DAC-58141

ORBITAL ASTRONOMY SUPPORT FACILITY (OASF) STUDY

VOLUME I
TECHNICAL SUMMARY

DOUGLAS MISSILE & SPACE SYSTEMS DIVISION

MCDONNELL DOUGLAS CORPORATION

28 JUNE 1968

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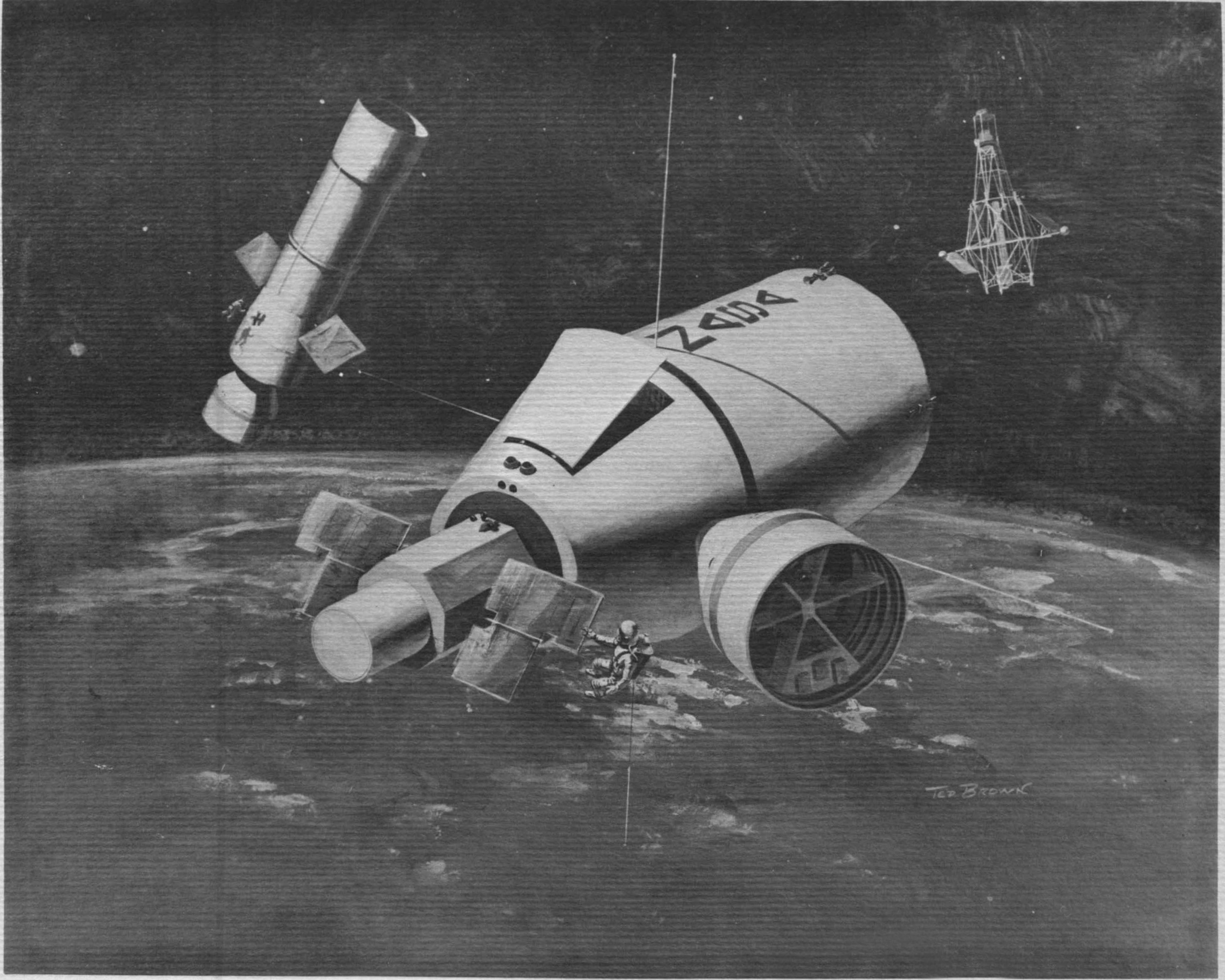
PREPARED BY
H.L. WOLBERS
PROGRAM MANAGER
ADVANCE SPACE AND LAUNCH SYSTEMS

APPROVED BY
T.J. GORDON
DIRECTOR
ADVANCE SPACE AND LAUNCH SYSTEMS

DOUGLAS
MISSILE & SPACE SYSTEMS DIVISION
SANTA MONICA, CALIFORNIA


NASA
TED BROWN

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 first of five and presents the technical summary of the study. The other four volumes (DAC-58142 through DAC-58145) present the detailed results of the study and a discussion of the research and technology implications for orbital astronomy.

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

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 individual 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:

1. The Orbital Astronomy Support Facility Study Final Report: Technical Summary (DAC-58141)

   This volume compactly summarizes the material contained in Volumes 2 through 5.

2. OASF Study Final Report: Task A--Orbital Astronomy Research Requirements (DAC-58142)

   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.

3. OASF Study Final Report: Task B--Instruments for Orbital Astronomy (DAC-58143)

   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.

4. OASF Study Final Report: Task C--Orbital Astronomy Support Facility Concepts (DAC-58144)

   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.

5. OASF Study Final Report: Research and Technology Implications for Orbital Astronomy (DAC-58145)

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

ACKNOWLEDGEMENTS

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 study reflects the combined contributions of many persons in and outside the Douglas Aircraft Company. Special appreciation is extended to Maurice J. Raffensperger and Charles A. Huebner of the NASA Office of Manned Space Flight for their continuing help and guidance during the study.

