*Obtained from subsystem development quantities

Table 3-78

FIELD IMAGE INSTRUMENTATION CHARACTERISTICS
0.8 Meter UV-Visible Normal-Incidence Solar Telescope--
OASF Instrument No. 44

Electro-optics camera characteristics	
Type	Slit-jaw camera with TV vidicon and image converter
Aperture	25.4 vidicon face mm
Resolution	525 TV lines/mm
Photo surface	Photocathode
Power consumption	10 W
Frame time	Variable
Weight	7 kg
Filter characteristics	
Type	Narrow-band Lyot
Wavelength (short)	6,560 Å
(long)	6,566 Å
Resolution ±	0.25 (0.5 Å bandwidth)
Band center	6,563 Å
Remote change cycle time	2 sec
Weight	8 kg

The predisperser grating is a conventional concave grating, but the echelle is a grating of somewhat different design. It is a "pile of steps" where the narrow space between the step levels is used to reflect the light. That light is incident on the grating at angles up to 75° from the normal.

Table 3-79

ECHELLE SPECTROGRAPH CHARACTERISTICS
0.8 Meter UV-Visible Normal-Incidence Solar Telescope--
OASF Instrument No. 44

Wavelength	
Short	1,500 Å
Long	7,500 Å
Resolution	0.01 Å at 3,000 Å
Entrance aperture	
Slit width	20μ
Slit height	12,500μ
Incident radiation	
f/No. limitation	40
Spatial resolution	0.096 sec
Predisperser grating	
Type	Concave (two)
Size	80 mm diam
Ruling frequency	275.5, 128 line/mm
Dispersion	13.35, 28.7 Å/mm
Angle of diffraction range	44° - 3.27 (dispenser)
Spectral order	1 usually
Main grating	
Type	Echelle (two) 1,450 - 3,240 Å; 3,150 - 7,000 Å
Size	30, 90 cm x 8 cm
Ruling frequency	539.6, 254.2 lines/mm
Dispersion	15 Å/mm at 3,000 Å
Angle-of-diffraction range	44°.31, 52°.43, 45°.63, 53°.76
Spectral order	9-18, 9-18
Recorder Characteristics	
Type	Cine-frame camera
Aperture	35 x 100 mm
Remote change cycle time	1 sec
Film-type limitations	Schumann-Panchromatic
Exposure per magazine load	750
Power consumption during cycle change	15 W
Power consumption during calibration	5 W
Weight	20 kg (including 12 kg for camera)

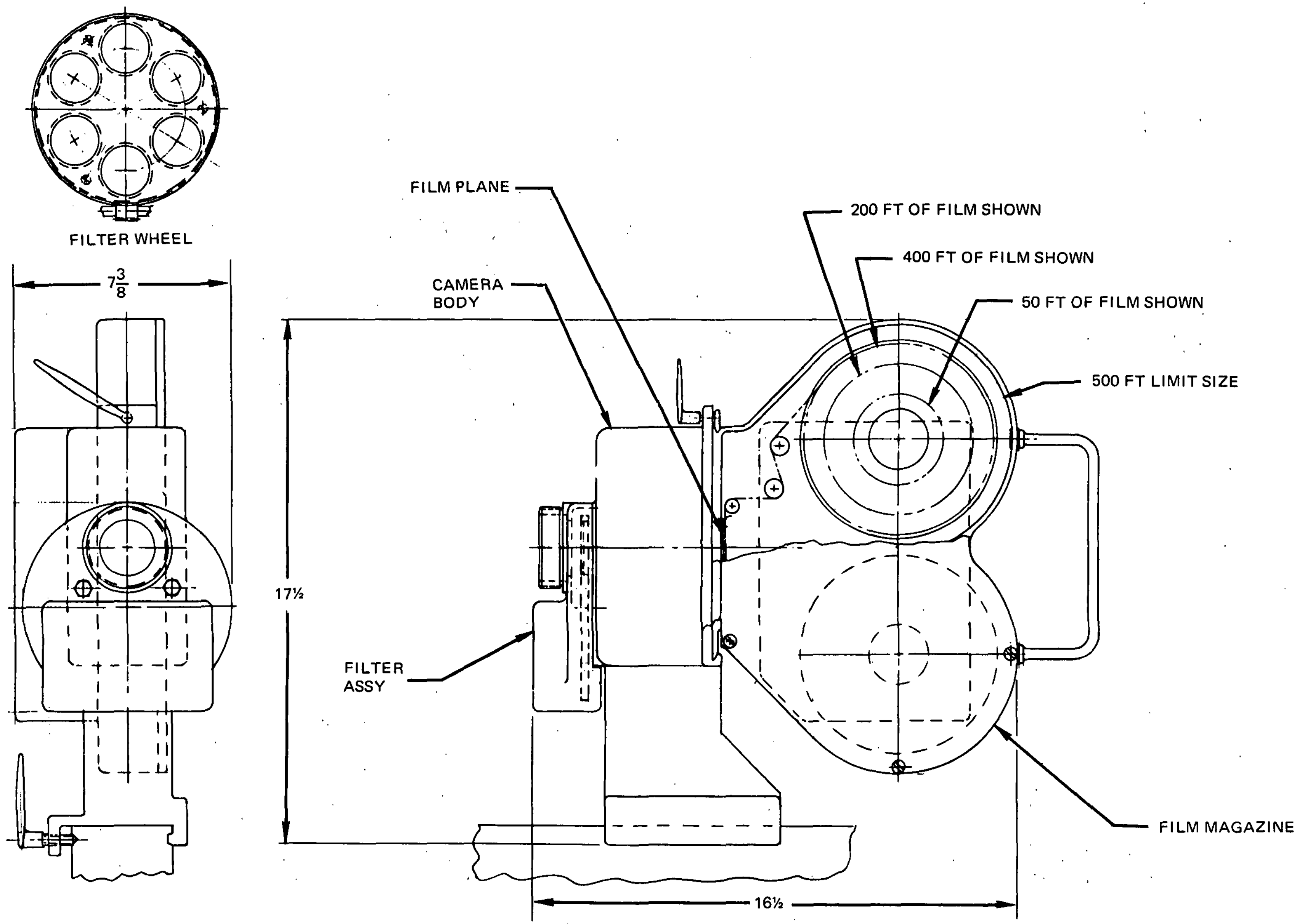

Figure 3-54. 35-Millimeter Cine Camera

Table 3-80

FIELD IMAGE INSTRUMENTATION CHARACTERISTICS
0.8 Meter UV-Visible Normal-Incidence Solar Telescope--
OASF Instrument No. 44

Film camera characteristics	
Type	Cine movie sequence
Aperture	35 x 35 (mm)
Remote change cycle time	<2 sec
Power consumption during change	10 W
Film-type limitations	Spectrographic emulsions
Exposures per magazine load	1,000-ft reels
Filter characteristics	
Type	Fabrey-Perot
Wavelength (short)	1,165.7 Å
(long)	1,265.7 Å
Resolution ±	50 Å
Band centers	1,215.7 Å
Remote change cycle time	10 sec
Power consumption during change	2 W
Weight	12 kg

Table 3-81

FIELD IMAGE INSTRUMENTATION CHARACTERISTICS
0.8 Meter UV-Visible Normal-Incidence Solar Telescope--
OASF Instrument No. 44

Film camera characteristics	
Type	Cine movie sequence
Aperture	35 x 35 mm
Remote change cycle time	<2 sec
Power consumption during change	10 W
Film type limitations	Spectrographic films
Exposures per magazine load	1,000-ft reels
Filter characteristics*	
Wavelength (short)	6,650 Å
(long)	6,566 Å
Resolution ±	0.25 (0.5-Å bandwidth)
Band centers	6,563 ± 3 Å
Remote change cycle time	50 sec
Power consumption during change	2 W
Weight	20 kg

*Narrow-band Lyot filter

Table 3-81A

FIELD IMAGE INSTRUMENTATION CHARACTERISTICS
0.8 Meter UV-Visible Normal-Incidence Solar Telescope--
OASF Instrument No. 44

Film camera characteristics	
Type	Cine movie sequence
Aperture	35 x 35 mm
Remote change cycle time	< 2 sec
Power consumption during change	10 W
Film-type limitations	Spectrographic emulsions.
Exposures per magazine load	1, 000-ft reels
Electro-optics camera characteristics	
Type	TV vidicon and image converter
Aperture	25.4 vidicon face
Resolution	525 lines/mm TV
Photo surface	Photocathode
Power consumption	10 W
Frame time	Variable
Filter characteristics*	
Wavelength (short)	3, 000 Å
(long)	6, 000 Å
Resolution	Band filters
Band centers	Assorted
Remote change cycle time	10 sec
Power consumption during change	2 W
Weight	13 kg

*Filter wheel

The echelle grating enables a large spectral range to be covered on a limited format when high dispersion is needed. The grating frequencies specified for this particular echelle spectrograph (539.6 and 254.2 lines/mm) are within present technological capabilities.

Recording Cameras

The three time-lapse/cine movies cameras are arranged in a fixed cluster weighing 45 kg in such a way that all can be focused as a unit. Each camera (Figure 3-54) contains a removable film cassette, motorized shutter (remotely adjusted for exposure time) and a bandpass filter or remotely controlled filter wheel (see Tables 3-80, 3-81, and 3-81A). The cassettes consist of film supply (up to 2,000 ft if necessary) and take up reels, camera mechanism, and motor. The cassettes can be sealed if a controlled atmosphere is desirable.

The incoming light beam is split by two dichroic beam splitters; the first beam splitter separates the energy into long and short wavelengths. The short (below 3,000 Å) reflects to a UV Camera, passing through a Fabry-Perot filter and other bandpass filters to the film. The long wavelengths pass through to the second beam splitter where the red light (6,000 Å and above) is reflected off to the Hydrogen Alpha (Hα) Camera and the balance passes through to the visible light camera.

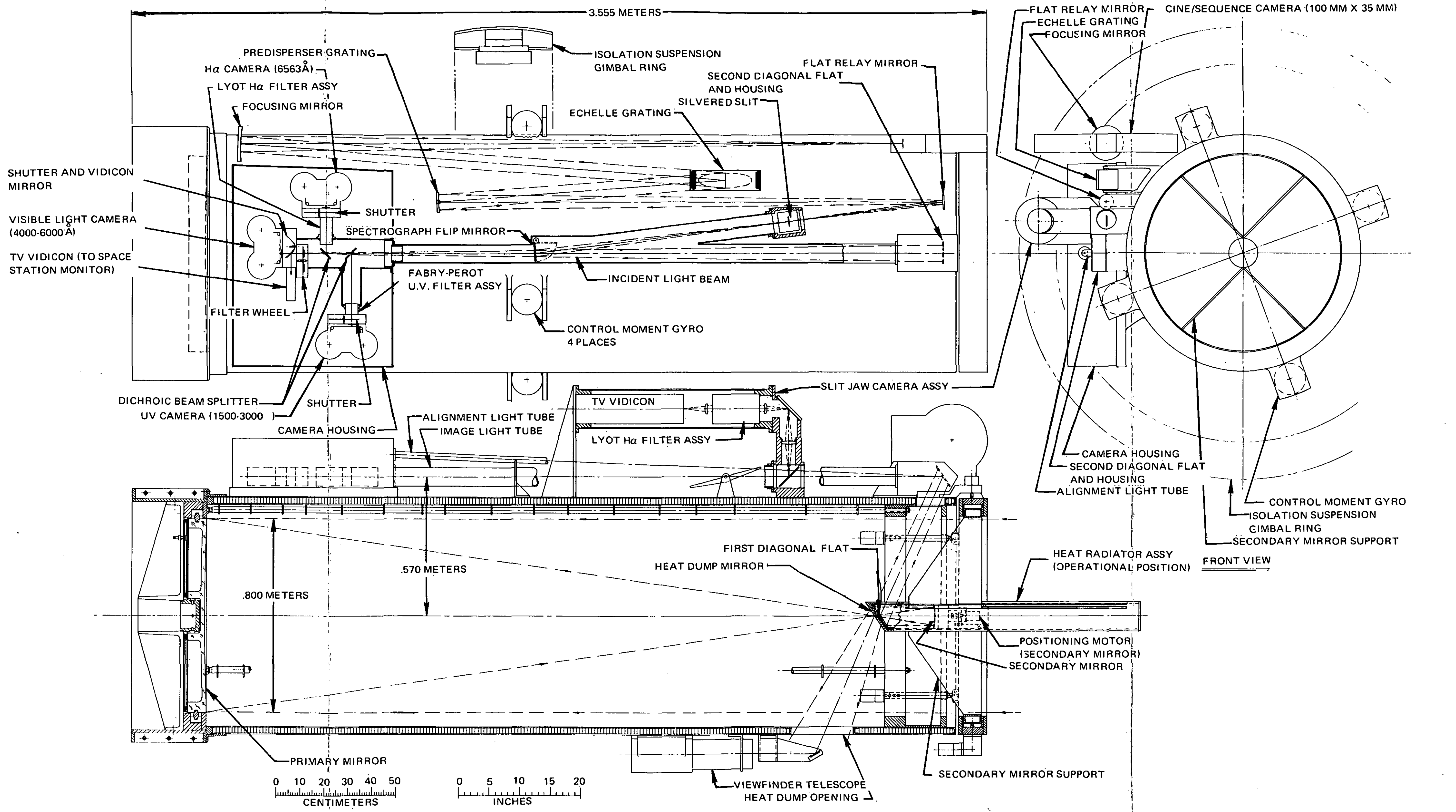

Figure 3-52. 0.8-Meter UV-Visible, Normal Incidence Telescope, Solar. OASF Instrument No. 44

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3.2.11 0.2 Meter UV (off-axis) Normal Incidence Telescope, Solar OASF-Instrument No. 4

3.2.11.1 General Characteristics

In order to reach wavelengths shorter than the 900 to 1,000 Å lower limit for adequate collection by Cassegrainian or other multiple element telescopes, an off-axis, or Herschelian, telescope is recommended (Figure 3-55). The advantage of this telescope is that the instrumentation section can be placed at the prime focus, thereby permitting the use of a single optical element in the collector, without obscuring the collecting mirror by the instrumentation package. A telescope of this configuration provides good collecting efficiency down to a lower wavelength limit of about 500Å, and is reasonably competitive with a Cassegrainian telescope out to 1,400 or 1,500Å.

For the intermediate time period of the OASF Study, an aperture of 0.20 meters is considered adequate from the standpoint of resolution and collecting area. A focal ratio of 12 provides a workable compromise between excessive length and insufficient scale factor. Therefore, the telescope design has been set at 0.2 m aperture and 2.4 m effective focal length.

Associated with this telescope as an instrumentation package is a spectrograph employing a concave grating in a nearly normal incidence configuration. The purpose of this arrangement is identical to the reasoning behind the selection of the single element telescope; namely, the reduction of reflections to a minimum. Also, incorporated in the instrument is a slit-jaw camera which serves the following dual functions:

1. Providing a reference image of the sun for each spectrogram, to identify the features recorded in the spectrogram.
2. Providing to the on-board observer an image of the sun for acquisition and tracking purposes.

The spectrograph consists of a slit at the prime focus of the telescope, a concave grating ruled to provide a reciprocal linear dispersion of 10Å per mm on the plate, and a magazine which stores the unexposed plates, advances them to the exposure position and returns them to storage in a manner similar to the operation of an automatic slide changer. Each plate consists of a strip of Schumann film mounted on a semi-rigid frame which serves as a vehicle to transport the film and at the same time to protect it from mechanical damage.

The slit-jaw camera takes the light reflected off the face of the slit, which is silvered and mounted at 45^{o} to the axis, and relays the image to the film camera and video camera by means of a field lens, a relay lens, and a beam splitter. A very narrow band filter, probably of the Lyot type, restricts the image to light in hydrogen alpha line for the purpose of highlighting the features of interest. Shutters are provided for both film cameras, spectrographic and slit-jaw, to control exposures.

Mounted on the telescope are four control moment gyros whose function is to direct the line of sight of the telescope according to commands of the on-board observer in pitch and yaw. Roll is derived from spacecraft orientation.

While the telescope has been designed around a short wavelength limit of 500 Å, the spectrograph geometry has been arranged so as to permit the 304 Å line of helium to be recorded. It is expected that, due to its exceptional strength, this line will be recorded despite the poor reflection of the mirrors at this wavelength.

In lieu of photographic recording of the spectrum, it is possible to use electronic recording. Channel photomultipliers are suitable transducers for this region of the spectrum; and in addition, are conveniently small, allowing reasonable packaging in the spectrometer package. An instrument already embodying these features is the spectroheliometer proposed by Harvard College Observatory for experiment S055 in the Apollo Telescope Mount (Reference 2-8). These instruments are considered nominally equivalent.

3.2.11.2 Design Criteria

The function of this instrument is to extend the lower wavelength limit for solar observation beyond the 1,000 Å region, at which point multiple reflections in Cassegrainian telescopes cause a sharp drop-off in collected energy. Because of the off-axis configuration, the resolution requirement must be relaxed from the diffraction-limited value (due to the inherent aberrations in off-axis systems). It is desired to have a collecting area equal to a 20 cm aperture and an angular resolution of 1 sec combined with adequate reflectivity down to 500 Å. A nominal field of view of two minutes is desired with resolution approaching one second. The tabular data that follow describe how these criteria can be met.

3.2.11.3 Detailed Characteristics

The basic characteristics of the 0.2-m UV (off-axis) normal-incidence solar telescope, have been summarized in Figure 3-3 in Section 3.1.

Additional details about the instrument are tabulated in Table 3-82, 3-83, and 3-84.

3.2.11.4 Utilization of Man

Setup and maintenance requirements are summarized for this instrument in Table 3-85. Because man's utilization in the operation of the instrument depends on the observational program, operational information is separately summarized in Table 3-86.

Deployment

The optical technician inspects the single mirror and the gratings of the spectrograph. The star tracker and/or sun sensor are activated. If channel multipliers are used, they must remain in vacuum to avoid contamination from the space station atmosphere.

Alignment

The phototechnician takes a series of spectrograms and slit-jaw-camera photographs to check that the system is in working order and has maintained alignment through launch.

Table 3-82

COLLECTOR PARAMETERS
0.2-M UV (Off Axis) Normal-Incidence Solar Telescope--
OASF Instrument No. 4

Aperture	0.2 m
Primary focal length	2.4 m
Effective focal length	2.4 m
Total fielf of view	2 arc min.
Angular resolution	
On axis	1 arc sec at 800 Å
Poorest in field of view	1.5 arc sec at 800 Å
Obscuration of aperture	0%
Minimum wavelength	300 Å
Maximum wavelength	>1,500 Å
Primary f/No.	12
System f/No.	12
Scale at system focal plane	86 arc sec (arc sec/mm)
Resolution at system focal plane	86 lines/mm
Linear field of view at system focal plane	1.4 mm

Calibration

The test photographs taken for alignment also serves for calibration requirements (in conjunction with a microdensitometer). Each particular observation of a solar prominence will require a test strip to determine proper exposure time.

Table 3-83

INTERFACE CHARACTERISTICS
0.2-m UV (Off-Axis) Normal-Incidence Solar Telescope--
OASF Instrument No. 4

General	
System weight (less expendables)	65 kg
System volume (launch configuration)	1.6 m^3
System shape (launch configuration)	Cylinder
Method of accomplishing	
Deployment	Remove plastic bag
Alignment	No in-flight alignment
Calibration	Photography of spectrum of quiet sun
Operation	Remote photography
Experiment change	Not required
Stowage requirements (launch)	
Mechanical	Plastic bag packaging
Electrical	None
Experiment data handling	
Format	35- x 120-mm photographic plate
Processing	On board
Recording media	Photographic emulsion (Schumann)
Mode of data recovery	Change plate cannister
Pointing requirements	
Pointing accuracy (acquisition)	Manual
Power consumption	
Stowed	None
Standby	≈35 W
Operate	≈40 W

Table 3-84

GUIDANCE AND CONTROL CHARACTERISTICS
0.2-m UV (Off-Axis) Normal-Incidence Solar Telescope--
OASF Instrument No. 4

Guidance characteristics	
Coarse	
Initial acquisition field of view	Manual
Resolution	---
Residual error	---
Intermediate	
Field of view	Manual
Resolution	---
Residual error	---
Fine	
Field of view	± 40 arc min.
Resolution	± 0.1 arc sec
Residual error	± 15 arc sec
Control characteristics	
CMG	
Type	Single degree of freedom, viscous damped
Wheel momentum	640°
Gimbal stops	±60 W
Spin motor power (start)	40 W
(run)	6 W
Servo power (peak)	10W
(average)	1.5 W
Max torque	3.8 oz-in.
Weight	16 lb
Diameter	5 in.
Length	8-1/2 in.

Table 3-85

SETUP AND MAINTENANCE REQUIREMENTS
0.2-M UV (Off-Axis) Normal-Incidence Solar Telescope--
OASF Instrument No. 4

Operation	Average Times/ Year	Duration (hours)	No. of Men	Skill Identification*	Hours/ Man	Average Power (W)	Special Equip Weight (lb)	Special Equip Volume (ft^3)
Deployment	---	2	1	21	2	---	---	---
			1	14	1			
Alignment	---	1	1	8	1	---	3	1
Calibration		(none required in orbit)						
Scheduled maintenance	6	1	1	12	1/2	---	---	---
			1	14	1/2	5	10	1
Unscheduled maintenance	1/3	1	1	12	1	40	100	3

*Skills are identified by number in Table 3-3.

Operation

Exposure time depends on the specifics of instrument design and film choice and is determined empirically. The astronaut identifies a prominence and acquires it on the slit. TV monitor (±10 to 15 arc sec) is a possibility. Exposure is every 30 sec in a 1- to 2-hour sequence for 12 sequences or every minute for 15 min., then every 5 min. for 1 hour.

Scheduled Maintenance

An optical technician examines the optics for damage or deterioration. An electromechanical technician checks the camera-sequencing mechanism on the spectrograph for deterioration.

Table 3-86

OPERATION SUPPORT AND REQUIREMENTS
0.2-M UV (Off-Axis) Normal-Incidence Solar Telescope--
OASF Instrument No. 4

ORDS No.	Time per Observation (hours)	No. of Men	Skill Identification*	Man-hours/ Observation	Start Time (hours from start of observation)	Number of Observations
042	1.0	1	5	1.1	-0.05	12
		1	8	0.2 (avg)	+48	
058	1.25	1	5	1.3	0.05	1,000
		1	8	0.1 (avg)	+48	

*Skills are identified by number in Table 3-3.

Unscheduled Maintenance

Unscheduled maintenance is most likely the result of unusual failures of the sun sensors, or a mechanical failure in the camera-sequencing mechanism.

3.2.11.5 Supporting Research and Technology

Supporting Research and Technology (SRT) requirements for the 0.2-m UV off-axis telescope (Instrument No. 4) are listed below. Full descriptions of SRT items are given in Section 4.3.

Research and Advance Technology

Develop mirror surfaces to provide high UV reflectivity, precision of figure and freedom from scattering (SRT 4).

Develop higher than current reflectivity in coatings for XUV below 900 Å (SRT 7).

Extend the XUV filter technology to provide structurally sturdy transmission filters of about 100 Å bandpass in the region from 170 Å longward (SRT 10).

Develop XUV sensitive imaging tubes for use below 1,050 Å (SRT 11).

Develop techniques to overcome electrostatic charge build-up and fog producing spark discharge on roll fim in hard vacuum (SRT 17).

Develop criteria for film transport mechanisms suitable for roll film in hard vacuum to avoid emulsion cracking and flaking (SRT 39).

Investigate degradation of telescope detector and reflective surfaces resulting from 0_2 exposure (SRT 42).

Investigate the dimensional stability of candidate mirror materials (SRT 56).

Advance Development

Assess materials for internal use to determine if rapid aging and breakdown are caused by internal atmosphere (SRT 82).

Assess materials for external use to evaluate (A) hard vacuum effects on materials, finishes, etc.; and (B) development of processing, handling, and assembly techniques (SRT 83).

Supporting Development

Develop image tubes with greater special resolution than currently obtainable (SRT 84).

3.2.11.6 Development Cost and Schedules

The Phase D cost is shown in Table 3-87, which shows both development and operations costs. The development schedule is shown in Figure 3-56. Quantities of equipment required in development are shown in Table 3-88.

3.2.11.7 Instrumentation Section

The off-axis telescope utilizes a single instrumentation device, a low-dispersion concave grating spectrograph (Figure 3-55) that operates at near-normal incidence. It consists of a slit, with its associated slip-jaw camera, a concave grating (see Table 3-89) and a plate camera consisting of a slide changer type of magazine. The slit-jaw camera (see Section 3.2.10.7) assembly (weight, 15 kg) takes both video and photographic pictures in hydrogen alpha light of the portion of the solar image surrounding the slit. The video picture is relayed to the on-board observer who uses it for acquisition and guidance and the photographic record is used as a reference when examining the spectra.

Table 3-87

TASK COST ESTIMATE--PHASE D
0.2-m UV (Off-Axis) Normal-Incidence Solar Telescope--
(OASF Instrument No. 4)
($ thousands)

Development total	2,250		
Engineering		165	
Detectors		*	
35-mm strip film			*
Spectrograph film			*
Collecting optics		15	
0.20-m primary mirror			*
Manual guidance	200		
Housing	75		
Structure			*
Experiment sensors	1,200		
Normal-incidence spectrograph			500
35-mm plate camera			700
Major hardware articles	595		
Mockup			*
Engineering model			*
Project verification model			*
Qualification model			*
Operations total	1,040		
Flight instrument		675	
Back-up flight instrument		270	
Engineering support		95	
Phase D total	3,290**		

*Cost item not derived where overall estimate for instrument is not significantly affected.

**Assumes previous development of ATM Experiment S056 (Reference 2-10).

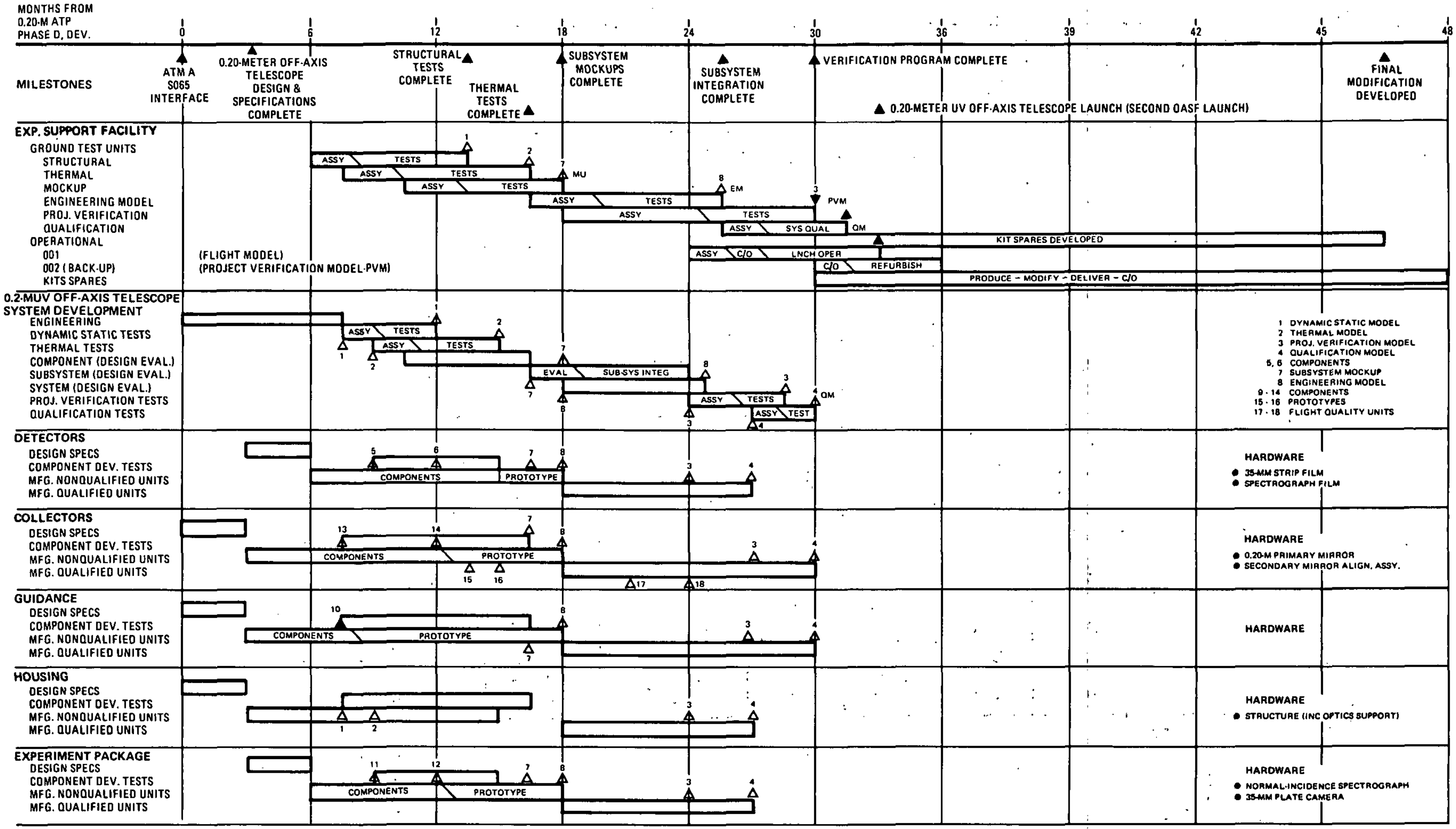

Figure 3-56. Development Schedule, 0.2 Meter UV Off-Axis Normal Incidnece Telescope, Solar (OASF Instrument No. 4)

Table 3-88

PRIMARY INSTRUMENT EQUIPMENT LIST--DEVELOPMENT PHASE D
0.2-M UV Off-Axis Normal-Incidence Solar Telescope--
(OASF Instrument No. 4)

Functional System (Major Element)	Subsystem	Assemblies	Quantity		
			Bread-board	Proto-type	Flight Quality
0.2-m UV off-axis solar telescope	Detectors	35-mm strip film Spectrograph film	2 2	1 1	2 2
	Collecting optics	0.20-m primary mirror	1	2	1
	Manual guidance	---	---	---	---
	Housing	Structure (including optics support)	---	1	2
	Experiment sensors	Normal-incidence spectrograph 35-mm plate camera	1 1	1 1	1 1
	Major hardware articles	Mockup Engineering model Project verification model Qualification model	1 --- --- ---	 1 60%* ---	 --- 40%* 1

*Obtained from subsystem development quantities.

Table 3-89

CONCAVE GRATING SPECTROGRAPH CHARACTERISTICS
0.2-m UV (Off-Axis) Normal-Incidence Solar Telescope--
OASF Instrument No. 4

Type	Normal incidence
Wavelength	
Short	300 Å
Long	1,500 Å
Resolution	0.2 Å at 700 Å
Entrance aperture	
Slit width	20 μ
Slit height	1,500 μ
Incident radiation	
f/No. limitation	12
Spectral resolution	1 sec
Spectral calibration	---
Predisperser grating	
Type	NA
Size	---
Ruling frequency	---
Dispersion	---
Angle of diffraction range	---
Spectral order	---
Main grating	
Type	Concave
Size	85 x 83 mm
Ruling frequency	1,000 lines/mm
Dispersion	±10 Å/mm at 300 Å
Range of angle of diffraction	1.7° to 8.6°
Range of spectral order	1
Recorder characteristics	
Type	Film
Aperture	25 x 120 mm
Remote change cycle time	5 sec
Film-type limitations	Schumann emulsion
Exposure per magazine load	640
Power consumption during cycle change	5 W
Power consumption during calibration	---
Weight	21.5 kg (including 20 kg for plate camera)

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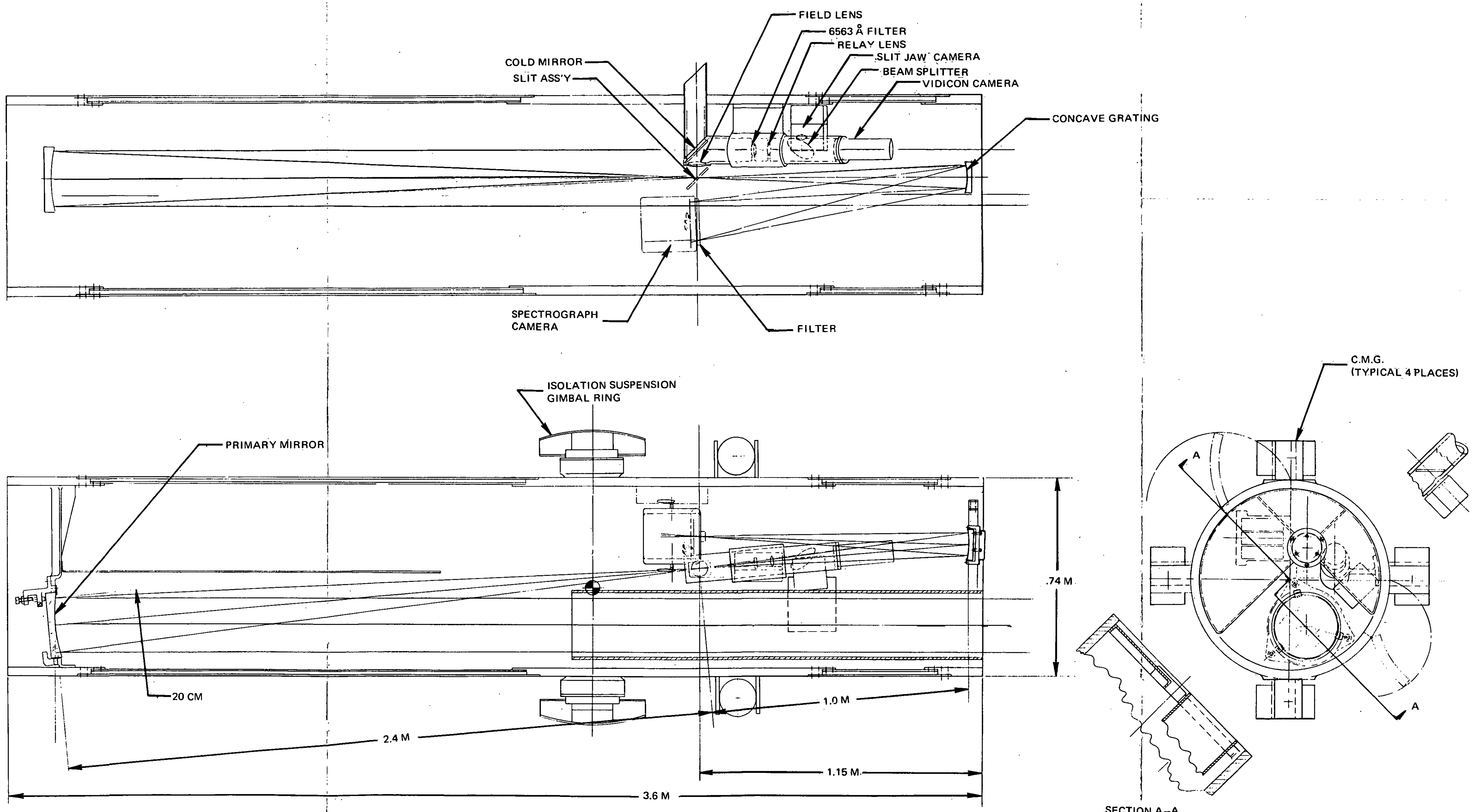

Figure 3-55. 0.2-Meter UV Off-Axis, Normal-Incidence Telescope, Solar. OASF Instrument No. 4

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3.2.12 0.25-Meter XUV Spectroheliograph Normal-Incidence Solar Telescope--OASF Instrument No. 6

3.2.12.1 General Characteristics

The 0.25-m XUV spectroheliograph is a special-purpose instrument designed to record the image of the solar disk in several extreme UV wavelengths simultaneously (Figure 3-57). Because of the history associated with this instrument, and the success enjoyed by the Naval Research Laboratory in rocket flights, the spectroheliograph is based on the Naval Research Laboratory design which is proposed for the Solar ATM as part of experiment S053. This is the logical successor to the earlier rocket borne instrument. The telescope has a concave grating with figure corrections to improve the image quality. The grating is plated with gold and ruled at 3,333 lines/mm. An aperture of about 0.25 m with a focal length of 3 m provides the scale factor and image brightness required.

An unbacked thin film of aluminum possesses the desired wavelength transmission range, while reflecting the much more intense visible energy. As a further protection, thermal mirrors are placed at strategic points to reflect the zero order image and the first order visible range energy back out into space through the entrance aperture. The camera consists of a magazine to store the film strips, advance them to exposure position, and return them to storage in the manner of an automatic slide changer. A shutter, operated on command, controls the exposure time.

An auxiliary telescope consisting of an objective lens of about 0.1-m aperture, a narrow band filter, and a video camera, is boresighted to the spectroheliograph telescope, to provide the astronaut-observer with guiding information. Control gyros provide the steering torques. An automatic guidance subsystem is also entirely feasible for this telescope.

3.2.12.2 Design Criteria

The purpose of this instrument is to record the image of the solar disk in the various bright-line wavelength between 170 Å and 650 Å. A resolution of one arc sec over the field of view of 30 min. will accomplish this. To achieve satisfactory images in the extreme ultraviolet, very effective rejection of the longer wavelength, which predominate in the sun, must be effected.

3.2.12.3 Detailed Characteristics

The basic characteristics of the 0.25-m XUV spectroheliograph normal-incidence solar telescope have been summarized in Figure 3-3 in Section 3.1.

Additional details about the instrument are tabulated in Tables 3-90, 3-91, 3-92, and 3-93.

3.2.12.4 Utilization of Man

Setup and maintenance requirements are summarized for this instrument in Table 3-94. Because man's utilization in the operation of the instrument depends on the observational program, operational information is separately summarized in Table 3-95.

Deployment

The optics require only focusing in orbit. The sun sensor and spectroheliograph optics are uncovered and the gimbal ring attached to the space station. An optical technician may inspect the concave gratings for damage.

Alignment

The need for minor focus adjustments is determined from the test plates made during calibration. No other alignments are necessary in orbit.

Calibration

A series of plates is made of the solar plages and inner corona, and then of some standard lamps. The two gratings are optimized for different wavelength regions, one for 170 to 650 Å and the other for 304 to 1,216 Å.

Table 3-90

COLLECTOR PARAMETERS
0.25-m XUV Spectroheliograph Normal-Incidence Solar Telescope--
OASF Instrument No. 6

Aperture	0.25 m
Primary focal length	3 m
Effective focal length	3 m
Total field of view	32 arc min.
Angular resolution	
On axis	1 arc sec at 170 Å
Poorest in field of view	1 arc sec at 170 Å
Obscuration of aperture	0%
Minimum wavelength	170 Å
Maximum wavelength	650 Å
Primary f/No.	12
System f/No.	12
Scale at system focal plane	69 arc sec/mm
Resolution at system focal plane	69 lines/mm
Linear field of view at system focal plane	27.9 mm

Table 3-91

INTERFACE CHARACTERISTICS
0.25-m XUV Spectroheliograph Normal-Incidence Solar Telescope--
OASF Instrument No. 6

General	
System weight (less expendables)	≈300 kg
System volume (launch configuration)	≈3-m^3
System shape (launch configuration)	Cylinder W/appendage one side for one-half length
Method of accomplishing	
Deployment	Uncapping only
Alignment	No in-flight alignment
Calibration	Photography of quiet sun
Operation	TV control of photography
Experiment change	Substitution of grating assembly
Stowage requirements (Launch)	
Mechanical	Plastic-bag packaging
Electrical	None
Experiment data handling	
Format	Film strip 70 x 504 mm
Processing	None on board
Recording media	Photographic film (Schumann)
Mode of data recovery	Manual change of film magazine
Pointing requirements	
Pointing accuracy (acquisition)	$\pm 1^{\circ}$
Power consumption	
Stowed	None
Standby	55 W
Operate	≈55 W (peak 60 W)

Table 3-92

GUIDANCE AND CONTROL CHARACTERISTICS
0.25-m XUV Spectroheliograph Normal-Incidence Solar Telescope--
OASF Instrument No. 6

Guidance characteristics	
Coarse	
Initial acquisition field of view	±7-1/2°
Resolution	±15 arc min.
Residual error	±1°
Intermediate	
Field of view	±2°
Resolution	±20 arc sec
Residual error	±5 min.
Fine	
Field of view	± 40 arc min.
Resolution	±0.02 arc sec
Residual error	±0.1 arc sec
Control characteristics	
CMG	
Type	Single degree of freedom, viscous damped
Wheel momentum	640 oz-in. sec
Gimbal stops	±60°
Spin motor power (start)	40 W
(run)	6 W
Servo power (peak)	10 W
(average)	1.5 W
Max. torque	3.8 oz-in.
Weight	16 lb
Diameter	5 in.
Length	8-1/2 in.

Table 3-93

SLITLESS SPECTROHELIOGRAPH CHARACTERISTICS
0.25-m XUV Spectroheliograph Normal-Incidence Solar Telescope--
OASF Instrument No. 6

Type	Spectroheliograph (Tousey)
Wavelength	
Short	170 Å
Long	650 Å
Resolution	0.015 Å at 170 Å
Entrance aperture	
Slit width	No slit, aperture 0.25-m diam
Slit height	
Incident radiation	
f/No. limitation	12
Spatial resolution	1 sec
Spectral calibration	
Main grating	
Type	Concave
Size	250-mm diam
Ruling frequency	3,333 lines/mm
Dispersion	1 Å/mm at 170 Å
Angle of diffraction range	3.3° - 12.5°
Spectral order	1
Recorder characteristics	
Type	Film
Aperture	30 x 495 mm
Remote change cycle time	5 sec
Film type limitations	Schumann emulsion
Exposure per magazine load	25
Power consumption during cycle change	10 W
Power consumption during calibrate	5 W
Weight	55 kg (including 40 kg for plate camera)

Table 3-94

SETUP AND MAINTENANCE REQUIREMENTS
0.25-m XUV Spectroheliograph Normal-Incidence Solar Telescope--
OASF Instrument No. 6

Operation	Average Times/ Year	Duration (hours)	No. of Men	Skill Identification*	Hours/ Man	Average Power (W)	Special Equip Weight (lb)	Special Equip Volume (ft^3)
Deployment	---	1/2	1	24	1/2	---	---	---
Alignment		None						
Calibration	---	1	1	21	1	3	---	---
Scheduled maintenance	6	1	1	12	1/2	15	10	1
			1	14	1/2			
Unscheduled maintenance	---	1	1	12	1	15	30	2

*Skills are identified by number in Table 3-3.

Table 3-95

OPERATION SUPPORT AND REQUIREMENTS
0.25-m XUV Spectroheliograph Normal-Incidence Solar Telescope--
OASF Instrument No. 6

ORDS No.	Time per Observation (hours)	No. of Men	Skill Identification*	Man-hours/ Observation	Start Time (hours from Start of observation)	Number of Observations
052	0.33	1	5	0.4	-0.05	100
		1	8	(combine with other observations)	±48	

*Skills are identified by number in Table 3-3.

Scheduled Maintenance

An optical technician inspects the optical surfaces for damage or deterioration. An electromechanical technician inspects the plate camera sequencing mechanism for possible sources of failure.

Unscheduled Maintenance

Unscheduled maintenance results primarily from failure of one of the camera mechanisms. In the case of a sun sensor failure, a backup instrument is available already mounted and the repair can be postponed until a scheduled maintenance period.

3.2.12.5 Supporting Research and Technology

The operation of the 0.25-m XUV spectroheliograph (Instrument No. 6) represents a significant improvement in performance. Its implementation does not require major state-of-the-art advances. Supporting Research and Technology (SRT) requirements are listed below. Full descriptions of SRT items are given in Section 4.3.

Research and Advance Technology

Develop mirror surfaces to provide high ultraviolet reflectivity, precision of figure and freedom from scattering (SRT 4).

Develop fabrication techniques for noncircular aspherics (SRT 6).

Develop ruling techniques for ruling gratings on aspherics (SRT 9).

Extend the XUV filter technology to provide structurally sturdy transmission filters of about 100 Å bandpass in the wavelength region from 170 Å longward (SRT 10).

Develop techniques to overcome electrostatic charge build-up and fog-producing spark discharge on roll film in hard vacuum (SRT 17).

Develop improved grating ruling techniques and equipment to provide closer ruling, spacing and greater uniformity of ruling spacing, blaze angle, and surface finish (SRT 38).

Develop criteria for film-transport mechanisms suitable for roll film in hard vacuum to avoid emulsion, cracking, and flaking (SRT 39).

Investigate degradation of telescope detector and reflective surfaces resulting from 0_2 exposure (SRT 42).

Advance Development

Assess materials for internal use to determine if rapid aging and breakdown are caused by internal atmosphere (SRT 82).

Assess materials for external use to evaluate (A) hard vacuum effects on materials, finishes, etc.; and (B) development of processing, handling, and assembly techniques (SRT 83).

Supporting Development

Develop image tubes with greater spatial resolution than currently available (SRT 84).

3.2.12.6 Development Cost and Schedules

The Phase D cost is shown in Table 3-96, which shows both development and operation costs. The development schedule is shown in Figure 3-58. Quantities of equipment required in development are shown in Table 3-97.