In addition, valuable contributions were provided by the scientific contributors tabulated below. The list includes astronomers and other scientific and technical personnel affiliated with major astronomical observatories, universities, NASA centers, and industrial research organizations. Individual participation ranged from substantial and detailed contributions throughout the study to brief discussions and reviews of specific issues. Several of the contributors who devoted considerable time and effort are identified as consultants to Douglas.

Progress reports on the OASF Study were presented to members of the NASA Subcommittee for Astronomy (Dr. Nancy G. Roman, Chairman, and Mr. Ernest J. Ott, Secretary) in May, September, and December 1967 and in January 1968. Similar reports were presented for review to members of the NASA Subcommittee for Solar Physics (Dr. Henry J. Smith, Chairman, and Dr. Harold Glaser, Vice-Chairman, prior to July 1967; Dr. Glaser, Chairman, and Mr. James M. Weldon, Secretary, beginning in July 1967) in May, November, and December 1967. Members of the subcommittees provided many useful suggestions and points for guidance during the course of the study.

Although responsibility for any errors or omissions that may have occurred in the study must be borne by Douglas, credit for its merits must be shared with the many scientists who contributed directly to the study and to others whose input was derived from their publications in the scientific literature. All of these contributions are gratefully acknowledged. However, it is not necessarily implied that each scientific contributor concurs in all respects with the results of the OASF Study.

SCIENTIFIC CONTRIBUTORS TO THE OASF STUDY

Contributor	Affiliation
Warren N. Arnquist	Douglas Advanced Research Laboratories
Gordon C. Augason	NASA Ames Research Center
Stanley S. Ballard	University of Florida
Albert Boggess, III	NASA Goddard Space Flight Center
Elihu A. Boldt	NASA Goddard Space Flight Center
Ira S. Bowen*	Mount Wilson and Palomar Observatories
C. West Churchman*	University of California, Berkeley
Arthur D. Code*	University of Wisconsin
Armin J. Deutsch*	Mount Wilson and Palomar Observatories
Dale F. Dickinson	University of California, Berkeley
John W. Evans	Sacramento Peak Observatory
Carl E. Fichtel	NASA Goddard Space Flight Center
David Fischel	NASA Goddard Space Flight Center
Kenneth J. Frost	NASA Goddard Space Flight Center
Riccardo Giacconi	American Science and Engineering, Inc.
Harold Glaser	NASA Headquarters

***Consultant to the Douglas Aircraft Company**

Contributor	Affiliation
Leo Goldberg	Harvard College Observatory
Arnold W. Guess	Douglas Advanced Research Laboratories
Herbert Gursky	American Science and Engineering, Inc.
Freeman F. Hall	Douglas Advanced Research Laboratories
Kenneth L. Hallam	NASA Goddard Space Flight Center
Karl G. Henize	NASA Manned Spacecraft Center
John H. Hill	Douglas Missile and Space Systems Division
Robert F. Howard	Mount Wilson and Palomar Observatories
Lewis Larmore	Douglas Advanced Research Laboratories
Robert B. Leighton*	California Institute of Technology
Willard F. Libby**	University of California, Los Angeles
Frank J. Low*	University of Arizona/Rice University
Raymond H. McFee	Douglas Advanced Research Laboratories
John D. Mangus	NASA Goddard Space Flight Center
Allan Marcus	Bellcomm, Inc.
Nicholas U. Mayall	Kitt Peak National Observatory
Donald H. Menzel*	Harvard College Observatory
Georges J. Michaud*	California Institute of Technology
James E. Milligan	NASA Goddard Space Flight Center
Alan T. Moffet*	California Institute of Technology
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
Nancy G. Roman	NASA Headquarters
Jeffrey D. Scargle*	California Institute of Technology
Sanford B. Schwartz	Douglas Advanced Research Laboratories
Bruce W. Shore	Harvard College Observatory
Philip C. Steffey	Douglas Missile and Space Systems Division
Robert G. Stone	NASA Goddard Space Flight Center
Conrad D. Swanson◊	NASA Marshall Space Flight Center
Alar Toomre*	Massachusetts Institute of Technology
James H. Underwood	NASA Goddard Space Flight Center
Arthur H. Vaughan*	Mount Wilson and Palomar Observatories
Donald K. West	NASA Goddard Space Flight Center
Albert G. Wilson	Douglas Advanced Research Laboratories
Donna Wilson	Douglas Advanced Research Laboratories
Harold Zirin	California Institute of Technology

In the analysis of astronomy instruments, Douglas was assisted by the Kollsman Instrument Corporation of Syosset, New York. Kollsman was responsible for the identification of the generic classes of instruments, including conceptual design, where necessary, and engineering analyses of the instrumentation operating characteristics and development requirements. 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 IR astronomy instruments.

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*Consultant to the Douglas Aircraft Company

**Member of the Douglas Scientific Advisory Council

◊ Deceased.

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INTRODUCTION

The managers and decision makers responsible for guiding this nation's space programs are continually faced with a diversity of alternative courses of action from which they must choose the approaches which appear to offer the greatest potential. These decisions affect the allocation of resources, the implementation and scheduling of programs, and the determination of costs and potential benefits.

During the past 20 years, a battery of explicit planning techniques has been used to aid in cost analysis and benefit optimization (see Volume II). They include cost effectiveness, PERT, scenarios, technological forecasting, and program budgeting. Collectively referred to as "systems analysis," these techniques have proved to be invaluable in weapon systems analysis, policy making, and experimentally in the social sciences where neither costs nor benefits can easily be made quantitative.