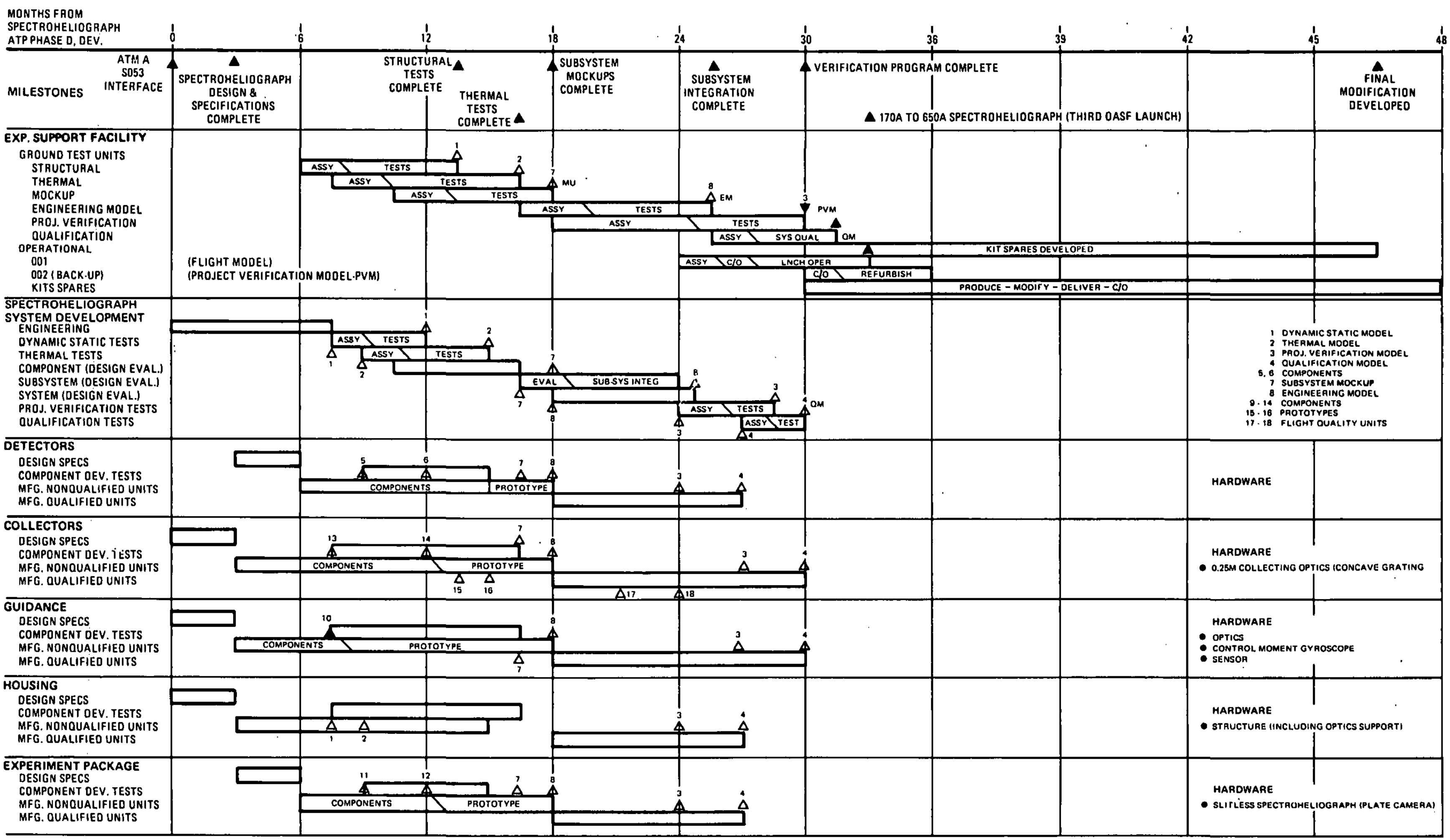


Figure 3-58. Development Schedule, 0.25-Meter XUV Spectroheliograph Normal Incidence Telescope, Solar (OASF Instrument No. 6)

Table 3-96

TASK COST ESTIMATE--PHASE D
0.25-Meter XUV Spectroheliograph Normal-Incidence Solar Telescope--
OASF Instrument No. 6
($ thousands)

Development total	2,385		
Engineering		180	
Detectors		*	
Collecting optics		75	
0.25-m collecting optics (concave grating)			*
Fine guidance (automatic)		400	
Optics			*
Control moment gyroscopes			*
Sensor			*
Housing		50	
Structure		50	
Experiment sensors		1,000	
Slitless spectroheliograph (plate camera)			1,000
Major hardware articles		630	
Mockup			*
Engineering model			*
Project verification model			*
Qualification model			*
Operations total	1,102		
Flight instrument		716	
Backup flight instrument		286	
Engineering support		100	
Phase D total	3,487**		

*Cost item not derived where overall estimate for instrument is not significantly affected.

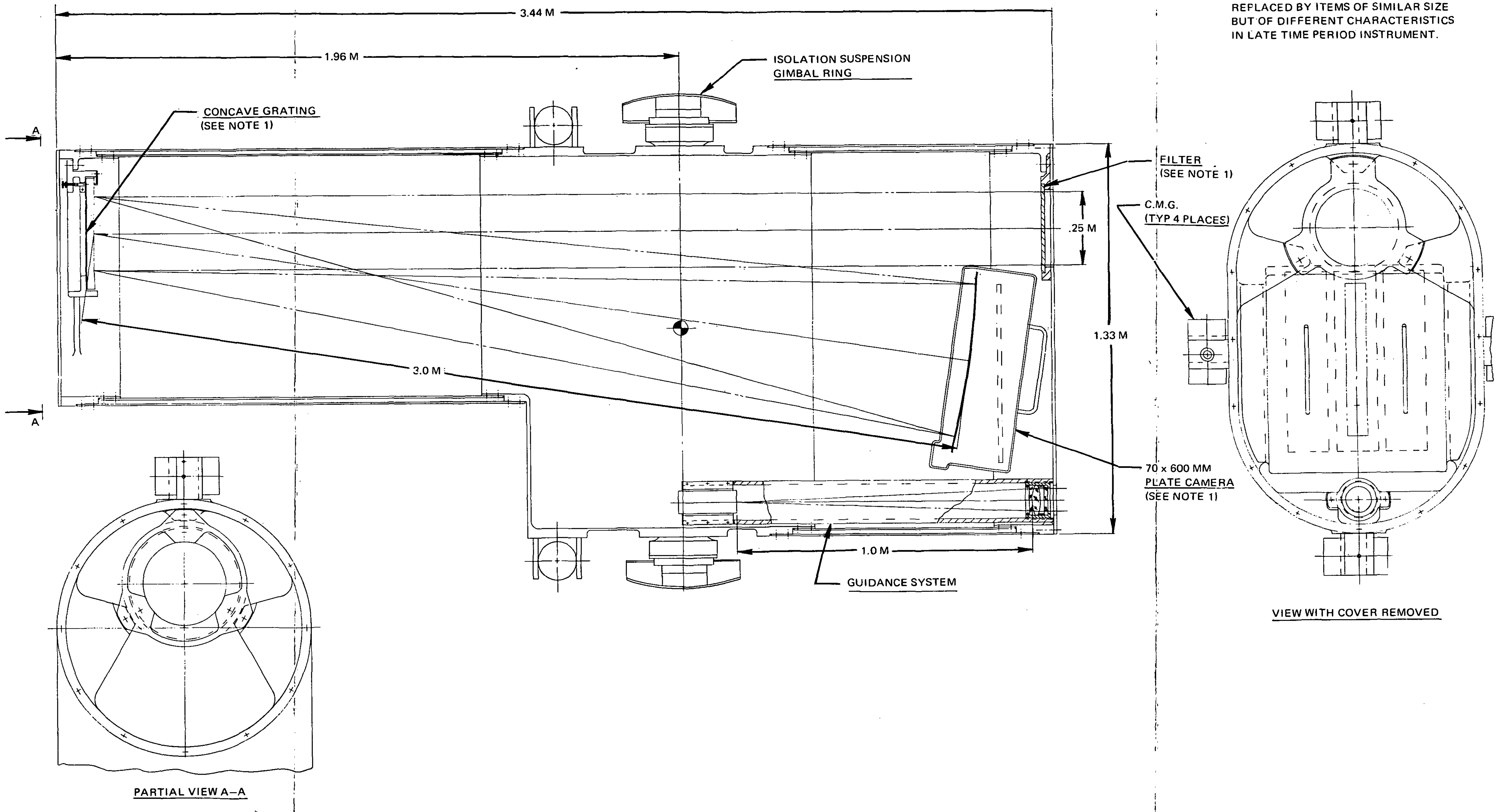
**Assumes previous development of ATM Experiment S053 (Reference 2-9)

Table 3-97

PRIMARY INSTRUMENT EQUIPMENT LIST--DEVELOPMENT PHASE D
0.25-m XUV Spectroheliograph Normal-Incidence Solar Telescope--
OASF Instrument No. 6

Functional System (Major Element)	Subsystem	Assemblies	Quantity		
			Bread-board	Proto-type	Flight Quality
0.25-m XUV spectroheliograph, solar	Detectors	---	---	---	---
	Collecting optics	0.25-m collecting optics (concave grating)	--	1	1
	Fine guidance (automatic)	Guidance optics	1	2	2
		sensor	1	2	2
		Control Moment gyroscope	1	2	2
	Housing	Structure (including optics support)	---	1	2
	Experiment sensors	Slitless spectroheliograph (plate camera)	1	1	1
	Major hardware articles	Mockup	1	---	---
		Engineering model	---	1	---
		Project verification model	---	60%*	40%*
		Qualification model	---	---	1

*Obtained from subsystem development quantities.



NOTES:

1. FILTER, GRATING AND CAMERA TO BE REPLACED BY ITEMS OF SIMILAR SIZE BUT OF DIFFERENT CHARACTERISTICS IN LATE TIME PERIOD INSTRUMENT.

Figure 3-57. 0.25-Meter XUV Spectroheliograph, Normal Incidence Telescope, Solar. OASF Instrument No. 6

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3.2.13 3-Meter Diffraction Limited Normal Incidence Telescope, Stellar--OASF Instrument No. 35

3.2.13.1 General Characteristics

The 3-m stellar telescope is proposed as the instrument to probe the frontiers of optical astronomy, particularly in the realm of spatial resolution and faint object detection (Figure 3-59). For the most part, its task will be to photograph distant galaxies, and to obtain spectra of quasi-stellar objects, the so-called quasars. In this respect, it is the successor to the earlier Cassegrain telescopes, extending the spectrographic observations to fainter objects and searching for more detailed spatial information on known bodies and also new stars and galaxies that are below the detection threshold of existing instruments.

The telescope portion is a Cassegrain collector with a primary mirror of 3-m aperture and 12-m focal length, and a secondary mirror which provides the 3.75 power magnification for an effective focal length of 45 m. A field of view of 15 arc-min. is desired for some of the photographic work. Because a field of these dimensions would be helpful in locating suitable guide stars, a Ritchey-Chretien figuring of the primary and secondary reflectors is recommended in preference to the classical Cassegrainian (paraboloid-hyperboloid) type because of its wider field of view.

The instrumentation section for this telescope as a minimum contains a 225-mm (9-in.) plate camera to survey celestial areas rich in galaxies, a 70-mm plate camera, which can take 35- or 70-mm film for use where the field requirements are most modest, and a spectrograph to study the spectra of quasi-stellar sources, with particular attention to Doppler shift measurements for determination of radial velocities.

Because this telescope is planned for a later generation, the design is left flexible to incorporate instruments required to answer questions raised by observations performed in the intervening period, and other equipment made possible by advances in the technology, such as "electronographic" recording, high-resolution image intensification or video transmission.

Because it is probably not feasible to attach a telescope as large as this to a spacecraft by means of a gimbaled suspension, provision is made for three-axis control-moment-gyro orientation control, rather than two-axis control. The excess energy stored in the gyros is dumped during periodic dockings with the manned spacecraft. These same dockings are used to service the telescope in other ways, such as photographic magazine changes and scheduled maintenance, or emergency repair.

Guidance is accomplished by star tracking systems; externally mounted star trackers are combined with integrated star tracking instrumentation that is part of the telescope optical system. The number of external trackers is sufficient to permit continuous control, despite the need to transfer from one tracker to another during slewing.

3.2.13.2 Design Criteria

It is the function of this telescope to provide the opportunity for making observations of the faintest celestial bodies with the highest achievable spatial resolution commensurate with the launch vehicle capabilities. The instrument that meets this description has been determined to be a telescope of three meters aperture which provides a possible resolution of 0.04 arc sec and a collecting area virtually an order of magnitude greater than the telescopes proposed for the intermediate time period. With its associated recording instruments, it must, as a minimum, be capable of measuring the radial velocity of quasi-stellar objects by means of a spectrograph and recording star fields of reasonable extent which are rich in distant galaxies. For these reasons a telescope of the Ritchey-Chretien configuration is recommended with extremely precise guidance capability and an instrumentation section including a spectrograph and an image recorder with provisions for expanding its scope to perform additional observations.

The following pages of tabular data describe in detail the physical and optical characteristics of the telescope.

3.2.13.3 Detailed Characteristics

The basic characteristics of the 3-m diffraction-limited normal-incidence stellar telescope, have been summarized in Figure 3-2 in Section 3.1.

Additional details about the instrument are tabulated in Tables 3-98, 3-99 and 3-100.

Table 3-98

COLLECTOR PARAMETERS
3-Meter Diffraction-Limited Normal-Incidence Telescope, Stellar--
OASF Instrument No. 35

Aperture	3.05 m
Primary focal length	12.16 m
Effective focal length	45 m
Total field of view	15 arc min.
Angular resolution	
On axis	0.04 arc sec at 5,000 Å
Poorest in field of view	0.10 arc sec at 5,000 Å
Obscuration of aperture	4.5 (%)
Minimum wavelength	<900 Å
Maximum wavelength	>12,000 Å
Primary f/No.	f/4
System f/No.	f/15
Scale at system focal plane	4.6 arc sec/mm
Resolution at system focal plane	110 lines/mm
Linear field of view at system focal plane	15 arc min.--134 mm

Table 3-99

INTERFACE CHARACTERISTICS
3-Meter Diffraction-Limited Normal-Incidence Stellar Telescope--
OASF Instrument No. 35

General	
System weight (less expendables)	≈ 12, 000 kg
System volume (launch configuration)	≈ 270 m^3
System shape (launch configuration)	Cylinder
Method of accomplishing	
Deployment	Remove inflated plastic bags and covers.
Alignment calibration	Autocollimation-motor controlled Spectral photography of standard sources
Operation experiment change	Remote photography Substitution of back ends
Stowage requirements (launch)	
Mechanical	Inflatable plastic bags and plastic bag covering
Electrical	None
Experiment data handling	
Format	On board
Processing	Photographic emulsion
Recording media	Replacement of cannister
Mode of data recovery	---
Pointing requirements	
Pointing accuracy (acquisition)	$\pm 1^{o}$
Power consumption	
Stowed	None
Standby	≈450 W
Operate	≈930 W

Table 3-100

GUIDANCE AND CONTROL CHARACTERISTICS
3-Meter Diffraction-Limited Normal-Incidence Stellar Telescope--
OASF Instrument No. 35

Guidance characteristics	
Coarse	
Initial acquisition field of view	±1°
Resolution	±120 arc sec
Residual error	±300 arc sec
Intermediate	
Field of view	±15 arc min.
Resolution	±10 arc sec
Residual error	±30 arc sec
Fine	
Field of view	±300 arc sec
Resolution	±0.005 arc sec
Residual error	±10 arc sec
Control characteristics	
CMG	
Type	Single degree of freedom, dual rotor
Wheel momentum	(Total, both wheels) pitch and yaw-20; roll-60 lb-ft-sec
Gimbal stops	±60°
Spin motor power (start) (run)	Pitch and yaw--avg 16 W
Servo power (peak) (average)	Roll--avg 11 W
Max. torque	Pitch and Yaw - 30 oz-in.
Weight	Roll--54-lb; pitch and yaw--90 lb
Diameter	Pitch and yaw--1.8 in.
Length	Roll--1.2 in.

3.2.13.4 Utilization of Man for OASF Instruments

Setup and maintenance requirements are summarized for this instrument in Table 3-101. Because man's utilization in the operation of the instrument depends on the observational program, operational information is separately summarized in Table 3-102.

Deployment

Because this very large telescope is initially operated as a photographic camera, and, hence, is mechanically simple, and because it is a late-time-period instrument, deployment is automatic, with man as a backup. The sunshade and star trackers are automatically erected, and the mirror coverings and camera-protective envelopes are removed by servo mechanisms.

Alignment

An optical technician, who observes a TV monitor screen (projected image from an autocollimator) and uses remote controls, checks and adjusts the optical alignment (tilt, centration, and focus). The procedure is similar to that described for the 1-m non-diffraction-limited UV-visible-IR telescope (OASF Instrument 45) in the corresponding paragraph of Section 2.3.5.4.

Calibration

Three cameras and a spectrograph are to be calibrated. Preprogrammed sequences of standard test stars are photographed with varying exposure times through each UBV filter. More time is required for calibration of this telescope as compared to the 1-m diffraction-limited UV-visible-IR telescope (OASF Instrument No. 34) because it is intended for use with fainter astronomical sources. The observer uses a microdensitometer to calibrate the spectrograms and an iris (or constant diaphragm) photometer for the photographic photometry.

The calibration time indicated in Table 3-101 is based on an estimate of the number of photographs and spectrograms needed for calibration. The observer loads appropriate plate and film magazines and monitors the system

Table 3-101

SETUP AND MAINTENANCE REQUIREMENTS
3-Meter Diffraction-Limited Normal-Incidence Stellar Telescope--
OASF Instrument No. 35

Operation	Average Times/ Year	Duration (hours)	No. of Men	Skill Identification*	Hours/ Man	Average Power (W)	Special Equip Weight (lb)	Special Equip Volume (ft^3)
Deployment	---	2	2	21	2	---	---	---
Alignment	---	15	1	14	15	20	---	---
Calibration	---	9	1	21	9	5	---	---
			1	12	1	5	---	---
Scheduled maintenance	6	4	1	14		15	15	2
Unscheduled maintenance	1/2	3	1	12	2	15	30	3
			1	14	1			

*Skills are identified by number in Table 3-3.

during the exposure. The time allotment of 9 hours is subject to some uncertainty, depending on unknowns such as the specific observing program and the reflection efficiency of the mirror coatings.

Operation

Each experiment requires observer and phototechnician skills. However, the observer, besides pointing the telescope and initiating and determining the exposure, could also load the camera magazines and develop the photographs, thus taking the place of the phototechnician.

Table 3-102

OPERATION SUPPORT AND REQUIREMENTS
3-Meter Diffraction-Limited Normal-Incidence Stellar Telescope--
OASF Instrument No. 35

ORDS No.	Time Per Observation (hours)	No. of Men	Skill Identification*	Man-Hours/ Observation	Start Time (hours from start of observation)	Number of Observations
018	5	1	5	5.25	-0.25	200
		1	8	0.1	+48	
023	12	1	5	12.25	-0.25	150
		1	8	0.1	+48	
024	3	1	5	3.25	-0.25	50
		1	8	0.2	+48	
026	6	1	5	6.25	-0.25	350
		1	8	0.1	+48	
038	3	1	5	3.25	-0.25	50
		1	8	0.2	+48	
039	0.3	1	5	0.55	-0.25	300
		1	8	0.1	+48	

*Skills are identified by number in Table 3-3.

The objects to be photographed are faint stars and galaxies in the +13 to +21 magnitude range. Because exposure times are upwards of 2 hours, a given plate must be exposed over a number of orbit traverses. "Composite" photographs of this sort have been taken successfully at ground observatories, even covering several successive nights. Problems of this sort and the extremely fine guidance required for diffraction-limited photography demand at least one-half of the observer's operation time.

Scheduled Maintenance

The optical technician inspects the optics for damage or deterioration (1 hour). The electromechanical technician will mainly be concerned with inspection and repair of the sequence camera mechanisms.

Unscheduled Maintenance

The electromechanical technician replaces camera mechanisms when failure occurs. This repair can be postponed until the regularly scheduled maintenance if other instrumentation can be used in the interim.

3.2.13.5 Supporting Research and Technology

Supporting Research and Technology (SRT) requirements for the 3-m Diffraction Limited UV-Visible-IR Normal-Incidence Telescope (Instrument No. 35) are listed below. Full descriptions of SRT items are given in Section 4.3.

Research and Advanced Technology

Develop methods for rapidly evaluating mirror figure and alignment under one-gravity and zero-gravity environments (SRT 1).

Conduct experimental studies of precision structural properties of mirror material related to optical performance (SRT 2).

Develop methods for generating and maintaining diffraction-limited (5,000 Å) mirror quality in orbital environments (SRT 3).

Develop mirror surfaces to provide high UV reflectivity, precision of figure, and freedom from scattering (SRT 4).

Develop cantilevered mirror as a reflective beam deflector (SRT 5).

Develop XUV-sensitive imaging tubes for use below 1,050 Å (SRT 11).

Develop techniques to overcome electrostatic charge build-up and fog-producing spark discharge on roll film in hard vacuum (SRT 17).

Develop flexible film substrata of higher dimensional stability than now available (SRT 18).

Develop criteria for film transport mechanisms suitable for roll film in hard vacuum to avoid emulsion, cracking, and flaking (SRT 39).

Investigate mirror-support structures that minimize the mechanical and optical problems of Cassegrainian telescopes (SRT 54).

Investigate techniques for alignment and focusing mechanisms for optical telescopes (SRT 55).

Investigate the dimensional stability of candidate mirror materials (SRT 56).

Evaluate sputtering on mirror surfaces from high-energy particles (SRT 57).

Advance Development

Assess materials for internal use to determine whether rapid aging and breakdown are caused by internal atmosphere (SRT 82).

Assess materials for external use to evaluate (A) hard vacuum effects on materials, finishes, etc., (B) development of processing, handling, and assembly techniques (SRT 83).

Supporting Development

Develop image tubes with greater spatial resolution than currently obtainable (SRT 84).

Develop photographic emulsions with improved spatial resolution (SRT 84A).

3.2.13.6 Development Cost and Schedules

The Phase D cost is shown in Table 3-103, which shows both development and operations costs. The development schedule is shown in Figure 3-60. Quantities of equipment required in development are shown in Table 3-104.

3.2.13.7 Instrumentation Section

70-mm Plate Camera (see Figure 3-61)

The function of the 70-mm camera is to record with the highest possible resolution the images of specific objects such as galaxies, globular clusters and quasi-stellar sources in different wave length bands in order to determine their structural characteristics. To this end, a plate camera with a 70 mm format (50 mm clear, see Table 3-105) has been devised. The camera provides a feed and a take-up magazine with a transport to take a plate from the feed magazine to the exposure position, and at the end of the observation, to the take-up magazine. Since a filter wheel with the required aperture would be excessively large, a similar device is used for selecting the

Table 3-103

TASK COST ESTIMATE--PHASE D (page 1 of 2)
3-Meter Diffraction-Limited UV-Visible-IR Normal-Incidence Telescope, Stellar (OASF Instrument No. 35)

($ thousands)

Development total	176,950		
Engineering		13,450	
Detectors		*	
70-mm and 9-in. plate			*
Spectrograph film			*
35-mm strip film			*
Field lens and/or image tube			*
35-mm digital magnetic tape recorder			*
Collecting optics		50,300	
3-m primary mirror			*
Secondary mirrors (32-in. and 19-in.)			*
Secondary mirror align/int assy			*
Folding mirror assemblies			*
Fine guidance		20,290	
Guidance optics			*
Sensor			*
Control moment gyro			*
Housing		39,090	
Structure (including optics support)			*
Inflatable sunshade			*
Experiment sensors		7,515	
Filter wheels			*
70-mm plate camera (prev dev on 1.0-m; mod for 3.0-m)			*
9-in. plate camera			*
35-mm strip camera (prev dev on 1.0-m; mod for 3.0-m)			*
Concave grating spectrograph			*
Mission modes		*	

*Cost item not derived where overall estimate for instrument is not significantly affected.

Table 3-103 (page 2 of 2)

Major hardware articles		46,305	
Mockup			*
Engineering model			*
Project verification model			*
Qualification model			*
Operations total	81,697		
Flight instrument		53,050	
Backup flight instrument		21,220	
Engineering support		7,427	
Phase D total	258,647**		

*Cost item not derived where overall estimate for instrument is not significantly affected.

**Assumes previous development of 1-m diffraction-limited OASF Instrument 34; same optics contractor for both instruments.

desired filter for the observation. A plate camera is preferred to a roll film camera because it avoids the electrostatic sparking problems and other deleterious effects of film friction.

225-mm Plate Camera (see Figure 3-62)

For the measurement of Cepheid variable stars, as a means of determining the distance of the galaxies in which they are located, it is helpful to photograph a reasonably large area so that many stars are recorded in a single exposure. To satisfy this requirement, a large format plate camera magazine is presented. The plate used is 225-mm square (200-mm clear, see Table 3-106) providing for a field of view of 15 arc-min. square. The camera and plate changer, magazine and filter mechanisms are enlarged versions of the 70-mm camera.

Concave Grating Spectrograph

For measuring the Doppler shift in the radiation received from quasi-stellar sources, a concave grating spectrograph is supplied. The spectrograph consists of a slit, a concave grating (see Table 3-107) and a camera.

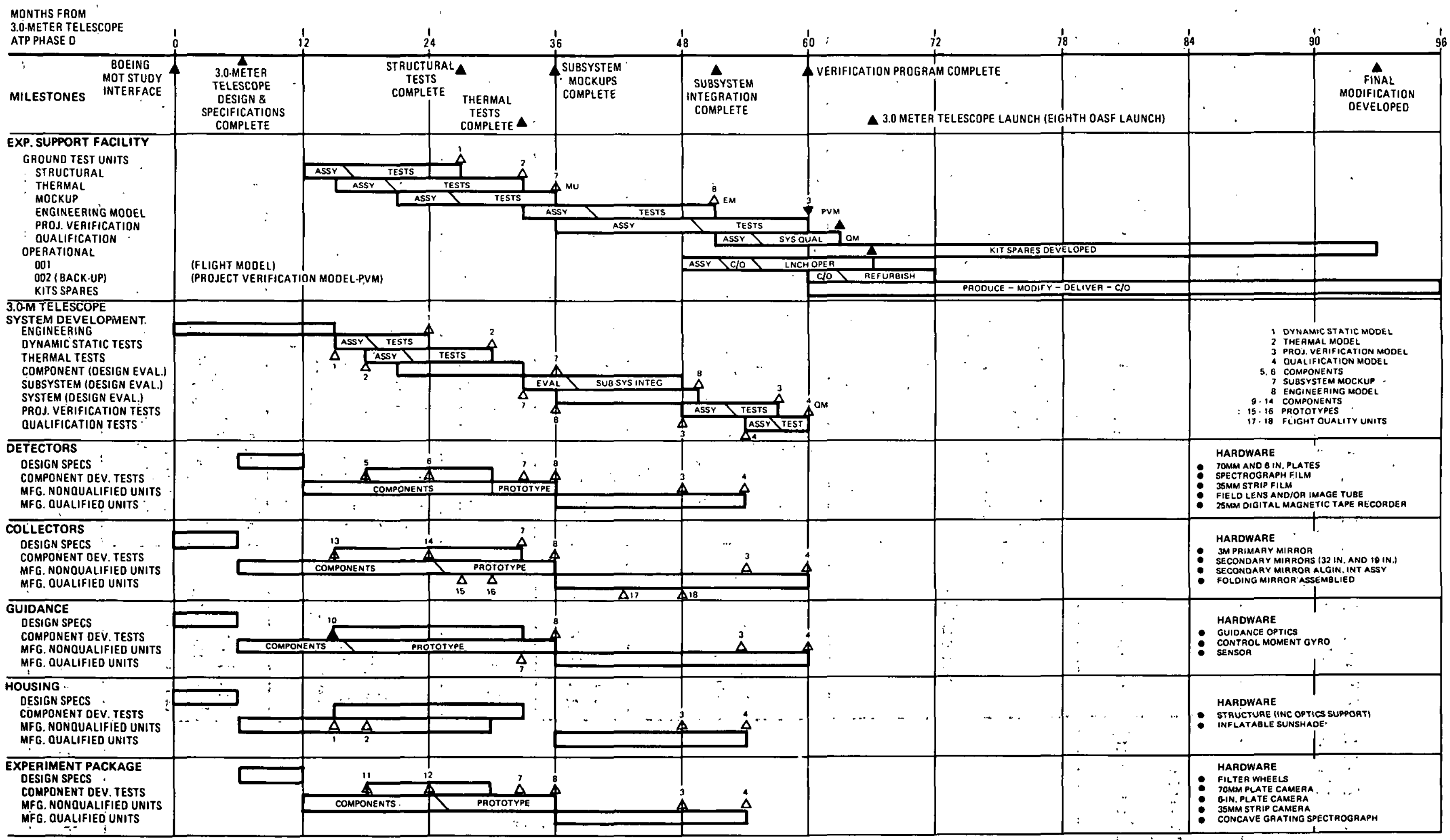

Figure 3-60. Development Schedule, 3-Meter Diffraction-Limited UV-Visible-IR Normal-Incidence Telescope, Stellar (OASF Instrument No. 35)

Table 3-104

PRIMARY INSTRUMENT EQUIPMENT LIST--DEVELOPMENT PHASE D
3-Meter UV-Visible-IR Normal-IncidenceTelescope, Stellar
(OASF Instrument No. 35)

Functional System (Major Element)	Subsystem	Assemblies	Quantity		
			Bread-Board	Proto-Type	Flight Quality
3.0-m diffraction limited UV-visible-IR telescope	Detectors	70-mm plates	1	2	2
		9-in. plates	2	2	2
		35-mm strip film	2	1	2
		Spectrograph film	2	1	2
		Field lens and/or image tube	1	2	1
		35-mm digital magnetic tape recorder	1	2	1
	Collecting optics	3-m primary mirror	1	2	1
		Secondary mirrors (32 in. and 19 in.)	1	2	2
		Secondary mirror align. /int assy	2	2	1
		Folding mirror assemblies	2	4	4
	Fine guidance	Guidance optics	1	1	2
		Sensor	1	1	2
		Control moment gyro	1	2	1
	Housing	Structure (inc. optics support)	1	1	2
		Inflatable sunshade			2
	Experiment sensors	Filter wheels	1	1	2
		70-mm plate camera	1	1	2
		9-in. plate camera	1	1	2
		35-mm strip camera	1	1	2
		Concave grating spectrograph	1	1	2
	Major hardware articles	Mockup	1	---	---
		Engineering model	---	1	---
		Project verification model	---	60%*	40%*
		Qualification model	---	---	1

*Obtained from subsystem development quantities.

Table 3-105

FIELD-IMAGE INSTRUMENTATION CHARACTERISTICS
3-Meter Diffraction-Limited Normal-Incidence Stellar Telescope--
OASF Instrument No. 35

Film camera characteristics	
Type	Plate
Aperture	50 x 50 mm
Remote change cycle time	30 sec
power consumption during change	2 W
Film type limitations	Panchromatic emulsion on glass plates
Exposures per magazine load	32 max.
Filter characteristics	
Wavelength (short)	3,477 Å
(long)	6,813 Å
Resolution ±	100 and 250 Å
Band centers	3,727, 4,101, 4,340, 4,861 Å 4,959, 5,007, 6,563 Å
Remote change cycle time	30 sec
Power consumption during change	2 W
Weight	25 kg

A reference light source illuminating the fringes of the slit provides a comparison spectrum to permit precise wavelength calibration. Because of its similarity to the spectrograph described in Section 3.2.7.2 (see Figure 3-29) it will not be discussed further except to state that it is about two and a half times as long while maintaining the same cross section.

PLATE SIZE	PLATES REQ'D	"A"	"B"	"C"	"D"	"E"	"F"
35 MM	8	8	3 3/16	3 3/8	9	3 1/2	1 1/2
	16	↓	↓	4 3/8	↓	↓	↓
	32	↓	↓	6 3/8	↓	↓	↓
	64	↓	↓	8 3/8	↓	↓	↓
70 MM	8	10	4 1/4	3 3/8	11	4 3/4	2
	16	↓	↓	4 3/8	↓	↓	↓
	32	↓	↓	6 3/8	↓	↓	↓
	64	↓	↓	8 3/8	↓	↓	↓
DIMENSIONS ARE IN INCHES, UNLESS NOTED							

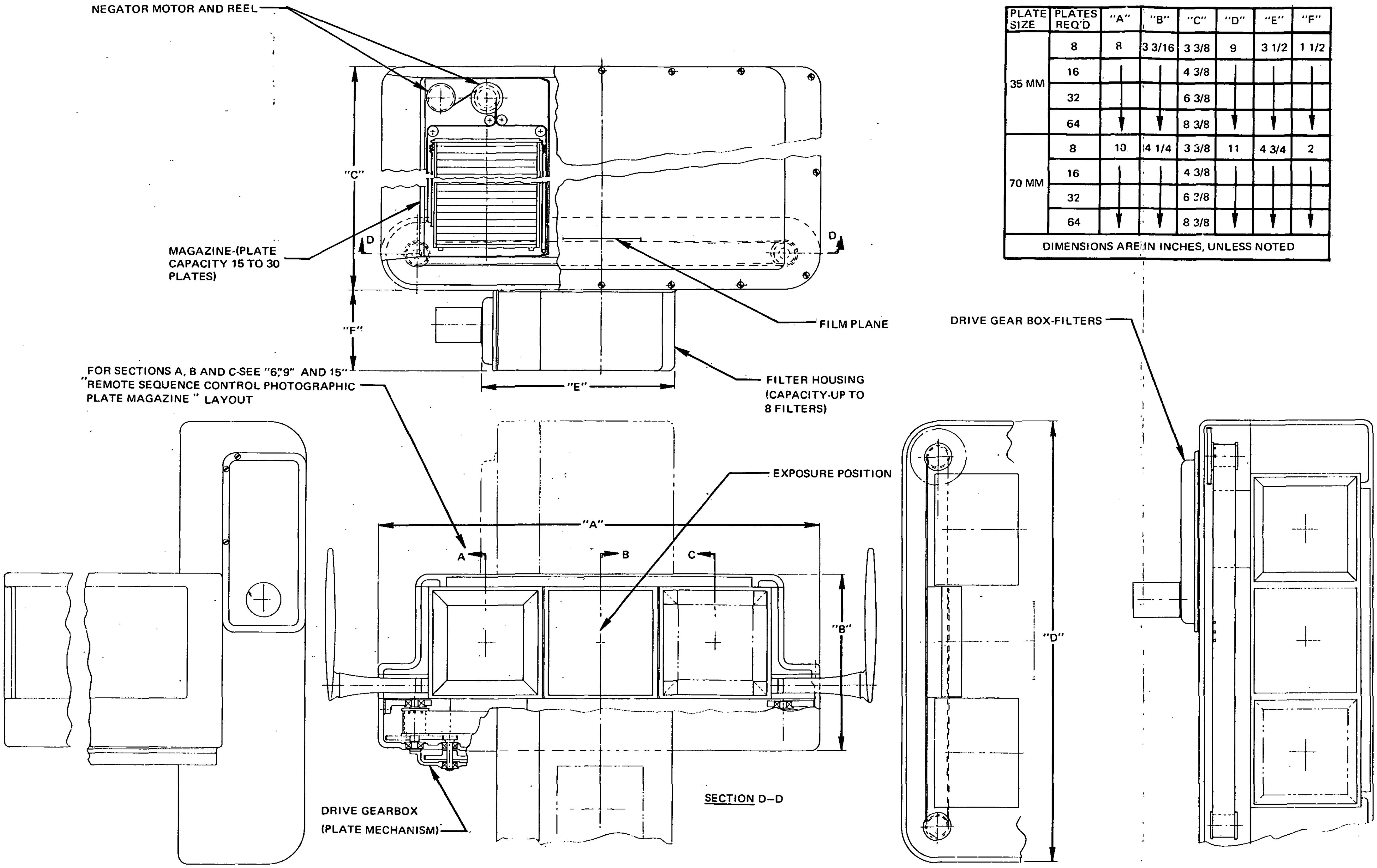

Figure 3-61. 35- or 70-Millimeter Plate Camera

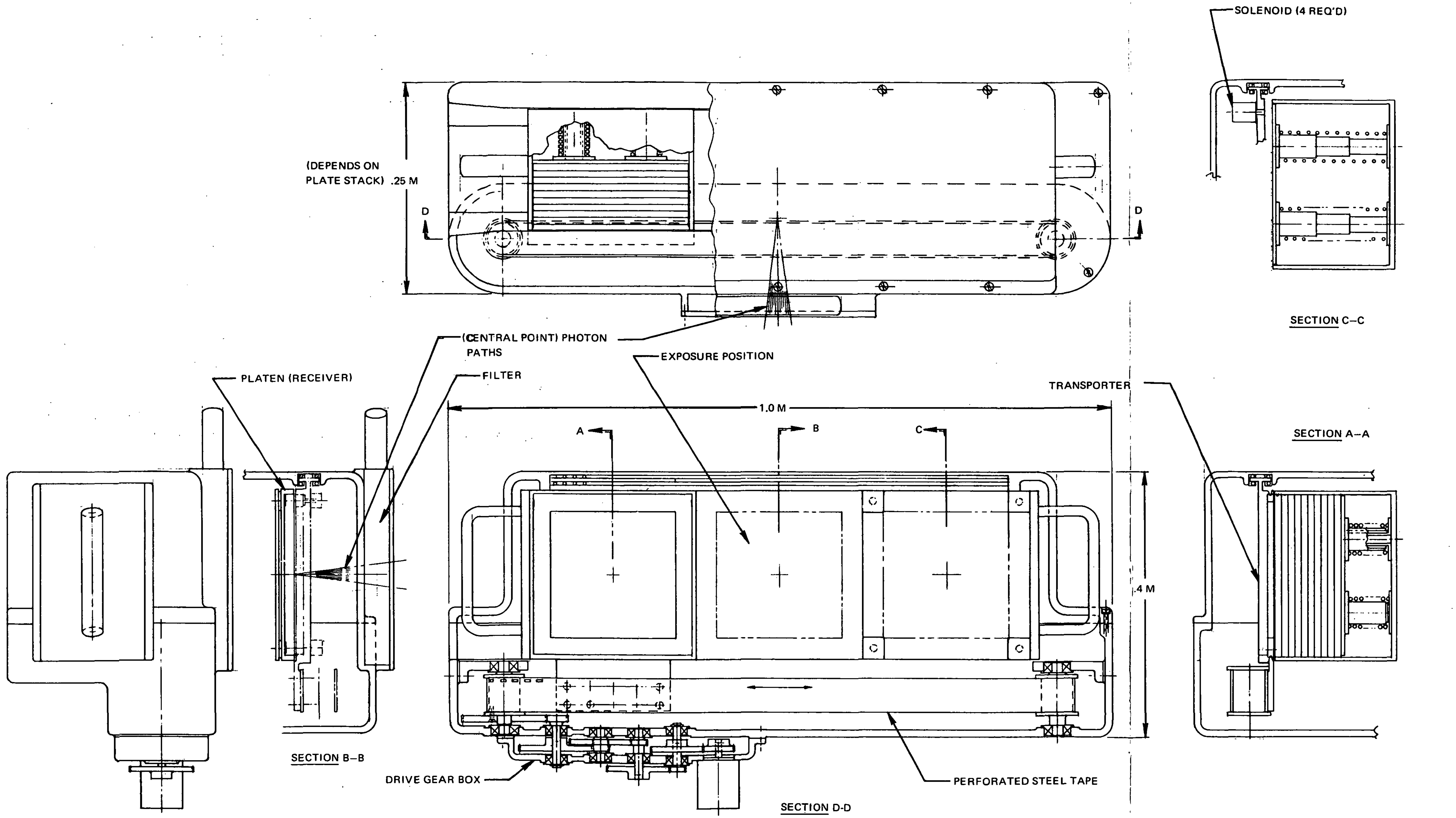

Figure 3-62. 225-Millimeter Plate Camera

Table 3-106

FIELD-IMAGE INSTRUMENTATION CHARACTERISTICS
3-Meter Diffraction-Limited Normal-Incidence Stellar Telescope--
OASF Instrument No. 35

Film camera characteristics	
Type	Plate
Aperture	200 x 200 mm
Remote change cycle time	60 sec
Power consumption during change	4 W
Film type limitations	Panchromatic emulsions on glass plates
Exposures per magazine load	16 max.
Filter characteristics	
Wavelength (short)	3,400 Å
(long)	5,500 Å
Resolution ±	100 Å
Band centers	3,500, 4,300, 5,400 Å
Remote change cycle time	60 sec
Power consumption during change	4 W
Weight	40 kg

Table 3-107

CONCAVE GRATING SPECTROGRAPH CHARACTERISTICS
3-Meter Diffraction-Limited Normal-Incidence Stellar Telescope--
OASF Instrument No. 35

Type	Normal incidence
Wavelength	
Short	800 Å
Long	3,000 Å
Resolution	1 Å at 2,000 Å
Entrance aperture	
Slit width	20
Slit height	150
Incident radiation	
f/No. limitation	15
Spatial resolution	1
Spectral calibration	
Main grating	
Type	Concave
Size	31.3 x 32.3 mm
Ruling frequency	400 lines/mm
Dispersion	50 Å/mm at 2,000 Å
Angle of diffraction range	-0.46° to $+4.59^{\circ}$
Spectral order	
Recorder characteristics	
Type	Film
Aperture	25 x 44.1 mm
Remote change cycle time	30 sec
Film-type limitations	Schumann
Exposure per magazine load	16
Power consumption during cycle change	2 W
Power consumption during calibration	---
Weight	28 kg (including 25 kg for plate camera)

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Figure 3-59. 3-Meter Diffraction-Limited UV-Visible-IR Normal Incidence Telescope, Stellar. OASF Instrument No. 35

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3.2.14 1-Meter UV Schmidt Normal-Incidence Telescope, Stellar OASF Instrument 13

3.2.14.1 General Characteristics

A 1-m (collecting aperture) Schmidt camera has been conceptually designed (Figure 3-63). It has a 1.8-m (diameter) spherical primary mirror and a 1-m correcting plate located at the center of curvature of the primary. The corrector has been tilted 15° so that the light rays coming to it are not blocked by the primary or its supports. The camera magazine incorporates an automatic plate changer capable of introducing the proper curvature to the plates or accepting preformed plates. A shutter and a filter changer are also included. The plates and filters are both approximately 38 cm^2. The camera is mounted on a roll-correcting turntable. The telescope, as with other stellar telescopes, is fitted with a sunshade, CMG's, and star trackers for guidance, and is mounted to the spacecraft by gimbaled suspension.

The basic principles of the classical Schmidt camera have been outlined in Section 3.2.7. The principal attraction of the Schmidt-type of optical system is the large field of view combined with a short focal length. The 1.0-m Schmidt camera design suggested here uses only reflective optics so as to be able to extend its performance into the UV region below 1,500 Å.

The physical arrangement of this large Schmidt camera is a further development of the optical design concept shown in the 0.3-m Schmidt (OASF Instrument No. 33) (Section 3.2.7). One of the major differences between the two telescopes is the off-axis location of the plate camera in the larger instrument. This was necessary because the 15 x 15-in. plate camera would create an intolerable obscuration if it were located in the on-axis position, as is the case with the fiber-optics-face-plate camera of the smaller Schmidt. The later design has a further virtue in that the improved modulation transfer function (MTF), resulting from the disappearance of the obscuration, results in improved image quality.

3.2.14.2 Design Criteria

The observation program for which the 1-m Schmidt camera has been designed is to repeat the Palomar Sky Survey in the spectral region below 3,000 Å. The Palomar Schmidt was unable to record the ultraviolet wavelengths because of atmospheric absorption.

The program's purpose is to survey stars, nebulae, and galaxies in the ultraviolet which have limiting apparent visual magnitudes of +20. A 5° field of view allows the entire sky to be recorded in 1,600 exposures.

Comparative spectral information can be obtained if filters covering bands centered at approximately 1,200, 1,800, 2,500, and 3,000 Å are used. The target angular resolution of 0.5 arc sec at 2,500 Å will be comparable to the Palomar photographs.

The 1.0-m Schmidt camera is designed to use glass plates because of the desirability of dimensional stability, and the need for a durable permanent record of the photographic information.

3.2.14.3 Detailed Characteristics

The basic characteristics of the 1-m UV Schmidt normal-incidence stellar telescope have been summarized in Figure 3-2 in Section 3.1.

Additional details about the instrument are tabulated in Table 3-108, 3-109, and 3-110.

3.2.14.4 Utilization of Man

Setup and maintenance requirements are summarized for this instrument in Table 3-111. Because man's utilization in the operation of the instrument depends on the observational program, operational information is separately summarized in Table 3-112.

Table 3-108

COLLECTOR PARAMETERS
1.0 Meter UV Schmidt Normal-Incidence Stellar Telescope--
OASF Instrument No. 13

Aperture	1 m
Primary focal length	4 m
Effective focal length	4 m
Total field of view	5^{o}
Angular resolution	
On axis	0.1 arc sec at 4,000 Å
Poorest in field of view	0.25 arc sec at 4,000 Å
Obscuration of aperature	0
Minimum wavelength	1,000 Å
Maximum wavelength	> 5,000 Å
Primary f/No.	4
System f/No.	4
Scale at system focal plane	55.5 arc sec/mm
Resolution at system focal plane	225
Linear field of view at system focal plane	350 mm

Deployment

The sunshade is erected, the star trackers are activated, the gimbal is erected, and the covers are removed from the two mirrors and the large plate camera. All these are simple functions that can be done automatically, with man as a backup.

Alignment

The focusing scheme that Northwestern University describes for their 0.3-m Schmidt telescope (Reference 2-5) appears to be a good method and it has been retained here (as well as for the early-time-period 0.3-m UV Schmidt, OASF Instrument 13). In this scheme, an optical technician observes a star image on a TV monitor. If two images are present, he moves a one-dimensional control which moves the camera along the optical axis until he sees a single star, indicating that proper focus has been achieved.