According to E. S. Quade of The Rand Corporation, the systems-analysis process generally consists of: (1) definition of objectives, (2) construction of the system model, (3) determination of alternatives, (4) establishment of costs, and (5) articulation of criteria selection (Reference 1). This approach has already been used in many technological disciplines. For the problem at hand, the key scientific research objectives, or the needs of the using agencies, dictate the new knowledge requirements. From these requirements, experimentation objectives can be selected and tested in program models against predetermined criteria. The measurement of costs then leads to the conceptualization of an orbital research program which promises to be efficient and economical. The program definition also includes the identification of supporting research and development, alternative space laboratory and facility concepts, and the interface required with the current and projected operational and ground support capabilities. Only through such a systematic approach can a logical and evolutionary program plan be provided that not only promises to be economically and technically sound, but responsive to the needs of the scientific community.

To accomplish the systematic definition of astronomy program requirements, (See Figure 1), the OASF Study was organized into three major tasks. Task A was the development of a comprehensive baseline research program and the establishment of space-dependent measurements and mission requirements. Task B was the identification of measurement instruments, the conceptual design of new instruments, if needed, and the preparation of development plans for time-phased instrument groups. Task C was the definition of OASF concepts, the specification of the scientific instrument groupings for each concept, and the definition of the operational interface between ground and flight facilities. Critical supporting research and technology development items to support the evolutionary program plan were also identified.

The following pages summarize the methodology and results of the three tasks, the research and technology requirements which appear to warrant further effort, and pertinent conclusions that were reached.

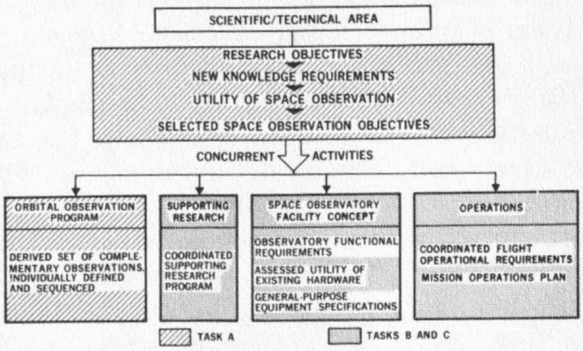

Figure 1. Requirements Analysis

ORBITAL ASTRONOMY RESEARCH REQUIREMENTS (TASK A)

The OASF baseline research program was prepared by a team of specialists using general and specific recommendations from members of the scientific community. The scientific consultants provided the major source of information for the formulation of research requirements. Their recommendations and advice were used to derive specific research objectives and to determine quantitative requirements for observations and measurements. At several points in the period of information generation, progress was reviewed with NASA and the scientific contributors. At all times, a diligent attempt was made to produce a research program scientifically valid for the 1974-to-1990 period on the basis of the present understanding of the universe and the anticipated research needs.

It was tempting at the outset to say simply that future orbiting astronomical observatories should capitalize on the new vantage point; that is, they should contain instruments which would permit observations in the regions of the spectrum opened by virtue of being above the atmosphere. Indeed, a number of the astronomer-consultants took the position that it was impossible to derive a strategy better than simply, "give us a platform stabilized to the highest possible accuracy, containing the most sensitive instruments possible, and let us scan the heavens in the new regions of the spectrum." While a case could be made for this kind of facility, real questions still remained such as priority among alternative astronomy research programs and the relative benefits of instruments of various capabilities.

An approach was therefore sought which, through its logical consistency, would promise to illuminate the issues of priority among alternative research programs, demonstrate the completeness and flexibility of the program selected, and serve to display the contribution of the selected research to the discipline as a whole. Volume II of this report, which explains Task A in more detiail, makes reference to earlier studies which employed a similar program-structuring logic. These were the Douglas study of MORL and the IBM study of ORL Experiments. While this earlier work appeared promising, the study team recognized that it did not deal with questions of research in the basic sciences; hence, it was expected that new challenges would be introduced in the current investigations.

At the start of the work, astronomical objectives were defined in terms of research steps or questions, rather than in terms of physical objects. With fundamental research as the starting point, various subobjectives were established, together with their attendant observation or measurement requirements. These requirements were summarized and documented on Observation Requirement Data Sheets (ORDS). A team of specialists prepared 91 ORDS* using both general and specific recommendations from the many scientific contributors. Approximately 50 parameters were tabulated on each of the special forms. Of these parameters, those considered to be basic in establishing observation requirements were: Epoch Span; Wavelength; Radiation Flux; Number and Frequency of Observations; Angular Field of View; Angular Resolution; and Accuracy of Data Required. Other entries were mission-oriented or represented initial estimates of data and of instrument characteristics. These estimates were iterated and augmented during the study to achieve a more refined set of observation parameters.

The ORDS described measurements across the electromagnetic spectrum except for two regions. One region was the sector from approximately 1 cm to 20 m in wavelength. This sector was not examined in depth because of the general transparency of the atmosphere in this spectral region. Similarly, it was believed that adequate data in the millimeter and submillimeter regions could be obtained at much lower cost by using ground and aircraft observations.

While the requirements summarized on the data sheets can be considered valid examples of potential orbital astronomy activities, they must not be construed either as research proposals or as an exhaustive grouping of potential orbital observations. Nevertheless, the measurement descriptions were sufficiently detailed to provide the initial analysis of needs for instrumentation and support facilities and for identification of necessary technological advances (Tasks B and C).