Table 3-109

INTERFACE CHARACTERISTICS
1.0 Meter UV Schmidt Normal-Incidence Stellar Telescope--
OASF Instrument No. 13

General	
System weight (less expendables)	930 kg
System volume (launch configuration)	53 m^3
System shape (launch configuration)	Rectangular prism and wedge
Method of Accomplishing	
Deployment	Uncap and extend baffle
Alignment	No in-flight alignment
Calibration	Photograph of standard source
Operation	Remote control photography
Experiment change	Manual change of cameras, remote control filter wheel
Stowage Requirements (launch)	
Mechanical	Plastic-bag packaging and shock mounting
Electrical	None
Experiment data handling	
Format	15 x 15-in. photographic plates
Processing	On-board developments
Recording media	Photographic emulsion (Schumann)
Mode of data recovery	Manual recovery of plate canister
Pointing requirements	
Pointing accuracy (acquisition) ± external acquisition (manual) (angle)	
Power consumption	
Stowed	0
Standby	167 W
Operate	167 W (peak 174)

Table 3-110

GUIDANCE AND CONTROL CHARACTERISTICS
1.0-Meter UV Schmidt Normal-Incidence Stellar Telescope--
OASF Instrument No. 13

Guidance characteristics	
Coarse	
Initial acquisition	±Manual - external
Resolution	N/A
Residual error	N/A
Intermediate	
Field of view	±Manual - external
Fine	
Field of view	±1-arc min.
Resolution	±0.05 arc sec
Residual error	±0.25 arc sec
Control characteristics	
CMG	
Type	Single degree of freedom
Wheel momentum	≈200 lb-ft-sec
Gimbal stops	60°
Spin motor power (start)	≈100 W
(run)	≈ 15 W
Servo power (peak)	≈ 60 W
(average)	≈ 8 W
Max. torque	≈200 oz.-in.
Weight	≈ 80 lb
Diameter	≈ 30 in.
Length	≈ 40 in. overall

Table 3-111

SETUP AND MAINTENANCE REQUIREMENTS
1.0-Meter UV Schmidt Normal-Incidence Stellar Telescope--
OASF Instrument No. 13

Operation	Average Times/ Year	Duration (hours)	No. of Men	Skill Identification*	Hours/ Man	Average Power (W)	Special Equip. ** Weight (lb)	Special Equip. ** Volume (ft^3)
Deployment	---	1	1	21	1	---	---	---
Alignment	---	1	1	14	1	3	3	1
Calibration	---	3	1	21	3	---	3	1
Scheduled maintenance	6	1-1/2	1	14	1-1/2	---	---	---
			1	12	1	5	5	1
Unscheduled maintenance	1/3	1	1	12	1	5	10	2

*Skills are identified by number in Table 3-3.

**Note if special equipment already in orbit because of previous equipment setup or instrumentation section modification.

Table 3-112

OPERATION SUPPORT AND REQUIREMENTS
1.0-Meter UV Schmidt Normal-Incidence Stellar Telescope--
OASF Instrument No. 13

ORDS No.	Time per Observation (hours)	No. of Men	Skill Identification*	Man-hours/ Observation	Start Time (hours from start of observation)	Number of Observations
071S	1	1	5	1.25	-0.25	1,800
		1	8		+48	
				(combine with other observations)		

*Skills are identified by number in Table 3-3.

Calibration

Calibration is done from densitometry of a sequence of photographs taken by the observer. The primary reason for the calibration plates is to determine appropriate exposure times for the telescope-plus-filter combination. The calibration plate also serves as a standard by which to measure the deterioration of the UV-reflective coatings over long periods of time.

Operation

Exposure time per frame (using the 15 x 15 in. plate camera) is assumed to be about 1-1/2 to 2 hours. The telescope may, upon completing an exposure, be programmed to move automatically to another preplanned location. Alternatively, an observer points the telescope to the proper star field, advances the plates, and initiates the exposure. The broadband UV filters just ahead of the plates are left in place during any sequence of exposures until the next change in plate magazines. The plates are developed in orbit to minimize radiation fogging.

Scheduled Maintenance

An electromechanical technician checks the camera-sequence mechanism at regular intervals. An optical technician checks the condition of the optical surfaces.

Unscheduled Maintenance

Electromechanical failure is considered very unusual and will probably call for use of electromechanical technicians for troubleshooting and material replacement.

3.2.14.5 Supporting Research and Technology

Supporting Research and Technology (SRT) requirements for the 1-m UV Schmidt Telescope (Instrument No. 13) are listed below. Full descriptions of SRT items are given in Section 4.3.

Research and Advance Technology

Develop methods for rapidly evaluating mirror figure and alignment under one and zero-g environments (SRT 1).

Conduct experimental studies of precision structural properties of mirror material related to optical performance (SRT 2).

Develop methods for generating and maintaining diffraction limited (1,500 Å) mirror quality in orbital environments (SRT 3).

Develop mirror surfaces to provide high ultraviolet reflectivity, precision of figure and freedom from scattering (SRT 4).

Develop fabrication techniques for non-circular aspherics (SRT 6).

Investigate transmissibilities of interference-type filters and reflective-type (dichroic) filters for use in the 1,000 Å to 2,000 Å wavelength region (SRT 10).

Develop techniques to overcome electrostatic charge buildup and fog producing spark discharge on roll film in hard vacuum (SRT 17).

Develop criteria for film-transport mechanisms suitable for roll film in hard vacuum to avoid emulsion cracking and flacking (SRT 39).

Investigate degradation of telescope detector and reflective surfaces resulting from 0_2 exposure (SRT 42).

Investigate techniques for alignment and focusing mechanisms for optical telescopes (SRT 55).

Investigate the dimensional stability of candidate mirror materials (SRT 56).

Evaluate sputtering on mirror surfaces from high-energy particles (SRT 57).

Advance Development

Assess materials for internal use to determine if rapid aging and breakdown are caused by internal atmosphere (SRT 82).

Assess materials for external use to evaluate (A) hard vacuum effects on materials, finishes, etc. ; and (B) development of processing, handling, and assembly techniques (SRT 83).

Supporting Development

Develop image tube with greater spatial resolution than now currently obtainable (SRT 84).

Develop photographic emulsions with improved spatial resolution (SRT 84A).

3.2.14.6 Development Cost and Schedules

The Phase D cost is shown in Table 3-113, which shows both development and operations costs. The development schedule is shown in Figure 3-64. Quantities of equipment required in development are shown in Table 3-114.

3.2.14.7 Instrumentation Section

380-mm Plate Camera

The 1.0-m Schmidt is needed to satisfy a single observational requirement, the "Ultraviolet Photographic Sky Survey." The "Sky Survey" plates must be durable and have high dimensional stability; the field of view required, is contained within a curved glass plate 38 cm^2 (35-cm clear aperture, see Table 3-115) (15 x 15 in.) which has been matched to the focal surface.

The Remote Sequence Control Photographic Plate Camera (and Magazine) Kollsman has conceptually designed for use with these large glass plates is shown in Figure 3-65. The method of operation is as follows: a plate from the unexposed stack is carried to the exposure position by the camera sequence mechanism. The unexposed plate is pressed against the platen. The shutter is opened and the end of the exposure, which is either automatically timed or manually controlled, closes. The exposed plate is then carried to the exposed plate receiver.

Table 3-113

TASK COST ESTIMATE--PHASE D
1-Meter UV Schmidt Normal-Incidence Stellar Telescope
(OASF Instrument No. 13)
($ thousand)

Development total	23,705		
Engineering		275	
Detectors		*	
15-in. plates			*
Collecting optics		780	
1-m primary mirror			80
Corrector mirror			250
Alignment assy			450
Manual guidance		300	
TV camera			*
Control moment gyro			*
Housing		270	
Structure (including optics support)			250
Inflatable sunshade			20
Experiment sensors		1,100	
Filter wheels			150
15-in. plate camera			950
Major hardware articles		980	
Mockup			*
Engineering model			*
Project verification model			*
Qualification model			*
Operations total	10,949		
Flight instrument		7,110	
Backup flight instrument		2,843	
Engineering support		996	
Phase D total	34,654**		

*Cost item not derived where overall estimate for instrument not significantly affected.

**Assumes previous development of 0.3-m Schmidt OASF Instrument 33; same optics contractor for each instrument.

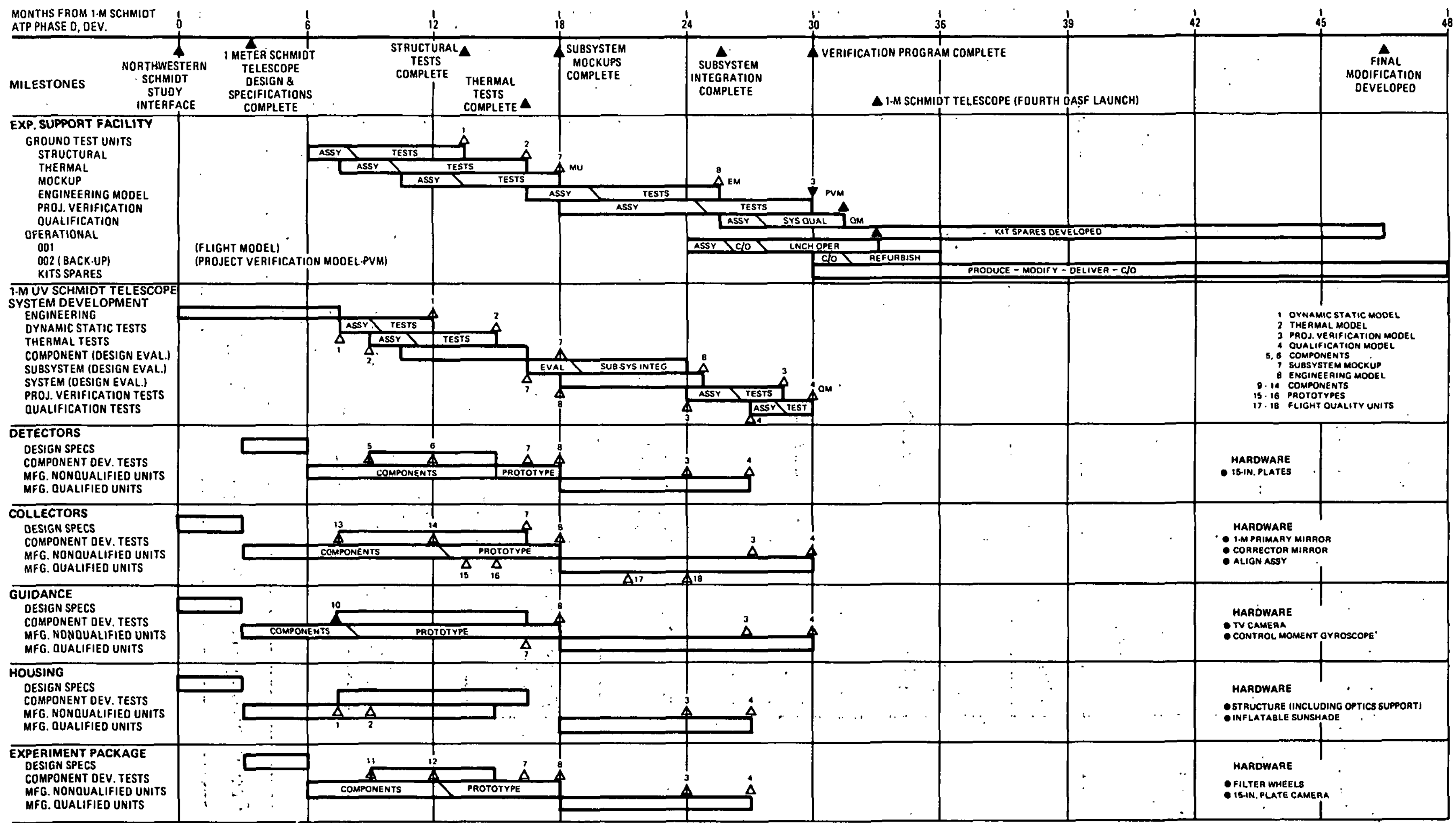

Figure 3-64. Development Schedule, 1-Meter UV Schmidt Normal Incidence Telescope, Stellar (OASF Instrument No. 13)

Table 3-114

PRIMARY INSTRUMENT EQUIPMENT LIST--DEVELOPMENT PHASE D
1-Meter UV Schmidt Normal-Incidence Stellar Telescope
(OASF Instrument No. 13)

Functional System (Major Element)	Subsystem	Assemblies	Quantity		
			Bread-Board	Proto-Type	Flight Quality
1-m UV Schmidt telescope	Detectors	15-in. plates	2	2	2
	Collecting optics	1-m primary mirror	---	1	1
		Corrector mirror	---	2	2
		Alignment assy	2	4	4
	Fine guidance	TV camera	1	2	2
		Control moment gyro	---	---	2
	Housing	Structure (including optics support)	---	1	2
		Inflatable sunshade	---	1	2
	Experiment sensors	Filter wheels	1	1	1
		15-in. plate camera	1	1	1
	Major hardware articles	Mockup	1	---	---
		Engineering model	---	1	---
		Project verification model	---	60%*	40%*
		Qualification model	---	---	1

*Obtained from subsystem development quantities.

Table 3-115

FIELD IMAGE INSTRUMENTATION CHARACTERISTICS
1.0-Meter UV Schmidt Normal-Incidence Stellar Telescope
(OASF Instrument No. 13)

Film camera characteristics	
Type	Plate camera
Aperture	350 x 350 mm
Remote change cycle time	90 sec
Power consumption during change	10 W
Film type limitations:	Schumann Type - sensitive from 1,000 Å to 5,000 Å
Exposures per magazine load	16 (max.)
Filter Characteristics	
Wavelength (short)	1,200 Å
(long)	3,000 Å
Resolution	±250 Å (approx half-width)
Band centers	1,200, 1,800, 2,500, 3,000 Å
Remote change cycle time	Manual
Weight	50 kg

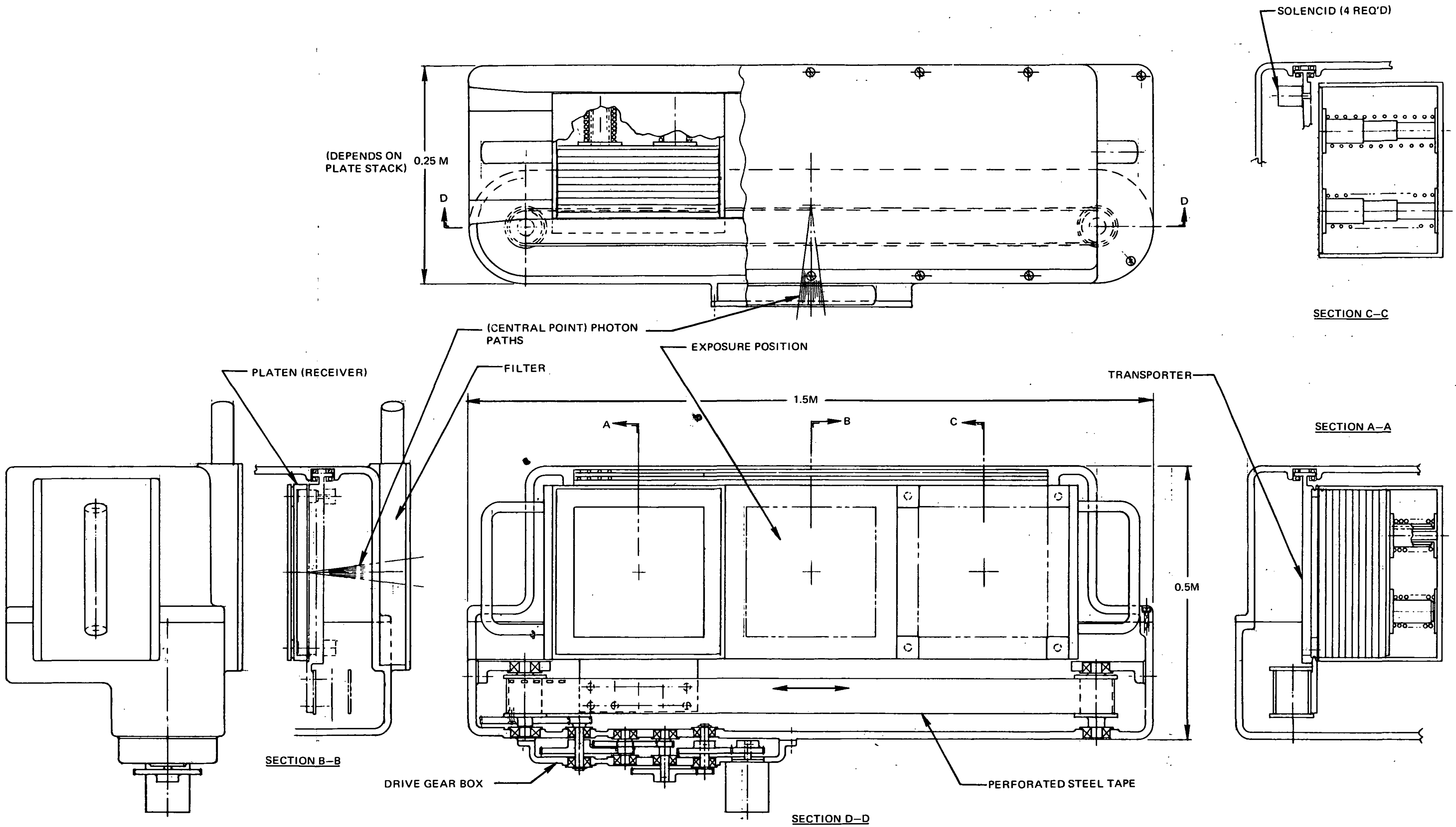

Figure 3-65. 380-Millimeter Plate Camera

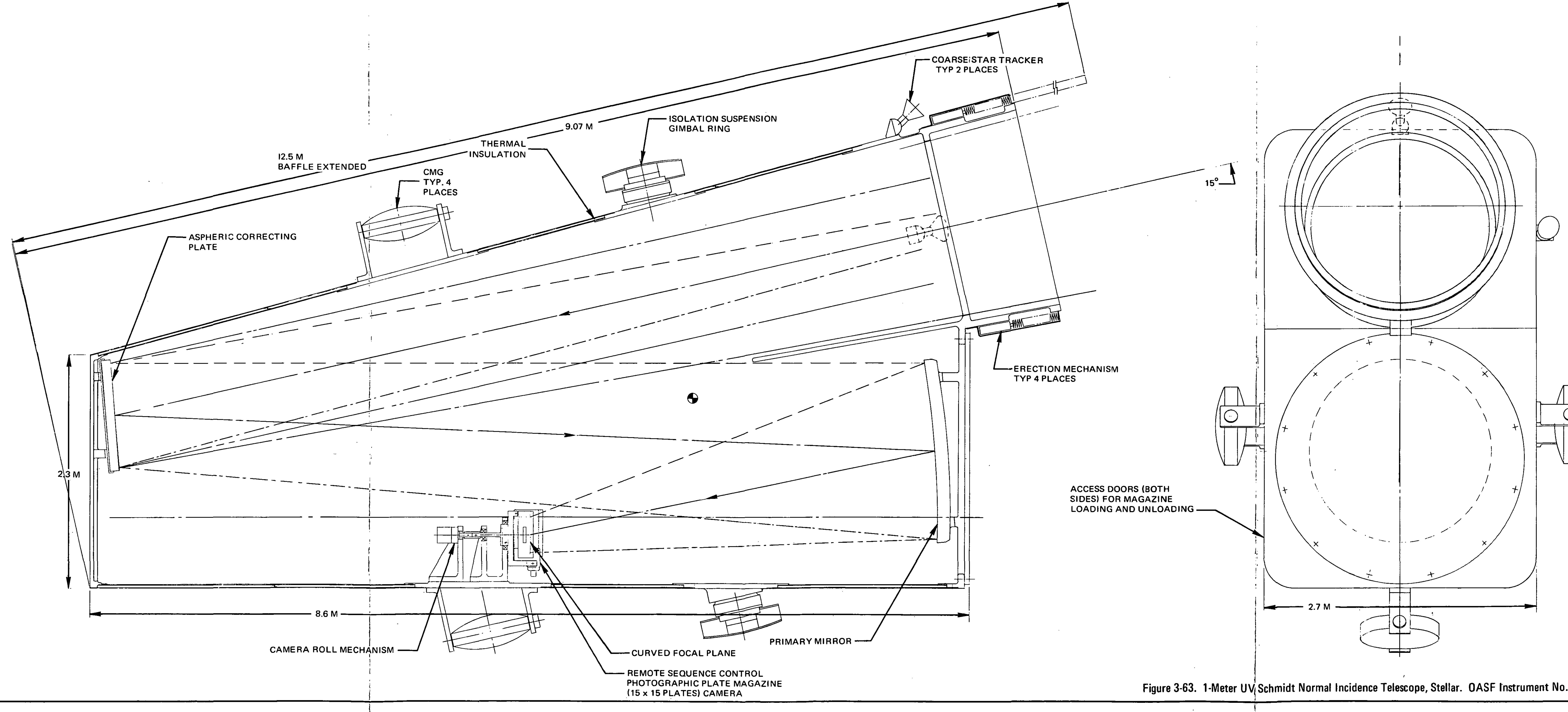

Figure 3-63. 1-Meter UV Schmidt Normal Incidence Telescope, Stellar. OASF Instrument No. 13

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3.2.15 1.5-Meter Diffraction-Limited UV-Visible Solar Telescope OASF Instrument 46

3.2.15.1 General Characteristics

The late-time-period solar telescopes are essentially larger and more refined versions of the earlier instruments. This holds true for the off-axis (Herschelian) and grazing-incidence telescopes, as well as for the Gregorian telescope described in this section. In general, the larger aperture provides increased resolution and, with its larger collecting area, permits higher linear magnification or linear dispersion with the same exposure time.

The late-time period solar telescope for the 1,500-Å and longer-wavelength range is a Gregoriantelescope of 1.5-m aperture and 75-m focal length. The collecting optics consist of a primary mirror of 1.5-m aperture and about 5.35-m focal length, and a secondary mirror providing about 14.0 diameters of magnification. The image is brought to a focus about 0.3 m behind the primary mirror (see Figure 3-66).

The instrumentation section behind the primary mirror consists of a triple range echelle spectrograph, a slit-jaw camera, and space provision for a solar magnetograph. The slit-jaw camera is similar to the one described for the 0.8-m solar telescope (Section 3.2.10), and is not discussed further here. The solar magnetograph is a specialized instrument of which only a very few exist at present. The choice between two known conceptual approaches approaches (Section 3.2.15.7) has not been attempted in this study.

In the solar telescopes, guidance will mainly be inertial, with updating coming either automatically from the image of the sun's limb with or without a programmed scan, or manually from an astronaut observer viewing an image of the sun on a monitor, and endeavoring to keep a specific feature of scientific interest in the field of view or on the slit of a spectrograph. Coarse resolution can be achieved through a modest sun sensor device.

3.2.15.2 Design Criteria

The study of UV line profiles of the fine structure of the solar granulation (ORDS-053) requires measurements of extreme spectral and angular resolution (about 0.002 Å and 0.1 arc-sec respectively).

The solar granulation is to be observed with spatial resolution of 0.1 arc-sec to examine its structure in fine detail and to determine its connection with the chromosphere. The light of the sun at 6,555 Å where the granulation is observed and at 6,563 Å where the chromosphere is observed will be isolated by Lyot filters.