Because it was recognized that the ORDS exercise was merely representative of a potential orbital astronomy program and did not provide the opportunity of testing completeness of the program or deriving priorities, a parallel investigation of methods of logical structuring was conducted; this investigation is summarized in Volume II of this report. Briefly, four methods of analysis were inves-

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*See Appendix B of Volume II – Part I.

tigated: an "object-oriented" approach, based on the system described by Churchman, Ackoff, and Arnoff (Reference 2); a morphological or "parametric matrix" approach patterned after Zwicky's work wherein particular parameters of interest such as angular resolution and spectral bands, were related to the astronomical bodies (Reference 3); a "consensus approach" to define "burning issues" of astronomy (Reference 4); and finally a "research-oriented relevance tree." This final approach differed from the earlier concepts in that it recognized the necessity of articulating the relationship between the theoretical and the experimental branches of the discipline. In effect, the earlier methods yielded only a systematic cataloging of potential experiments and observations with little cohesive structure to indicate logical relationships among experiments. This missing intrastructure represented the connection among the theories, the hypothesis, the models of the discipline, and the experimental programs which evolve from these concepts.

The theoretical line of the research-oriented approach consisted of statements of the paradigms of the discipline and revision and refinement to these as new data are derived by experiments. The experimental branch consisted of a spectrum of potentially feasible experiments within the limits set by currently held views of the discipline. Clearly, there is an adaptive feedback between theoretical and experimental considerations in which new or unexpected experimental data cause theory revision and revised theories suggest new experimental domains. This is illustrated in Figure 2.

This model was applied to astronomy, labeling the theoretical model-building aspects: "definition of the origin and future of the universe" (evolution) and "establishment of principles of change and order of the universe" (laws). The experimental branch was called "observation of the present characteristics (state) of the universe." This breakdown served as the top level of the final relevance tree format and was used in the form shown in Figure 3.

These three categories represent three points of departure for the discipline. Taken together they fully define its present state of knowledge and are capable of being expanded to include new knowledge as it is collected. The division among these points of departure is coincident with the contemporary subdisciplines of astronomy: cosmology and cosmogeny; observational astronomy; and astrophysics. This breakdown of evolution, state, and laws of order apparently has general application to relevance-tree structuring of many other scientific disciplines.

To move from these top-level questions to a statement of the requirements of research programs necessitated the development of logic processes which were peculiar to the theoretical and experimental domains. As indicated earlier, the state column (experimental) involves the generation of a relatively complete set of potentially feasible observation and experiment requirements within the constraints of currently held astronomical models. An example of the particular logic used is shown in Figure 4. At the lowest level of this chart, some 3,000 potential measurement requirements were identified. These research objectives, as with Kuhn's "normal science" (Reference 5) were generally devoted to increasing the precision of astronomical constants, to comparing the results of observation with those forecasted by the discipline's working

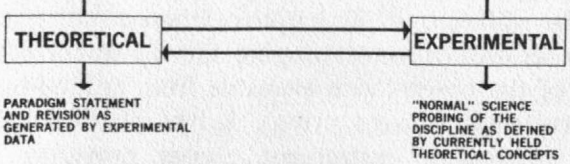

Figure 2. Intrastructure of Research

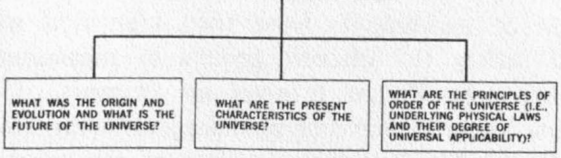

Figure 3. Objective Approach

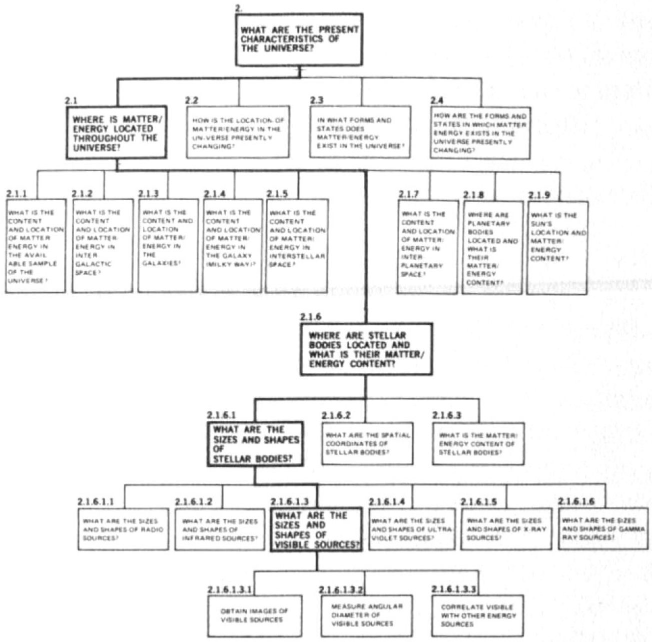

Figure 4. Selected Subobjectives, Including Present Characteristics of Universe

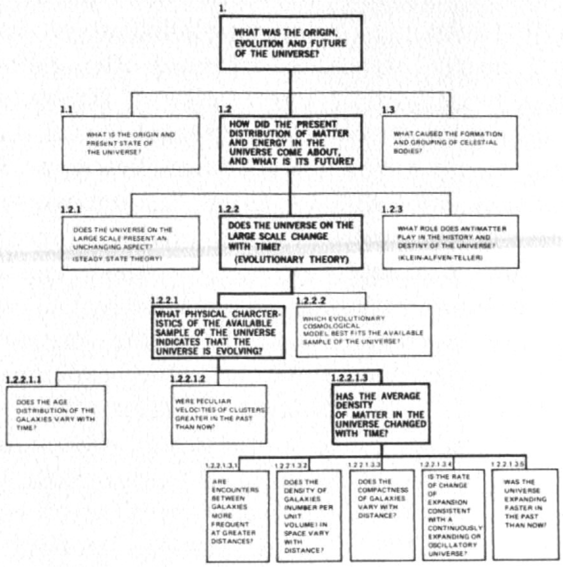

Figure 5. Selected Subobjectives, Including Evolution of Universe

paradigms, and to refining and articulating the paradigms.