The ability to use the telescope for high resolution, solar, magnetic and velocity field, measurements is required.

Echelle spectrograph observations of near infrared line profiles from small solar photospheric features are also of interest.

3.2.15.3 Detailed Characteristics

The basic characteristics of the 1.5-m UV-visible normal-incidence solar telescope have been summarized in Figure 3-3 in Section 3.1.

Additional details about the instrument are tabulated in Table 3-116, 3-117, and 3-118.

3.2.15.4 Utilization of Man

Setup and maintenance requirements are summarized for this instrument in Table 3.119. Since man's utilization in the operation of the instrument is dependent upon the observational program, operational information is separately summarized in Table 3-120.

Deployment

Most if not all deployment is automatic. The sun sensor is erected, and the mirrors, gratings, and cameras are uncovered. The spectrographs (with their cameras) and Lyot filter are premounted that is, before launch) on the instrument pallet. The magnetograph may be premounted or may require manned in-orbit mounting, depending on the ruggedness and the size of the final instrument design.

Outgassing after exposure to atmospheric contaminants is a problem for this telescope. Because it has a number of TV vidicons, photomultiplier tubes, and other electronic components that have high voltages, high-voltage

Table 3-116

COLLECTOR PARAMETERS
1.5-Meter Diffraction-Limited UV-Visible Normal-Incidence Solar Telescope--OASF Instrument No. 46

Aperture	1.5 m
Primary focal length	5.35 m
Effective focal length	75 m
Total field of view	1.1 arc min.
Angular resolution	
On axis	0.1 arc sec at 6,200 Å
Poorest in field of view	0.1 arc sec at 6,200 Å
Obscuration of aperture	3.5%
Minimum wavelength	<1,500 Å
Maximum wavelength	>12,000 Å
Primary f/No.	6
System f/No.	50
Scale at system focal plane	2.75 arc sec/mm
Resolution at system focal plane	24 mm
Linear field of view at system focal plane	24 mm

arc-over and consequent deterioration of optical surfaces can become important considerations during later phases of operation. Therefore, the telescope surfaces must be given sufficient opportunity to outgas in vacuum before the electrical components are energized.

Alignment

An optical technician (No. 14) observes a TV screen to interpret a display of star images. The TV camera takes the place of the eyepiece of an autocollimator which is rigidly attached to the instrumentation pallet. The autocollimator is used in two modes. In the first mode, it projects an image

Table 3-117

INTERFACE CHARACTERISTICS
1.5-Meter Diffraction-Limited UV-Visible-Normal-Incidence Solar Telescope--OASF Instrument No. 46

General	
System weight (less expendables)	1,600 kg
System volume (launch configuration)	32.5 m^3
System shape (launch configuration)	Cylindrical (13.5 m long)
Method of accomplishing	
Deployment	Uncap and unwrap
Alignment	Motor-driven EVA-autocollimation
Calibration	Photography of quiet sun
Operation	Remote operation
Experiment change	Change gratings
Stowage requirements (launch)	
Mechanical	Inflatable plastic bags
Electrical	None required
Experiment data handling	
Format	35-mm plates
Processing	On board
Recording media	Photographic emulsion
Mode of data recovery	Manual exchange of cannisters
Pointing requirements	
Pointing accuracy (acquisition)	Manual pointing
Power consumption	
Stowed	None
Standby	150 W
Operate	150 W (peak 165)

Table 3-118

GUIDANCE AND CONTROL CHARACTERISTICS
1.5-Meter Diffraction-Limited UV-Visible-Normal-Incidence Solar Telescope--OASF Instrument No. 46

Guidance characteristics	
Coarse	
Initial acquisition field of view	Manual
Intermediate	
Field of view	Manual
Fine	
Field of view	±32 arc min.
Resolution	±0.05 arc sec
Residual error	±15 arc sec
Control characteristics	
Control moment gyro	
Type	Single degree of freedom
Wheel momentum	270 lb-ft-sec
Gimbal stops	$\pm 50^{\circ}$
Spin motor power (start)	≈150 W
(run)	≈ 25 W
Servo power (peak)	≈100 W
(average)	≈ 12 W
Max. torque	≈250 oz-in.
Weight	≈100 lb
Diameter	≈ 36 in.
Length	≈ 50 in. overall

Table 3-119

SETUP AND MAINTENANCE REQUIREMENTS
1.5-Meter Diffraction-Limited UV-Visible-Normal-Incidence Solar Telescope--OASF Instrument No. 46

Operation	Average Times/ Year	Duration (hours)	No. of Men	Skill Identification*	Hours/ Man	Average Power (W)	Special Equip. Weight (lb)	Special Equip. Volume (ft^3)
Deployment	-	2	1	11	1-1/4	---	---	---
			1	14	3/4	---	---	---
			1	21	2	---	---	---
Alignment	-	12	1	14	12	15	---	---
Calibration	-	12	1	14	12	5	---	---
Scheduled Maintenance	6	4	1	12	1-1/2	15	25	3
			1	14	1-1/2	---	---	---
			1	21	1	---	---	---
Unscheduled Maintenance	2/3	3	1	12	3	25	30	3

*Skills are identified by number in Table 3-3.

which is reflected off the rotatable mirror (optical switch) and then off an optically flat area ground and polished on the center of the secondary mirror and then reflected back through the system. If the projected and reflected images are in coincidence (in the manner of a range-finder) then the secondary mirror is centered and normal to the telescope optical axis. (The technician manipulates servo-motor controls to achieve this alignment.) In the second mode, the autocollimator (with its image projector off) is used as an alignment telescope. The technician views the star image (on the TV monitor) and further adjusts the controls until he obtains the best possible star image shape on the TV monitor.

The scheme described above has been derived from Kollsman experience on the Goddard Experiment Package. In the light of this experience, 12 hours appears to be a reasonable time allotment for the alignment procedures (Table 3-119). This time may be reduced, depending upon the skill of the operator, the design of the servo mechanisms, and a number of partially controllable parameters such as machined tolerances, temperature variations, and structural hysterisis.

Table 3-120

OPERATION SUPPORT AND REQUIREMENTS
1.5-Meter Diffraction-Limited UV-Visible-Normal-Incidence Solar Telescope--OASF Instrument No. 46

ORDS No.	Time per Observation (hours)	No. of Men	Skill Identification*	Man-hours/ observation	Start Time (hours from start of observation)	Number of Observations
053	0.33	1	5	0.5	-0.1	Open
		1	8	1	+48	
057	0.5	1	5	0.6	-0.1	15 periods
		1	8	2	+48	
064	30 days contin hour	1	5	2/day	-0.25	1
		1	8	4/day	+24	
066	0.1	1	5	0.2	-0.1	1/hr during solar active periods
069	0.5	1	5	0.75	-0.25	3
		1	8	0.2	+48	
079	0.33	1	5	0.5	-0.1	Open
		1	8	1	+48	
080	0.1	1	5	0.35	-0.25	50
		1	8	2	+48	

*Skills are identified by number in Table 3-3.

Other alignment tasks include checking and adjustment of the rotational axis of the rotatable mirror, and ensuring that the star trackers are boresighted with the telescope axis. Photographic test sequences may be made to check the correctness of the TV monitor veiw through the TV vidicon on the bore-sighted wide-field guide telescope of the position of the spectrograph split on the sun. Corrections are then made if necessary.

Calibration

Calibration will require a number of photographic sequences with each of the three echelle spectrographs. Some of these may be test plates taken during alignment. The Lyot filter used in the chromospheric experiment is checked to be sure that it is centered on 6,563 Å.

The spectrograms are examined with a densitometer. The Lyot and Fabry-Perot filters are calibrated with the help of a standard source or lamp.

The time involved in calibrating and checking out the magnetograph is an open-ended question, because so few of them have been built and some of these have taken years to become fully operational. About 10 of the 12 hours allotted for calibration in Table 3-119 is associated with the magnetograph. However, this figure must be regarded as speculative.

Operation

The observer locates the object of interest on the sun in the TV monitor view-finder. He stabilizes the telescope on the object, placing either the image of the slit or the center of the field of view on the object. The rotating mirror has already been turned to the appropriate experiment. He then initiates the experiment. Depending on the experiment, type of object of interest, and the stage of development of the phenomenon, he may first take a test strip to determine the correct exposure time (exposures will be of the order of seconds to minutes). The observer or phototechnician is responsible for the loading of plate magazines.

The magnetograph is expected to operate automatically once the telescope is pointed properly and the exposure initiated. Exposure time would be about 20 min. for a Babcock type (polarization recorder) while on the order of only a few minutes for the Leighton type (velocity recorder). Neither of these types is likely to create any problems from the operational point of view. An observer or phototechnician will be needed to load the plates into plate holders or film magazines.

Scheduled Maintenance

The optical technician checks the mirrors, the Lyot filter, the guide telescope, and the other optics. The electromechanical technician checks the two TV vidicons and the plate-camera sequencing mechanisms. The observer can assist.

Unscheduled Maintenance

Sudden failure of a camera mechanism or TV camera is the most likely cause of unscheduled maintenance. The use of the magnetograph decreases system reliability and increases the probability of electromechanical repairs. More motors, vidicon circuits, camera mechanisms, and delicately aligned optics have to be maintained.

3.2.15.5 Supporting Research and Technology

Supporting Research and Technology (SRT) requirements for the 1.5-Meter Diffraction limited UV-Visible telescope (Instrument No. 46) which is a further development beyond the 0.8-Meter UV-Visible-IR telescope (instrument No. 44), described in Section 3.2.10, are listed below. Full descriptions of SRT items are given in Section 4.3.

Research and Advance Technology

Develop methods for rapidly evaluating mirror figure and alignment under one and zero-g environments (SRT 1).

Conduct experimental studies of precision structural properties of mirror (SRT 2).

Develop methods for generating and maintaining diffraction limited (5,000 Å) mirror quality in orbital environments (SRT 3).

Develop mirror surfaces to provide high ultraviolet reflectivity, precision of figure and freedom from scattering (SRT 4).

Develop cantilevered mirror as a reflective beam deflector (SRT 5).

Develop techniques to overcome electrostatic charge build-up and fog producing spark discharge on roll film in hard vacuum (SRT 17).

Develop flexible film substrata of higher dimensional stability than now available (SRT 18).

Develop improved grating ruling techniques and equipment to provide closer ruling spacing and greater uniformity of ruling, spacing, blaze angle and surface finish (SRT 38).

Develop criteria for film transport mechanisms suitable for roll film in hard vacuum to avoid emulsion cracking and flaking (SRT 39).

Investigate degradation of telescope detector and reflective surfaces resulting from O_2 exposure (SRT 42).

Investigate techniques for alignment and focusing mechanisms for optical telescopes (SRT 55).

Investigate the dimensional stability of candidate mirror materials (SRT 56).

Evaluate sputtering on mirror surfaces from high-energy particles (SRT 57).

Advance development

Assess materials for internal use to determine if rapid aging and breakdown are caused by internal atmosphere (SRT 82).

Assess materials for external use to evaluate (A) hard vacuum effects on materials, finishes, etc. ; (B) development of processing, handling, and assembly techniques (SRT 83).

Supporting Development

Develop image tubes with greater spatial resolution than now available (SRT 84).

Develop photographic emulsions with improved spatial resolution (SRT 84A).

3.2.15.6 Development Cost and Schedules

The Phase D cost is shown in Table 3-121, which shows both development and operations costs. The development schedule is shown in Figure 3-67. Quantities of equipment required in development are shown in Table 3-122.

3.2.15.7 Instrumentation Section

Echelle Spectrograph

The echelle spectrograph on the 1.5-m solar telescope is different from the spectrograph on the 0.8-m solar telescope. This spectrograph is a triple range instrument designed to cover the spectral range from 1,500 Å to 10,000 Å with no range covering more than an octave. Each range has its

Table 3-121

TASK COST ESTIMATE--PHASE D
1.5-Meter Diffraction-Limited UV-Visible-Normal-Incidence Solar Telescope--OASF Instrument No. 46
($ thousands)

Development total	5,896		
Engineering		440	
Detectors		*	
Spectrograph film			*
Collecting optics		666	
1.5-m primary mirror			300
Secondary mirror			90
Secondary mirror alignment assembly			276
Manual guidance		300	
TV camera			*
Control moment gyros			*
Housing		360	
Structure			*
Experiment sensors	2,570		
Lyot filter			400
Echelle spectrograph			820
35-mm plate camera			630
Solar magnetograph			720
Major hardware articles		1,560	
Mockup			*
Engineering model			*
Project verification model			*
Qualification model			*
Operations total	2,722		
Flight instrument		1,768	
Backup flight instrument		707	
Engineering support		247	
Phase D total	8,618**		

*Cost item not derived where overall estimate for instrument is not significantly affected.

**Assumes previous development of 0.8-m solar OASF Instrument No. 44; same optics contractor for both instruments.

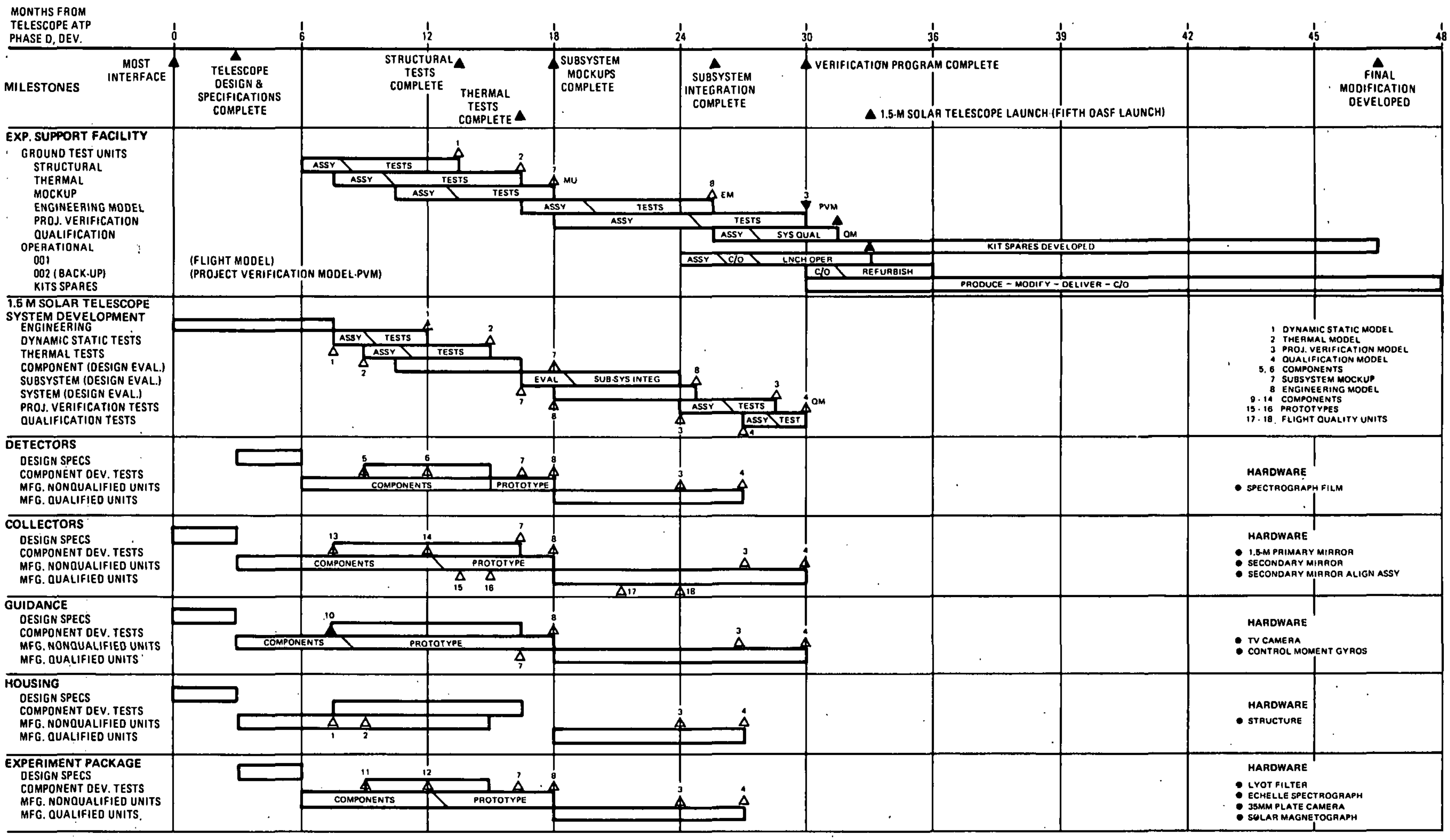

Figure 3-67. Development Schedule, 1.5 Meter Diffraction Limited UV-Visible Normal Incidence Telescope, Solar (OASF Instrument No. 46)

Table 3-122

PRIMARY INSTRUMENT EQUIPMENT LIST--DEVELOPMENT PHASE D
1.5-Meter Diffraction-Limited UV-Visible Normal-Incidence Telescope, Solar (OSAF Instrument No. 46)

Functional System (Major Element)	Subsystem	Assemblies	Quantity		
			Bread-Board	Proto-Type	Flight Quality
Normal incidence telescope solar	Detectors	Spectrograph film	2	2	2
	Collecting optics	1.5-m primary mirror	1	2	1
		Secondary mirror	1	2	1
		Secondary mirror Alignment assembly	2	2	1
	Manual guidance	TV camera	1	1	2
		Control moment gyros	1	1	2
	Housing	Structure	---	1	2
	Experiment sensors	Lyot filter	1	1	2
		Echelle spectrograph	1	1	2
		35-mm plate camera	1	1	2
		Solar magnetograph	1	1	2
	Major hardware articles	Mockup	1	---	---
		Engineering model	---	1	---
		Project verification model	---	60%*	40%*
		Qualification model	---	---	1

*Obtained from subsystem development quantities.

own complete set of spectrograph optics, including predisperser, echelle grating, focusing mirror and camera (see Table 3-123, 3-124, and 3-125). Thus, the grating rulings, film characteristics and mirror coatings can all be selected for the particular wavelength range. The entire spectrograph weighs 10 kg.

The three predisperser gratings are mounted on a platen that can be translated to any of three indexed positions to bring the appropriate predisperser into the cone of light diverging from the spectrograph slit. The predisperser does two things: it collimates the light from the slit into the proper echelle grating; and it restricts the wavelength range remaining within the field of the following optics to a single order. Rotation of the predisperser permits the selection of the order to be recorded.

The echelle gratings are also mounted so that they can be rotated about an axis that is perpendicular to both the rotation axis of the predispersers and the axis of the telescope. This rotation determines the portion of the order already selected by the predisperser that will be recorded on the film format. Typically, the spectra recorded are between the 40th and 80th orders.

The focusing mirrors collect the light for the spectral range to be recorded and form an image at the camera image plane. To achieve the desired reciprocal linear dispersion of 0.1 Å/mm, these mirrors must have a focal length of 5m, thus explaining the large size of the spectrograph.

Three plate cameras, each weighing 20 kg, record the spectra from the three spectrographs; they have recording formats of 100-mm length of 35-millimeter film.

Slit-Jaw Camera

The slit-jaw camera is similar to that described in Section 3.2.10, with the addition of a film camera for spatial correlation of the spectrographic data. The specific characteristics of this instrumentation device are described in Table 3-126.

Table 3-123

ECHELLE SPECTROGRAPH (RANGE 1) CHARACTERISTICS
1.5-Meter Diffraction-Limited UV-Visible-Normal-Incidence Solar Telescope--OASF Instrument No. 46

Wavelength	
Short	1,300 Å
Long	3,000 Å
Resolution	0.002 Å at 3,000 Å
Entrance Aperture	
Slit width	20 μ
Slit height	2.18 cm (1 min. field of view)
Incident radiation	
f/No. limitation	50
Spatial resolution	0.055 sec
Spectral calibration	
Predisperser grating	
Type	Concave
Size	41.8 x 20 mm
Ruling frequency	2,230 line/mm
Dispersion	1 Å/mm at 3,000 Å
Range of angle of diffraction	8.3° to 19.87°
Spectral order	1
Main grating	
Type	Echelle
Size	70.8 x 44.1 mm
Ruling frequency	209.96 lines/mm
Dispersion	0.1 Å/mm at 3,000 Å
Range of angle of diffraction	68.01° to 74.15°
Spectral order	30 to 69 (in 10 sections)
Recorder characteristics	
Type	Film
Aperture	28 x 100 (x10) mm
Remote change cycle time	2 sec
Film type limitations	Schumann Type
Exposure per magazine load	128
Power consumption during cycle change	10 W
Weight	8 kg

Table 3-124

ECHELLE SPECTROGRAPH (RANGE 2) CHARACTERISTICS
1.5-Meter Diffraction-Limited UV-Visible-Normal-Incidence Solar Telescope--OASF Instrument No. 46

Wavelength	
Short	3,000 Å
Long	7,000 Å
Resolution	0.002 at 5,000 Å
Entrance aperture	
Slit width	20 μ
Slit height	2.18 cm
Incident radiation	
F/No. limitation	≥f/50
Spatial resolution	0.1 sec at 6,000 Å (diffraction limit)
Spectral calibration	
Predisperser grating	
Type	Concave
Size	41.8 x 20 mm
Ruling frequency	2035.6 line/mm
Dispersion	1.955 Å/mm at 5,000 Å
Angle of diffraction range	17.6° to 38.08°
Spectral order	1
Main grating	
Type	Echelle
Size	121 x 45.7 mm
Ruling frequency	472.4 line/mm
Dispersion	0.1 Å/mm at 5,000 Å
Range of angle of diffraction	75.58° to 80.5°
Spectral order	69.138
Recorder characteristics	
Type	Film
Aperture	100 x 25 mm
Remove change cycle time	2 sec
Film type limitations	Panchromatic spectrographic
Exposure per magazine load	128
Power consumption during cycle change	10 W
Focal length	5.0 m
Weight	9 kg

Table 3-125

ECHELLE SPECTROGRAPH (RANGE 3) CHARACTERISTICS
1.5-Meter Diffraction-Limited UV-Visible-Normal-Incidence Solar Telescope--OASF Instrument No. 46

Wavelength	
Short	6,000 Å
Long	11,000 Å
Resolution	0.002 Å at 5,000 Å
Entrance aperture	
Slit width	20 μ
Slit height	2.18 cm
Incident radiation	
f/No. limitation	≥f/50
Spatial resolution	0.1 sec at 6,000 Å (diffraction limit)
Spectral calibration	
Predisperser grating	
Type	Concave
Size	41.8 x 20 mm
Ruling frequency	1257.9 line/mm
Dispersion	3.18 Å/mm at 5,000 Å
Angle of diffraction range	22.0° to 44.21°
Spectral order	1
Main grating	
Type	Echelle
Size	179 x 45.5 mm
Ruling frequency	208.42 line/mm
Dispersion	0.1 Å/mm at 5,000 Å
Range of angle of diffraction	22.0° to 44.21°
Spectral order	1
Recorder characteristics	
Type	Film
Aperture	142 x 9 mm
Remote change cycle time	2 sec
Film type limitations	Panchromatic spectrographic
Exposure per magazine load	128
Power consumption during cycle change	10 W
Focal length	5.0 m
Weight	10 kg

Table 3-126

FIELD IMAGE INSTRUMENTATION CHARACTERISTICS
1.5-Meter Diffraction-Limited UV-Visible-Normal-Incidence Solar Telescope--OASF Instrument No. 46

Film camera characteristics*		
Type		35 mm cine movie camera
Aperture		35 x 160 mm
Remote change cycle time		2 sec
Power consumption during change		10 W
Film type limitations		All types of spectrographic film
Exposures per magazine load		128 or more (1,000 ft/roll)
Weight		10 kg
Electro-optics camera characteristics*		
Type		TV vidicon and image converter
Aperture		25.4 mm vidicon
Resolution		20 lines/mm
Photo surface		Photocathode
Power consumption		10 W
Frame time		Variable
Weight		4 kg
Filter characteristics		
Type		Narrow-band lyot
Wavelength	(short)	6,555 Å
	(long)	6,567 Å
	Resolution	±0.1 Å
	Band centers	6,555 Å, 6,563 Å, 6,567 Å
Weight		6 kg

*Both cameras are part of the slit-jaw camera assembly

Magnetograph

The magnetograph is a device for determining the intensity of the sun's magnetic field over the solar disk as called for in some of the observation requirements. Two conceptual approaches are known, one associated with Babcock (Reference 3-10) and one associated with Leighton (Reference 3-11). In each of these approaches the magnetic intensity is determined by measuring the splitting of spectral lines in the visible range resulting from the Zeeman magnetic effect, using polarization measurements to separate the Zeeman splitting from broadening of the lines caused by thermal effects. In the Babcock concept, a scanning spectroheliograph is used, requiring scanning of the desired portion of the surface of the sun, whereas in the Leighton concept a Lyot tunable narrowband filter is used to give a picture of the entire solar disk at once (Reference 3-12). Space for one (or possibly both) of these instruments is provided in the instrumentation section, but no parametric data are presented.

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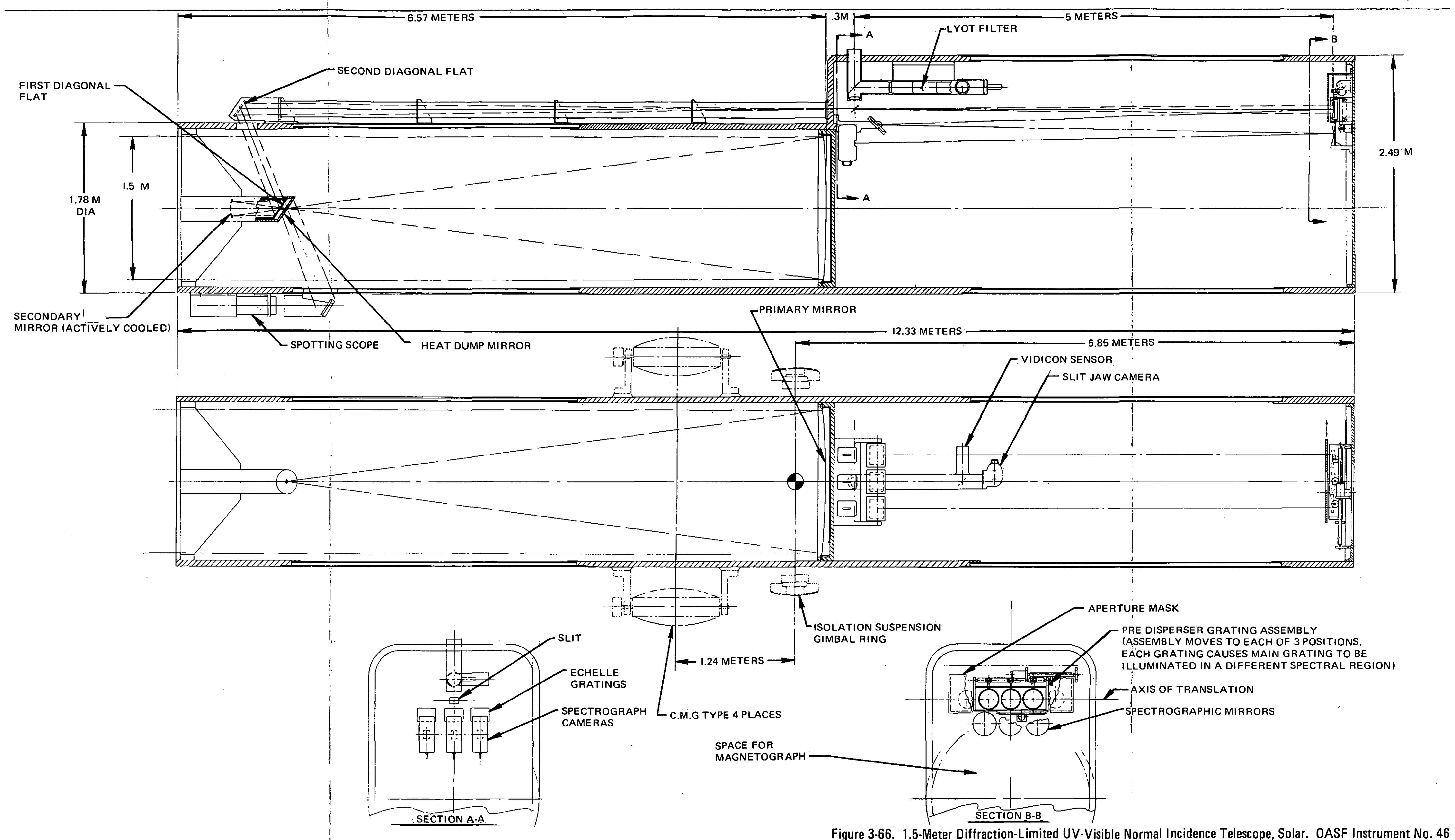

Figure 3-66. 1.5-Meter Diffraction-Limited UV-Visible Normal Incidence Telescope, Solar. OASF Instrument No. 46

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3.2.16 0.5-Meter UV (Off-Axis) Normal-Incidence Telescope, Solar-OASF Instrument No. 5

3.2.16.1 General Characteristics

Instrument No. 5 is depicted in Figure 3-68. The late-period, off-axis telescope is essentially a magnified version of the 0.2-m telescope and it has an aperture that is increased by a factor of 2.5 and a collecting area that is 6.25 times larger. It retains the same focal ratio of 12 so that its focal length becomes 6 m.

The instrumentation package consists chiefly of a concave grating spectrograph to cover the range from 300 to 1,500 Å at a dispersion of about 1 Å/mm. To keep the camera from becoming too unwieldy by requiring it to record a meter of spectrum on a single exposure, the spectrum is recorded in two ranges. The change is achieved either by changing gratings or by rotating the grating with the accompanying adjustment of the camera.

A slitless spectroheliograph in the range of 170 to 650 Å may be used as an alternate mode of operation. This mode of operation is attained by replacing the slit with a field stop, introducing an aluminum filter to block unwanted energy, changing the camera to one capable of rapid frame change, and making alterations in the grating pointing capability.

A slit-jaw camera, incorporating both video and film recording, is used for comparison purposes and for guidance, with the steering torques provided by control moment gyros.

3.2.16.2 Design Criteria

The function of this telescope is essentially the same as the smaller off-axis telescope with the added requirement of larger collecting aperture and finer resolution. Extension of spectral coverage to shorter wavelengths is desired if the spectroheliograph function is to be achieved in this instrument. The alternative is to incorporate this function in the grazing-incidence telescope where better reflectivity is achieved at the expense of field of view.

3.2.16.3 Detailed Characteristics

The basic characteristics of the 0.5-m UV (off-axis) normal-incidence solar telescope have been summarized in Figure 3-3 in Section 3.1.

Additional details about the instrument are tabulated in Table 3-127, 3-128, and 3-129.

3.2.16.4 Utilization of Man

Setup and maintenance requirements are summarized for this instrument in Table 3-130. Because the use of man in the operation of the instrument depends on the observation program, operational information is separately summarized in Table 3-131.

Deployment

Protective caps and coverings on the optics and instruments are removed by the optical technician. He inspects the mirror and the gratings of the spectrographs. The sun sensor, the guide telescope, and its TV vidicon are turned on and checked out. The telescope gimbal is attached to the space station structure (if not done before launch).

Alignment

The phototechnician takes a series of spectrograms, cine exposures (movie camera), and slit-jaw camera photographs to verify that the system is working. He checks the TV-monitor viewfinder and the boresighted alignment of the guide telescope (including TV vidicon attached) with the optical axis of the main telescope.

There are two instruments on the back end: (1) a normal-incidence grating spectrograph with a plate camera attached and (2) a slitless spectrograph with a cine camera attached. These are simple instruments and because of the simplicity of the telescope itself, only focusing is required.

Table 3-127

COLLECTOR PARAMETERS
0.5-M UV (Off-Axis) Normal-Incidence Solar Telescope--
OASF Instrument No. 5

Aperture	0.5 m
Primary focal length	6 m
Effective focal length	6 m
Total field of view	2 arc min.
Angular Resolution	
On axis	0.5 arc sec at 800 Å
Obscuration of aperture	0%
Minimum wavelength	170 Å
Maximum wavelength	1,500 Å
Primary f/No.	12
System f/No.	12
Scale at system focal plane	34 arc sec/mm
Resolution at system focal plane	68.8 lines/mm
Linear field of view at system focal plane	3.5 mm

Calibration

The test photographs taken for the alignment check, together with comparison photographs and a microdensitometer suffice for the general calibration requirements. Each observation of a prominence requires a test strip to determine proper exposure time. After experience has been gained, the observer should be able to estimate exposure time satisfactorily without the need of test strips.

Table 3-128

INTERFACE CHARACTERISTICS
0.5-Meter UV (Off-Axis) Normal-Incidence Solar Telescope--
OASF Instrument No. 5

General	
System weight (less expendables)	1,800 kg
System volume (launch configuration)	10.8 m^3
System shape (launch configuration)	Long cylinder
Method of accomplishing	
Deployment	Remove plastic bag
Alignment	No in-flight alignment
Calibration	Photography of spectrum of quiet sun
Operation	Remote photography
Experiment change	Grating and slit change
Stowage requirements (launch)	
Mechanical	Plastic-bag packaging
Electrical	None
Experiment data handling	
Format	35 x 600 mm photo plate
Processing	On board
Recording media	Photographic emulsion (Schumann)
Mode of data recovery	Change plate canister
Pointing requirements	
Pointing accuracy (acquisition)	± Manual
Power consumption	
Stowed	None
Standby	≈117 W
Operate	≈125 W

Table 3-129

GUIDANCE AND CONTROL CHARACTERISTICS
0.5-Meter UV (Off-Axis) Normal-Incidence Solar Telescope--
OASF Instrument No. 5

Guidance characteristics	
Coarse	
Initial acquisition field of view	Manual
Intermediate	
Field of view	N/A
Fine	
Field of view	±40 arc min.
Resolution	±0.05 arc-sec
Residual error	±5 arc-sec
Control characteristics	
CMG	
Type:	Single degree of freedom
Wheel momentum:	≈250 lb-ft-sec
Gimbal stops	$\pm 50^{\circ}$
Spin motor power (start)	≈120 W
(run)	≈18 W
Servo power (peak)	≈80 W
(average)	≈10 W
Max. torque	≈200 oz -in.
Weight	≈100 lb
Diameter	≈36 in.
Length	overall ≈50 in.

Table 3-130

SETUP AND MAINTENANCE REQUIREMENTS
0.5-Meter UV (off-axis) Normal-Incidence Solar Telescope--
OASF Instrument No. 5

Operation	Average Times/ Year	Duration (hours)	No. of Men	Skill* Identification	Hours/ Man	Average Power (W)	Special Equip Weight (lb)	Special Equip Volume (ft^3)
Deployment	---	2	1	21	2	---	---	---
			1	14	1			
Alignment	---	1	1	8	1	---	3	1
Calibration			None required in orbit					
Scheduled maintenance	6	1	1	12	1	5	10	1
			1	14	1			
Unscheduled maintenance	1/3	1	1	12	1	40	100	3

*Skills are identified by number in Table 3-3

Table 3-131

OPERATION SUPPORT AND REQUIREMENTS
0.5-Meter UV (off-axis) Normal-Incidence Solar Telescope--
OASF Instrument No. 5

ORDS No.	Time per Observation (hours)	No. of Men	Skill Identification*	Man-hours/ observation	Start Time (hours from start of observation)	Number of Observations
043	1.0	1	5	1.1	-0.05	12
044	1.0	1	5	1.1	-0.05	12
051	0.17	1	5	0.25	-0.08	Open
		1	8	0.2 (avg)	+48	
060	1.25	1	5	1.3	-0.05	Open
		1	8	0.2 (avg)	+48	

*Skills are identified by number in Table 3-3

Operation

The observer manually points the telescope (which has been following the sun with the use of its sun sensor) at the desired object or area of interest by watching the guide-telescope TV monitor. After the test strips have been taken, if needed, he initiates the exposure and sets the timer. After exposure, the films, plates, etc. are developed by the observer, or by a phototechnician, inside the space station.

Scheduled Maintenance

The optical technician examines the optics for damage or deterioration. The electromechanical technician checks the camera-sequencing mechanisms on the spectrographs and cine camera for deterioration. He also checks the TV vidicon and monitor circuits for weakened components; modular replacements are used if necessary.

Unscheduled Maintenance

Unscheduled maintenance is required in the case of unusual electronic failure of the sun sensor or TV camera, or in case of a mechanical failure such as in the camera sequencing mechanisms.

3.2.16.5 Supporting Research and Technology

The 0.5-Meter UV Off-Axis Telescope (Instrument No. 5) is a scaled-up version of the 0.2-Meter UV Off-Axis Telescope (Instrument No. 4) discussed in Section 3.2.11. Supporting research and technology (SRT) requirements, which are the same for both instruments, are listed below. Full descriptions of SRT items are given in Section 4.3.

Research and Advance Technology

Develop mirror surfaces to provide high UV reflectivity, precision of figure, and freedom from scattering (SRT 4).

Develop higher than current reflectivity in coatings for XUV below 900 Å (SRT 7).

Extend XUV filter technology to provide structurally sturdy transmission filters of about 100 Å bandpass in the region from 170 Å longward (SRT 10).

Develop XUV-sensitive imaging tubes for use below 1,050 Å (SRT 11).

Develop techniques to overcome electrostatic charge build-up and fog-producing spark discharge on roll film in hard vacuum (SRT 17).

Develop criteria for film-transport mechanisms suitable for roll film in hard vacuum to avoid emulsion cracking and flaking (SRT 39).

Investigate degradation of telescope detector and reflective surfaces resulting from O_2 exposure (SRT 42).

Investigate the dimensional stability of candidate mirror materials (SRT 56).

Advance Development

Assess materials for internal use to determine if rapid aging and breakdown are caused by internal atmosphere (SRT 82).

Assess materials for external use to evaluate (A) hard vacuum effects on materials, finishes, etc., and (B) development of processing, handling, and assembly techniques (SRT) 83).

Supporting Development

Develop image tubes with greater special resolution than currently obtainable (SRT 84).

3.2.16.6 Development Cost and Schedules

The Phase D cost is shown in Table 3-132, which shows both development and operations costs. The development schedule is shown in Figure 3-69. Quantities of equipment required in development are shown in Table 3-133.

3.2.16.7 Instrumentation Section

Concave Grating Spectrograph

Unlike the 0.2-in off-axis telescope (OASF Instrument No. 4), this telescope has two (rather than one) instrumentation devices in the instrumentation section. The first is a larger version of the concave grating spectrograph described in Section 3.2.11.1, the most striking difference being the size and aspect ratio of the film strips used (Table 3-134). To prevent the strips

Table 3-132

TASK COST ESTIMATE--PHASE D
0.5-METER UV OFF-AXIS NORMAL-INCIDENCE TELESCOPE, SOLAR (OASF Instrument No. 5)
($ thousands)

Development total	4,010		
Engineering		300	
Detectors		*	
35-mm strip film			*
Spectrograph film			*
Collecting optics		50	
0.5-m primary mirror			50
Manual guidance		250	
Housing		150	
Structure			*
Experiment sensors		2,200	
Normal-incidence spectrograph			500
35-mm plate camera			700
Slitless spectroheliograph			1,000
Major hardware articles		1,060	
Mockup			*
Engineering model			*
Project verification model			*
Qualification model			*
Operations total	1,852		
Flight instrument		1,203	
Backup flight instrument		481	
Engineering support		168	
Phase D total	5,862**		

*Cost item not derived where overall estimate for instrument is not significantly affected.

**Assumes previous development of 0.2-m off-axis OASF Instrument No. 4; same optics contractor for both instruments.

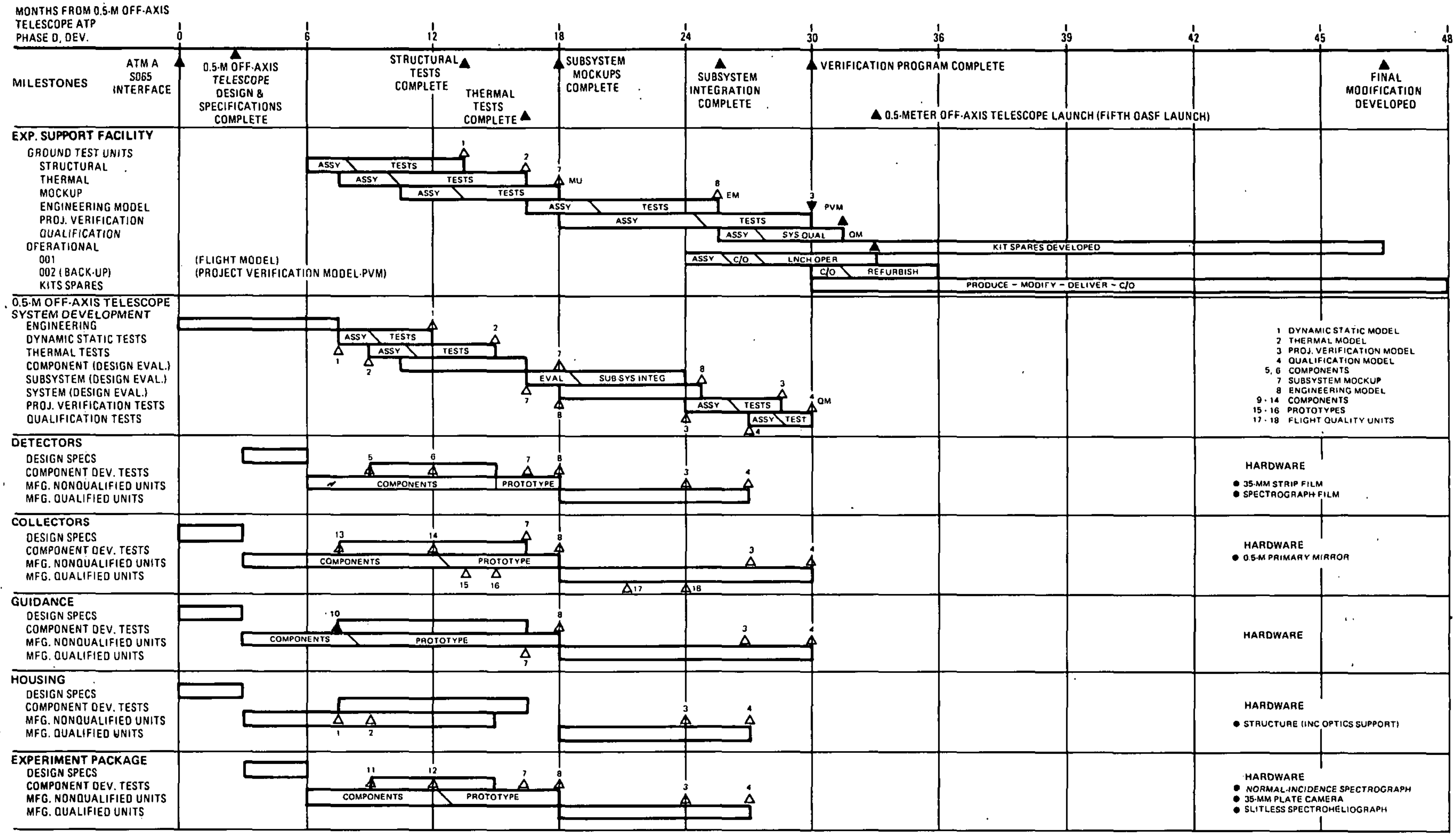

Figure 3-69. Development Schedule, 0.5-Meter UV Off-Axis Normal Incidence Telescope, Solar (OASF Instrument No. 5)

Table 3-133

PRIMARY INSTRUMENT EQUIPMENT LIST--DEVELOPMENT PHASE D
0.5-meter UV Off-Axis Normal-Incidence Telescope, Solar
(OASF Instrument No. 5)

Functional System (Major Element)	Subsystem	Assemblies	Quantity: Bread-board	Quantity: Proto-type	Quantity: Flight Quality
0.5-m UV off-axis telescope solar	Detectors	35-mm strip film	2	1	2
		Spectrograph film	2	1	2
	Collecting optics	0.5-m primary mirror	1	2	1
	Manual guidance	---	---	---	---
	Housing	Structure (inc optics support)	---	1	2
	Experiment sensors	Normal-incidence spectrograph	1	1	1
		Slitless spectroheliograph	1	1	1
		35-mm plate camera	1	1	1
	Major hardware articles	Mockup	1	---	---
		Engineering model	---	1	---
		Project verification model	---	60%*	40%*
		Qualification model	---	---	1

*Obtained from subsystem development quantities

Table 3-134

CONCAVE GRATING SPECTROGRAPH CHARACTERISTICS
0.5-Meter UV (Off-Axis) Normal-Incidence Solar Telescope--
OASF Instrument No. 5

Type	Normal incidence
Wavelength	
Short	300 Å
Long	1,500 Å
Resolution	0.02 Å at 800 Å
Entrance aperture	
Slit width	20μ
Slit height:	3,750μ
Incident radiation	
f/No. limitation	12
Spatial resolution	0.64 sec
Main grating	
Type	Concave
Size	232 x 236 mm
Ruling frequency	3,600 lines/mm
Dispersion	1Å/mm at 800 Å
Angle of diffraction range	-10.37^{o} to $+14.60^{o}$
Spectral order	1
Recorder characteristics	
Type	Film
Aperture	10 x 600 mm (X2)
Remote change cycle time	5 sec
Film type limitations	Schumann emulsion
Exposure per magazine load	128
Power consumption during cycle change	10 W
Weight	52.5 kg (including 45 kg for plate camera)

from becoming prohibitively long, each exposure is divided into two steps, each with its own grating, or if a suitable design can be implemented, with a shift of the grating position. Serious consideration should also be given to reducing the dispersion by a factor of two to record it all on a single frame. The reason for this is that even with the reduced dispersion the film format is 60 cm long.