The theoretical lines (the origin and evolution of the universe and the laws of change) required the development of a different sort of logic. Here the plan moved from articulation of operational theories, to statement of consequences of the theory, to development of critical tests of the theory. Figure 5 is a simplified illustration of the derivation used. If complete, this structure would index all of the theories under test in the discipline and the crucial tests which would establish their superiority over competing concepts. In the OASF Study, it was estimated that 1,000 crucial tests could have been defined.

Although it was clearly beyond the scope of the study to develop this epistemological approach beyond the point indicated above, the analysis was carried far enough to indicate the powerful tool which it could provide for research program planning and the tremendous potential of further work in this area. The analysis did provide valuable insights for the study team and helped them structure the measurements derived from the Observation Requirement Data Sheets (ORDS) into a more usable form for the Task B effort.

INSTRUMENTS FOR ORBITAL ASTRONOMY (TASK B)

The measurement requirements defined in the ORDS were grouped into classes according to the degree of similarity of their characteristics. Generic classes of instruments were then identified which could satisfy the discrete groups of measurement requirements. Figure 6 gives an example of this process using stellar and planetary observations for the IR, visible, and UV portions of the spectrum. Each vertical line indicates the wavelength range and the angular resolution required in one of the ORDS; the dot indicates the wavelength at which the angular resolution was specified. Study of the groupings of observation requirements with respect to the diffraction limitations inherent in optical telescope performance (sloping lines) and consideration of the observations available from ground-based observatories (shaded areas), led to the identification of general instrument classes providing the specified capabilities. The considerations illustrated were the first step in a selection process that eventually let to the suggestion for four types of instruments for IR, visible, and UV measurements:

A. A wide-angle telescope (0.3-m UV Schmidt)* 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, and capable of being upgraded with an advanced version (1-m) in later years for more advanced sky-survey requirements.

B. A telescope of large aperture but less than the highest quality optics (1-m, non-diffraction-limited, UV-visible)* to provide adequate capability for significant spectrographic observation in the UV region and for some UV imaging.

C. A large-aperture, high-quality-optics telescope (1-m, diffraction-limited, UV-visible-IR)* for observations with a finer angular resolution than possible from ground-based telescopes in the visible region, and for fine-angular-resolution observations in the UV.

D. A very-large-aperture telescope (3-m, diffraction-limited, UV-visible-IR)* to extend the angular resolution of both visible and UV observations, which is a generation later than the 1-m diffraction-limited telescope.

Similar analyses which were conducted for each of the other measurement areas involved a preliminary consideration of over 60 different instruments. NASA-furnished information on instrument concepts and designs was used where possible to take advantage of experience from previous and current design activities; where no data existed, new instrument designs were conceived.

The study team reviewed the instrument designs with scientific contributors and instrument specialists. As a result of these discussions, more promising design approaches were made possible and many design criteria derived from the consultants' collective experience were included; consequently, 29 generic instrument types were defined which are considered as meeting projected orbital observation requirements through the 1990 period.

It was found useful to divide the instrument classes into two time-phased generations of instrument development based on (1) projection of development times starting from current technology, and (2) the successor-predecessor relationships of observation programs established in the research requirements phase of the study (Task A).

The first Apollo Telescope Mount (ATM) mission was assumed to be implemented in the early 1970's. Because the ATM effort has been already defined, the OASF Study emphasized the intermediate period (1974 to 1979, i.e., post-ATM) and a late period (1980 to 1990). During the intermediate period, a 1- to 2-year mission space station was assumed to be operational; in the late period, a 5-year, extended-life space station was assumed. Figure 7 summarizes the 29 generic instrument types and Table 1 describes their characteristics.

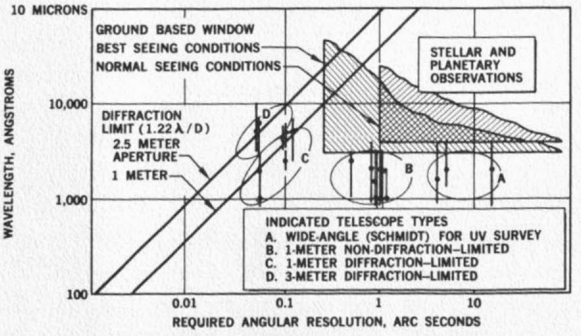

Figure 6. Observation Commonality Assessment

		1974-1980 INTERMEDIATE TIME PERIOD (POST ATM)		1980-1990 LATE TIME PERIOD	
RADIO TELESCOPES		(32) CROSSED H TETHERED INTERFEROMETER OR (30) TERMINATED LOOP TETHERED INTERFEROMETER		(ADVANCED VERSIONS OF INTERFEROMETRIC INSTRUMENTS) (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) 0.175-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) 75-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	

(THE INSTRUMENT IDENTIFICATION NUMBERS ARE IN PARENTHESIS. SEE TABLE 1.)

Figure 7. OASF Time-Phased Instrument Groups

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*The dimensions listed are apertures.

The instruments considered in the study fell into three general classes: radio telescopes, optical telescopes, and radiation counters. Only the optical telescopes focus radiated energy in the normal sense: they collect and redirect this energy in an organized manner into some instrument that can extract information from it. Generally, radio telescopes integrate the effects of radiated energy incident upon the antennas. Radiation counters do not meaningfully change the direction of the high-energy radiation; they identify (count) radiation pulses that fall into specified ranges of energy level and direction of approach, and reject those that do not.

Optical telescopes can logically be divided into two categories, normal incidence and grazing incidence. The former are satisfactory in the IR and visible regions and in a portion of the UV region, but reflectivity falls off drastically as the X-ray region is approached. In the X-ray and the extreme UV (XUV) regions, satisfactory reflectivity can be achieved only if the radiation strikes a reflective surface at a grazing angle, which gives rise to grazing-incidence telescopes, a relatively new area of technology.

Of the 29 generic instruments identified in Table 1, 22 were based on current instrument-development activities. In the intermediate period, 15 of the 19 instruments had counterparts in current development activities. To provide the information required for Task C, each instrument in the time-phased groups had to be brought to a fairly uniform level of conceptual design. As appropriate, instruments based on known designs were adapted or modified or new conceptual designs were provided. During the conceptual design process, provision for crew participation in the in-orbit operation of the instruments was reflected in the designs wherever this was judged to provide the greatest effectiveness.

Volume III of this report includes data packages for each instrument; each package contains specific parametric information on collectors, space-station interface characteristics, guidance and control requirements, and instrumentation capabilities. Also included is information on current status, mission limitations, operational demands, human factors considerations, requirements for supporting research and technology, and estimates of development schedules and development costs. Working size drawings of the instruments were prepared and delivered to NASA.

Analysis of crew operation of various instruments (see Figure 8) indicates a significant role for man in the astronomy program. Crew members are expected to participate in orbital astronomy operations with all instruments, but to varying degrees. Radio telescopes are essentially automatic; however, man may prove valuable for corrective or periodic maintenance and modifications. With optical telescopes, man is involved in nearly all functions; i.e., from updating or retrofitting sensors or changing film cassettes, to locating specific observational objectives such as areas of high solar activity. The crew may not be required for operating and monitoring radiation counters.

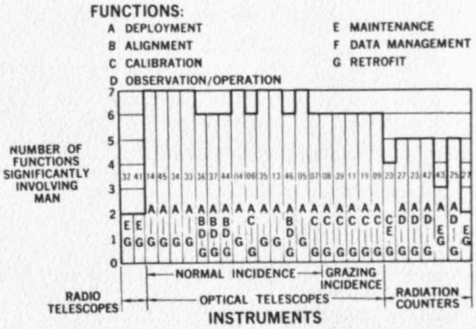


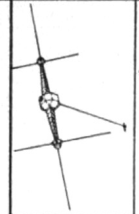
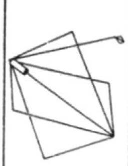
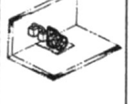
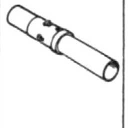
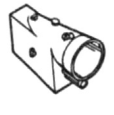
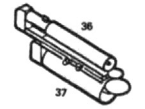
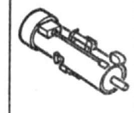
Figure 8. Crew Participation

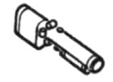
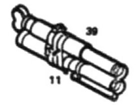
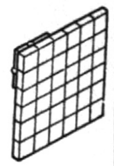
ORBITAL ASTRONOMY SUPPORT FACILITY CONCEPTS (TASK C)

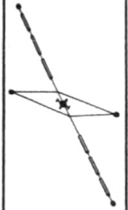
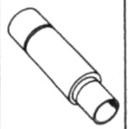
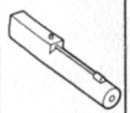
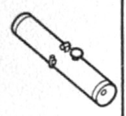
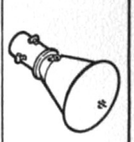
Douglas, together with NASA, developed an assumed schedule for certain generic classes of space stations. This mission plan forecast is illustrated in Figure 9. This program model was used as a basis for testing various approaches for satisfying astronomy objectives.

Table 1

ASTRONOMY INSTRUMENT DATA SUMMARY

		INTERMEDIATE TIME PERIOD									
INSTRUMENT CATEGORY		RADIO TELESCOPES		OPTICAL TELESCOPE							
				NORMAL INCIDENCE							
				STELLAR				SOLAR			
INSTRUMENT NAME		CROSSED-H TETHERED INTERFEROMETER	TERMINATED-LOOP TETHERED INTERFEROMETER	1-METER INFRARED	1-METER NON-DIFF-LIM UV-VIS-IR	1-METER DIFF-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)
											