Slitless Spectroheliograph

The second instrumentation device is a slitless spectroheliograph. In this device, the slit is replaced by a field stop, and a different grating is introduced to cover a much shorter wavelength (see Table 3-135); the grating is adjusted to focus on a different camera outfitted with unbacked metallic thin film filters; and the grating is provided with a drive to change recorded wavelengths. As stated previously this instrument is contingent on the development of reflection enhancement techniques for the wavelength range shortward of 500 Å; otherwise, it must be incorporated into one of the grazing incidence telescopes.

Slit-Jaw Camera

A slit-jaw camera (weight, 15 kg) similar to that described in Section 3.2.11.7 is included.

Table 3-135

SLITLESS SPECTROGRAPH CHARACTERISTICS
0.5-Meter UV (off-axis) Normal-Incidence Solar Telescope--
OASF Instrument No. 5

Type	Normal incidence
Wavelength	
Short	170 Å
Long	650 Å
Resolution	1 Å at 600 Å
Entrance aperture	
Slit width	Slitless stop 35.8 mm
Slit height	35.8 mm
Incident radiation	
f/No. limitation	12
Spatial resolution	1 arc sec
Main grating	
Type	Concave
Size	232 x 236 mm
Ruling frequency	3,600 (lines/mm)
Range of angle of diffraction	To be determined
Spectral order	1
Recorder characteristics	
Type	Film
Aperture	70 x 100 mm
Remote change cycle time	5 sec
Film type limitations	Schumann
Exposure per magazine load	128
Weight	32.5 kg (including 25 kg for plate camera)

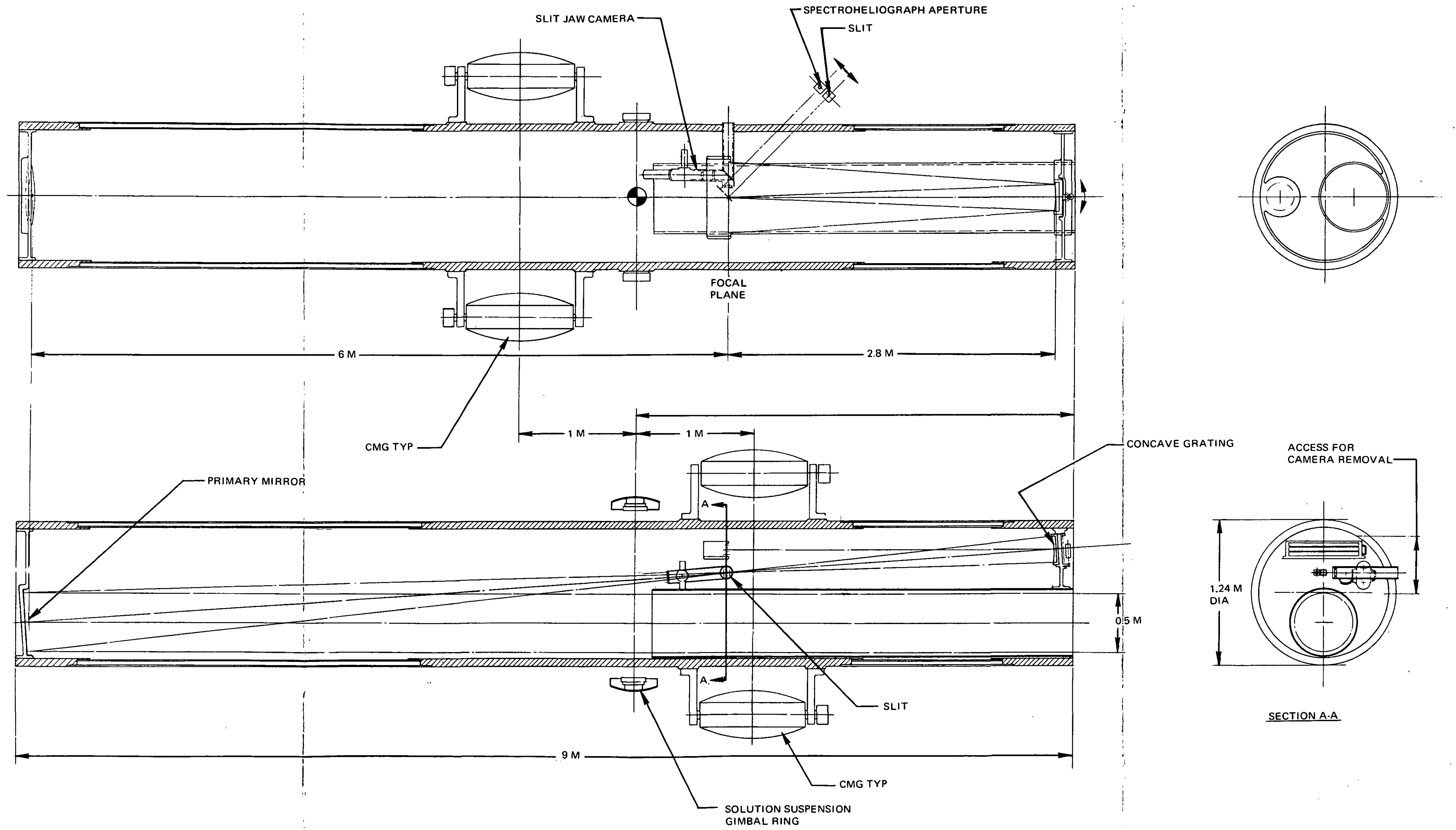

Figure 3-68. 0.5-Meter UV Off-Axis Normal Incidence Telescope, Solar. OASF Instrument No. 5

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3.2.17 0.125-Meter High-Dispersion Spectroheliograph Normal-Incidence Telescope, Solar-OASF Instrument No. 7

3.2.17.1 General Characteristics

The high-dispersion spectroheliograph is an outgrowth of the instrument described in Section 3.2.12 insofar as it uses similar optics as a predisperser section (Figure 3-70). The high dispersion, however, is achieved with a concave echelle section. A field stop at the focus of the predisperser permits the energy from a 10 x 10 arc-min. portion of the sun to pass through to the echelle grating while the remaining energy is reflected out of the system by the mirrored face of the field stop. This instrument is derived from the Lyman alpha spectroheliograph and the stigmatic high resolution Lyman alpha line spectrograph from the Naval Research Laboratory (Reference 3-13). The present spectroheliograph contains the following basic items: A turret with four concave gratings each of which serve the dual function of objective mirror and predisperser; a field stop which limits the field of view to 10 arm-min.; a concave echelle grating which disperses the spectrum along the film strip, and a camera. Ancillary equipment includes a video guidance telescope, control moment gyros for pointing control and the necessary hardware for mounting the spectroheliograph to the telescope.

3.2.17.2 Design Criteria

The observation requirements, on which the concept of this spectroheliograph is based, are quite specific. A wavelength range from 304 to 1,216 Å, a field of view of 10 arc min., a resolution of 1 Å, and a dispersion of 0.02 Å/mm and a focal length and aperture are recommended. Taken one at a time, all the requirements can be met rather readily with the exception of the dispersion. Fundamentally, high dispersion is achieved either by keeping the angle of diffraction very high, where its sine is close to unity and cosine extremely low, or by using a long focal length. A combination of these approaches has been taken in which a concave echelle grating blazed at a very high angle, and in which a large radius of curvature is used.

The echelle grating requires prefiltering or predispersion. Since narrowband filters are not readily available over the 300- to 1,200 Å range, order separation is achieved by predispersion. Order selection is achieved by a slight tilt of the predisperser. Four pairs of gratings are postulated to keep the operation of the gratings near the design angles, since the combined grating systems will be corrected to reduce aberrations.

The instrument described in the following pages of tabular data is a first approximation and must be considered preliminary in all respects.

3.2.17.2 Detailed Characteristics

The basic characteristics of the 0.125-Meter High Dispersion Spectroheliograph Normal Incidence Telescope, Solar have been summarized in Figure 3-3 in Section 3.1.

Additional details about the instrument are tabulated in Tables 3-136, 3-137, 3-138 and 3-139.

3.2.17.4 Utilization of Man

Setup and maintenance requirements are summarized for this instrument in Table 3-140. Because man's utilization in the operation of the instrument depends on the observational program, operational information is separately summarized in Table 3-141.

Deployment

The optics, including a boresighted guide telescope with TV vidicon, are aligned on the ground and only focusing is done in orbit. The sun sensor and spectroheliograph optics are uncovered and the gimbal ring attached to the space station. The optical technician inspects the concave gratings for damage.

Alignment

Minor focus adjustments are made as needed, as determined from test plates made during calibration.

Table 3-136

COLLECTOR PARAMETERS
0.125-Meter High-Dispersion Spectroheliograph
Normal-Incidence Telescope, Solar--
OASF Instrument No. 7

Aperture	0.125 m
Primary focal length	2.5 m
Effective focal length	2.5 m
Total field of view	10 arc min.
Angular resolution	
On axis	1 arc sec at 600 Å
Poorest in field of view	2 arc sec at 600 Å
Obscuration of aperture	0%
Minimum wavelength	304 Å
Maximum wavelength	1,216 Å
Primary f/No.	20
System f/No.	20
Scale at system focal plane	80 arc sec/mm
Resolution at system focal plane	80 lines/mm
Linear field of view at system focal plane	7.5 mm

Calibration

A series of plates of the plages and inner corona, and then of various standard lamps, establishes a basis for estimating required exposures. For certain types of observation, the calibration procedure may be lengthened beyond the value suggested in Table 3-140.

Table 3-137

INTERFACE CHARACTERISTICS
0.125-Meter High-Dispersion Spectroheliograph
Normal-Incidence Telescope, Solar--
OASF Instrument No. 7

General	
System weight (less expendables)	≈300 kg
System volume (launch configuration)	≈2.75 m^3
System shape (launch configuration)	cylinder
Method of accomplishing	
Deployment	Uncapping only
Alignment	No in-flight alignment - remote
Calibration	Photography of quiet sun
Operation	TV control of photography
Experiment change	Substitution of grating assembly
Stowage requirements (launch)	
Mechanical	Plastic-bag packaging
Electrical	None
Experiment data handling	
Format	Film strip 35 x 250 mm
Processing	None on-board
Recording media	Photographic film (Schumann)
Mode of data recovery	Manual change of film magazine
Pointing requirements	
Pointing accuracy (acquisition)	$\pm 1^{o}$
Power consumption	
Stowed	None
Standby	55 W
Operate	≈55 W, peak 60 W

Table 3-138

GUIDANCE AND CONTROL CHARACTERISTICS
0.125-Meter High-Dispersion Spectroheliograph
Normal-Incidence Telescope, Solar--
OASF Instrument No. 7

Guidance characteristics	
Coarse	
Initial acquisition field of view	±7-1/2°
Resolution	±15 arc min.
Residual error	±1°
Intermediate	
Field of view	±2°
Resolution	±20
Residual error	±5 arc min.
Fine	
Field of view	±40 arc min.
Resolution	±0.02 arc sec
Residual error	±0.1 arc sec
Control characteristics	
CMG	
Type	Single degree of freedom, viscous damped
Wheel momentum	640 oz-in.-sec
Gimbal stops	±60°
Spin motor power (start)	40 W
(run)	6 W
Servo power (peak)	10 W
(average)	1.5 W
Max. torque	3.8 oz-in.
Weight	16 lb
Diameter	5 in.
Length	8-1/2 in.

Table 3-139

SLITLESS SPECTROHELIOGRAPH CHARACTERISTICS
0. 125-Meter High-Dispersion Spectroheliograph
Normal-Incidence Telescope, Solar--
OASF Instrument No. 7

Type	Spectroheliograph (Tousey)
Wavelength	
Short	304 Å
Long	1, 216 Å
Resolution	0. 02 Å at 600 Å
Entrance aperture	
Slit width	No slit, aperture 7. 25 mm
Slit height	7. 25 mm
Incident radiation	
f/no. limitation	20
Spatial resolution	1 sec
Predisperser grating	
Type	Concave
Size	125 mm
Ruling frequency	~500, 707, 1, 000, and 1, 414 line/mm
Dispersion	--- angstrom/mm at 600 Å
Angle of diffraction range	0° to 6° (dispenser)
Spectral order	1; radius 5 m
Main grating	
Type	Concave echelle
Size	24 x 200 mm
Ruling frequency	1, 200, 1, 700, 2, 400, and 3, 400 lines/mm
Dispersion	0. 02 Å/mm at 300 Å
Range of rangle of diffraction	62° and 70°
Spectral order	~14 - 20; radius 5 m
Recorder characteristics	
Type	Film
Aperture	35 and 250 mm
Remote change cycle time	5 sec
Film type limitations	Schumann Emulsion
Exposure per magazine load	25
Power consumption during cycle change	10 W
Power consumption during calibrate	5 W
Weight	40 kg (incl. 30 kg for plate camera)

Table 3-140

SETUP AND MAINTENANCE REQUIREMENTS
0. 125-Meter High-Dispersion Spectroheliograph
Normal-Incidence Telescope, Solar--
OASF Instrument No. 7

Operation	Average Times/ Year	Duration (hours)	No. of Men	Skill Identification*	Hours/ Man	Average Power (W)	Special Equip Weight (lb)	Special Equip Volume (ft^3)
Deployment	---	1/2	1	24	1/2	---	---	---
Alignment	---	None	---	---	---	---	---	---
Calibration	---	1	1	21	1	3	---	---
Scheduled maintenance	6	1	1	12	1/2	15	10	1
			1	14	1/2			
Unscheduled maintenance	1/3	1	1	12	1	15	30	2

*Skills are identified by number in Table 3-3.

Table 3-141

OPERATION SUPPORT AND REQUIREMENTS
0. 125-Meter High-Dispersion Spectroheliograph
Normal-Incidence Telescope, Solar--
OASF Instrument No. 7

ORDS No.	Time per Observation (hours)	No. of Men	Skill Identification*	Man-hours/ observation	Start Time (hours from start of observation)	Number of Observations
070	0. 02	1	5	0. 05	-0. 03	600
		1	8	0. 01	+48	

*Skills are identified by number in Table 3-3.

Operation

In observations of the plages, exposures will be made in series of one every 10 to 30 sec for 10 min., and then one per hour for 12 hours.

In the corona observations, the telescope field of view covers the entire sun so that all that need be done is to keep the telescope centered on the sun with the aid of the sun sensor. Exposures will be made at the rate of one frame per minute for 20 min.

Scheduled Maintenance

The optical technician inspects the optical surfaces for damage or deterioration and makes changes in modes of observation as may be required. The electro-mechanical technician inspects the plate camera sequencing mechanism for possible sources of failure.

Unscheduled Maintenance

Only a failure of one of the camera mechanisms would be likely to require unscheduled maintenance.

3.2.17.5 Supporting Research and Technology

The 0.125-Meter XUV High Dispersion Spectroheliograph (Instrument No. 7) is a high-dispersion version of the 0.25-m XUV Spectroheliograph (Instrument No. 6) discussed in Section 3.2.12. The difference in performance is derived from the use of a double dispersion spectrograph in place of a single dispersion spectrograph. The use of crossed grating system to increase the dispersion of Spectrographs is a current technique, not requiring appreciable refinement. Thus, the design and fabrication of the single dispersion spectroheliograph (Instrument No. 6) is a stage in the development of the high-dispersion spectroheliograph (Instrument No. 7). The two instruments require identical Supporting Research and Technology (SRT) activity. Full descriptions of SRT items are given in Section 4.3.

Research and Advance Technology

Develop mirror surfaces to provide high-UV reflectivity, precision of figure, and freedom from scattering (SRT 4).

Develop fabrication techniques for non-circular aspherics (SRT 6).

Develop ruling techniques for ruling gratings on aspherics (SRT 9).

Extend the XUV filter technology to provide structurally sturdy transmission filters of about 100 Å bandpass in the wavelength region from 170 Å longward (SRT 10).

Develop techniques to overcome electrostatic charge build-up and fog-producing spark discharge on roll film in hard vacuum (SRT 17).

Develop improved grating ruling techniques and equipment to provide closer ruling spacing and greater uniformity of ruling spacing, blaze angle and surface finish (SRT 38).

Develop criteria for film-transport mechanisms suitable for roll film in hard vacuum to avoid emulsion, cracking, and flaking (SRT 39).

Investigate degradation of telescope detector and reflective surfaces resulting from 0_2 exposure (SRT 42).

Advance Development

Assess materials for internal use to determine if rapid aging and breakdown are caused by internal atmosphere (SRT 82).

Assess materials for external use to evaluate (A) hard vacuum effects on materials, finishes, etc., and (B) development of processing, handling, and assembly techniques (SRT 83).

Supporting Development

Develop image tubes with greater spatial resolution than currently available (SRT 84).

3.2.17.6 Development Cost and Schedules

The Phase D cost is shown in Table 3-142, which shows both development and operations costs. The development schedule is shown in Figure 3-71. Quantities of equipment required in development are shown in Table 3-143.

Table 3-142

TASK COST ESTIMATE--PHASE D
0.125-Meter XUV High-Dispersion Spectroheliograph
Normal-Incidence Telescope, Solar--
(OASF Instrument No. 7)
($ thousands)

Development total	2,385		
Engineering		180	
Detectors		*	
Collecting optics		75	
0.25-m collecting optics (concave grating)			75
Fine guidance (automatic)		400	
Optics			*
Control moment gyroscope			*
Sensor			*
Housing		50	
Structure			50
Experiment sensors		1,000	
Slitless spectroheliograph (plate camera)			1,000
Major hardware articles		630	
Mockup			*
Engineering model			*
Project verification model			*
Qualification model			*
Operations total	1,102		
Flight instrument		716	
Backup flight instrument		286	
Engineering support		100	
Phase D total	3,487**		

*Cost item not derived where overall estimate for instrument is not significantly affected.

**Assumes previous development of 0.25-m spectroheliograph OASF Instrument No. 6; same optics contracts for both instruments.

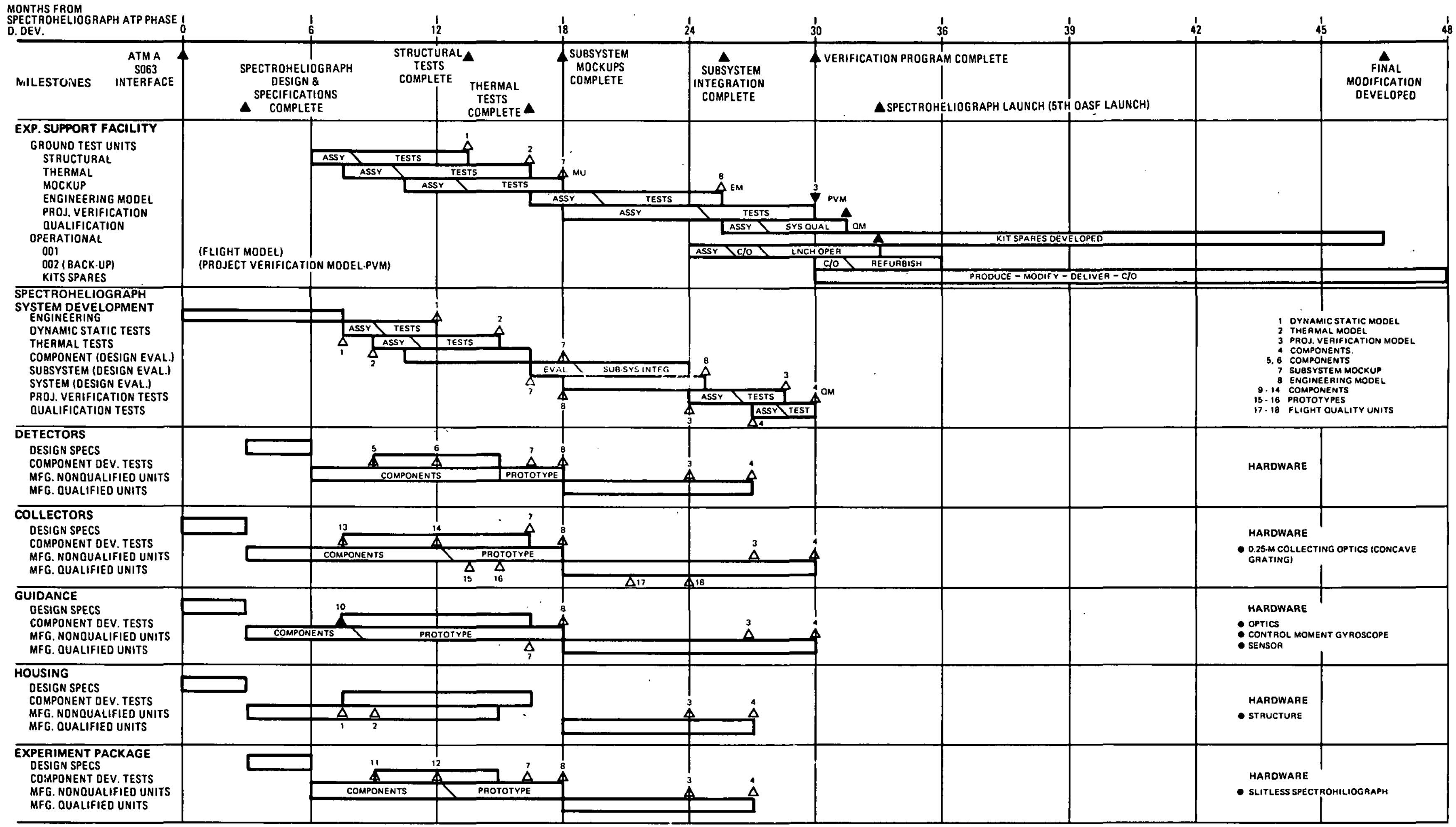

Figure 3-71. Development Schedule, 0.125-Meter XUV High-Dispersion Spectroheliograph Normal-Incidence Telescope, Solar (OASF Instrument No. 7)

Table 3-143

PRIMARY INSTRUMENT EQUIPMENT LIST--DEVELOPMENT PHASE D
0.125-Meter XUV High-Dispersion Spectroheliograph
Normal-Incidence Telescope, Solar--
(OASF Instrument No. 7)

Functional System (Major Element)	Subsystem	Assemblies	Quantity		
			Bread-board	Proto-type	Flight Quality
0.125-meter XUV high-dispersion spectro-heliograph	Detectors	---	---	---	---
	Collecting optics	0.25-m collecting optics (concave grating)	---	1	1
	Fine guidance (auto-matic)	Guidance optics sensor	1	2	2
			1	2	2
		Control moment gyroscope	1	2	2
	Housing	Structure (including optics support)	---	1	2
	Experi-ment sensors	Slitless spectro-heliograph (plate camera)	1	1	1
	Major hardware articles	Mockup	1	---	---
		Engineering model	---	1	---
		Project verification model	---	60%*	40%*
		Qualification model	---	---	1

*Obtained from subsystem development quantities.

Figure 3-70. 0.125-Meter XUV High-Dispersion Spectroheliograph Normal-Incidence Telescope, Solar, OASF Instrument No. 7

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DOUGLAS MISSILE & SPACE SYSTEMS DIVISION

5301 Bolsa Avenue Huntington Beach, California 92646 (714) 897-0311

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