INSTRUMENT NUMBER		32	30	14	45	34	33	36	37	44	04
APPLICABLE AREA OF ASTRONOMY		LONG-WAVE RADIO IMAGERY, SPECTROSCOPY, AND POLARIMETRY	LONG-WAVE RADIO IMAGERY, SPECTROSCOPY, AND POLARIMETRY	IR SPECTROSCOPY	UV IMAGERY AND SPECTROSCOPY	PLANETARY PHOTOGRAPHY AND STELLAR SPECTROSCOPY	UV SKY SURVEY	PHOTOGRAPHY OF CORONA FROM 1 TO 6 SOLAR RADII	PHOTOGRAPHY OF CORONA FROM 5 TO 30 SOLAR RADII	UV-VISIBLE IMAGERY AND SPECTROSCOPY	XUV SPECTROSCOPY
COLLECTOR	APERTURE	10 km	40 km	1.0 m	1.0 m	1.0 m	0.3 m	0.0245 m	0.040 m	0.8 m	0.2 m
	EFFECTIVE FOCAL LENGTH	N/A	N/A	10.0 m	5.0 m	10.2 m	0.91 m	0.315 m	0.090 m	39.2 m	2.4 m
	EFFECTIVE COLLECTING AREA	N/A	N/A	7,050 cm^2	6,290 cm^2	6,930 cm^2	706 cm^2	4.48 cm^2	11.9 cm^2	4,280 cm^2	315 cm^2
	SPECTRAL RANGE	0.5 MHz TO 10 MHz	0.05 MHz TO 15 MHz	0.7 μ TO 1,000 μ	<900 Å TO >12,000 Å	900 Å TO 6,000 Å	1,000 Å TO >2,000 Å	4,000 Å TO 10,000 Å	4,000 Å TO 10,000 Å	1,200 Å TO 10,000 Å	300 Å TO >1,500 Å
	ANGULAR RESOLUTION	1.7°	1°	1 $\widehat{SEC}$ AT 4 μ	0.2 $\widehat{SEC}$ AT 4,000 Å	0.1 $\widehat{SEC}$ AT 4,000 Å	0.25 $\widehat{SEC}$ AT 1,200 Å	10 $\widehat{SEC}$ AT 5,000 Å	30 $\widehat{SEC}$ AT 5,000 Å	0.16 $\widehat{SEC}$ AT 5,000 Å	1 $\widehat{SEC}$ AT 800 Å
	FINE GUIDANCE RESOLUTION	N/A	N/A	± 0.1 $\widehat{SEC}$	± 0.05 $\widehat{SEC}$	± 0.01 $\widehat{SEC}$	± 0.5 $\widehat{SEC}$	± 5 $\widehat{SEC}$		± 0.02 $\widehat{SEC}$	± 0.1 $\widehat{SEC}$
	FIELD OF VIEW	130° X 90°	130° X 90°	5 $\widehat{MIN}$	10 $\widehat{MIN}$	2 $\widehat{MIN}$	10°	3.25°	15°	2.6 $\widehat{MIN}$	2 $\widehat{MIN}$
	TOTAL SIGNAL COUNT	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	EXPECTED COUNT IN TOTAL BAND	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	SPECTRAL RESOLUTION	50 KHz	50 KHz	16 Å AT 4 μ	0.2 Å AT 2,000 Å	0.1 Å AT 2,000 Å	2Å AT 1,200 Å	N/A	N/A	0.01Å AT 3,000 Å	0.2 Å AT 300 Å
COLLECTOR WITH INSTRUMENTATION DEVICES	LENGTH, STOWED POSITION	3.3 m; 10.8 FT	2.4 m; 7.9 FT	1.75 m; 5.75 FT (EXCLUDING SHIELD)	2.8 m; 9.2 FT	2.7 m; 8.8 FT	3.1 m; 10.1 FT	3.7 m; 12.15 FT	2.8 m; 9.2 FT	3.6 m; 11.8 FT	3.6 m; 11.8 FT
	VOLUME, STOWED POSITION	10 m^3; 353 FT^3	0.75 m^3; 26.4 FT^3	50 m^3; 1,760 FT^3 (INCLUDING SHIELD)	3.5 m^3; 124 FT^3	4.1 m^3; 145 FT^3	2.5 m^3; 88 FT^3	COMBINED 2.3 m^3; 81 FT^3		3.3 m^3; 115 FT^3	1.6 m^3; 56.5 FT^3
	WEIGHT	1,900 kg; 4,200 LB	1,450 kg; 3,200 LB	1,000 kg; 2,200 LB (INCLUDING SHIELD)	1,000 kg; 2,200 LB	240 kg; 530 LB	430 kg; 950 LB	COMBINED 400 kg; 880 LB		800 kg; 1,760 LB	65 kg; 143 LB
INSTRUMENTATION DEVICES		SWEPT-FREQUENCY RADIOMETRY RECEIVER WIDE-BAND RADIOMETRY RECEIVER	SWEPT-FREQUENCY RADIOMETRY RECEIVER WIDE-BAND RADIOMETRY RECEIVER	INTERFEROMETER RADIOMETER SOLID-STATE DETECTOR MATRIX MAGNETIC TAPE RECORDER	NORMAL-INCIDENCE SPECTROGRAPH ECHELLE SPECTROGRAPH SLITLESS SPECTROGRAPH PLATE CAMERA IMAGE INTENSIFIER SPECTROPHOMETER	ECHELLE SPECTROGRAPH 20-POWER RELAY LENS S.E.C. VIDICON	NORMAL-INCIDENCE SPECTROGRAPH PLATE CAMERA FILTER ASSEMBLY	CINE FRAME CAMERA, 35 mm	CINE FRAME CAMERA, 35mm	ECHELLE SPECTROGRAPH NARROW-BAND LYOT FILTER CINE FRAME CAMERA, 35 mm	NORMAL INCIDENCE SPECTROGRAPH PLATE CAMERA
INSTRUMENT ACTIVITY FROM WHICH DERIVED		LARGE SPACE STRUCTURES EXPERIMENT STUDY	(NEW)	(NEW)	GODDARD EXPERIMENT PACKAGE (GEP)	ADVANCED PRINCETON SATELLITE (APS)	NORTHWESTERN UNIVERSITY SCHMIDT	ATM EXPERIMENT S052	ATM EXPERIMENT S052	ATM SOLAR TELESCOPE (JPL)	ATM EXPERIMENT S055
DEVELOPMENT PREREQUISITES		CROSSED-H CONCEPT STUDIES	CROSSED-H CONCEPT STUDIES	APS STUDIES 1-M NON-DIFF-LIM INSTR NO. 45	STELLAR ATM (MAST)	APS STUDIES 1-M NON-DIFF-LIM INSTR NO. 45	NORTHWESTERN UNIVERSITY SCHMIDT STUDIES	ATM EXPERIMENT S052	ATM EXPERIMENT S052	ATM SOLAR TELESCOPE (JPL)	ATM EXPERIMENT S055
DEVELOPMENT (PHASE D) COST		$39.2 MILLION	$34.5 MILLION	$6.3 MILLION	$15.7 MILLION	$9.8 MILLION	$4.9 MILLION	$1.9 MILLION	$4.3 MILLION	$10.0 MILLION	$3.3 MILLION
CRITICAL SUPPORTING RESEARCH AND TECHNOLOGY		—	—	DETECTOR MOUNTINGS DETECTOR CRYOGENIC COOLING (1.5°K)	—	DIFFRACTION-LIMITED-QUALITY OPTICS	FABRICATION OF NONCIRCULAR ASPHERICS	—	—	—	HIGH-REFLECTIVE COATINGS FOR XUV FABRICATION OF NON-CIRCULAR ASPHERICS

		INTERMEDIATE TIME PERIOD								
INSTRUMENT CATEGORY		OPTICAL TELESCOPE				RADIATION COUNTERS				
		NORMAL INCIDENCE	GRAZING INCIDENCE							
		SOLAR								
INSTRUMENT NAME		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
										
INSTRUMENT NUMBER		06	08	39	11	20	22	23	42	43
APPLICABLE AREA OF ASTRONOMY		XUV SPECTROHELIOGRAPHY	XUV HIGH RESOLUTION SPECTROSCOPY	X-RAY IMAGERY OF SOLAR FLARES	X-RAY SPECTROSCOPY OF SOLAR FLARES	X-RAY SKY SURVEY AND SPECTROSCOPY	X-RAY SKY SURVEY AND SPECTROSCOPY	GAMMA RAY SPECTROSCOPY AND PHOTOMETRY	GAMMA RAY SPECTROSCOPY AND PHOTOMETRY	GAMMA RAY SKY SURVEY AND SPECTROSCOPY
COLLECTOR	APERTURE	0.25 m	0.25 m	0.25 m	0.225 m	N/A	N/A	N/A	N/A	N/A
	EFFECTIVE FOCAL LENGTH	3.0 m	3.0 m	2.4 m	2.4 m	N/A	N/A	N/A	N/A	N/A
	EFFECTIVE COLLECTING AREA	490 cm^2	125 cm^2	50 cm^2	20 cm^2	1.3 X 10^5 cm^2	300 cm^2	100 cm^2	100 cm^2	230 cm^2
	SPECTRAL RANGE	170 Å TO 750 Å	170 Å TO >650 Å	2 Å TO 10 Å	1 Å TO 40 Å	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
	ANGULAR RESOLUTION	1 $\widehat{SEC}$ AT 170 Å	2.5 $\widehat{SEC}$ AT 300 Å	5 $\widehat{SEC}$ AT 6 Å	5 $\widehat{SEC}$ AT 6 Å	1°	3°	3°	3°	2.5°
	FINE GUIDANCE RESOLUTION	± 0.02 $\widehat{SEC}$	± 0.1 $\widehat{SEC}$	± 1 $\widehat{SEC}$		± 3.3 $\widehat{SEC}$	± 1 $\widehat{MIN}$	± 1 $\widehat{MIN}$	± 5 $\widehat{MIN}$	± 30 $\widehat{SEC}$
	FIELD OF VIEW	32 $\widehat{MIN}$	2 $\widehat{MIN}$	30 $\widehat{MIN}$	10 $\widehat{MIN}$	3°	6°	6°	6°	60°
	TOTAL SIGNAL COUNT	N/A	N/A	N/A	N/A	10^4 PHOTON · SEC^{-1} · keV^{-1}	3 X 10^{-2} PHOTON-SEC^{-1} · keV^{-1}	10^{-6} PHOTON · SEC^{-1} · keV^{-1}	10^{-6} PHOTON · SEC^{-1} · keV^{-1}	10^{-8} PHOTON · SEC^{-1} · keV^{-1}
	EXPECTED COUNT IN TOTAL BAND	N/A	N/A	N/A	N/A	600 PHOTON/SEC TO 5 X 10^5 PHOTON/SEC	10 PHOTON/SEC TO 10^4 PHOTON/SEC	0.02 PHOTON/SEC TO 2 PHOTON/SEC	0.02 PHOTON/SEC TO 2 PHOTON/SEC	10^{-2} PHOTON/SEC TO 1 PHOTON/SEC
	SPECTRAL RESOLUTION	0.015 Å AT 170Å	0.5 Å AT 300 Å	N/A	0.1 Å AT 3 Å	10% AT 10 keV	20% AT 50 keV	8% AT 600 keV	5% AT 1 MeV	35% AT 100 MeV
COLLECTOR WITH INSTRUMENTATION DEVICES	LENGTH, STOWED POSITION	3.4 m; 11.3 FT	3.2 m; 10.4 FT	3.1 m; 10.2 FT	2.9 m; 9.7 FT	4.3 m; 14.1 FT	1.5 m; 4.9 FT	1.2 m; 3.9 FT	1.0 m; 3.3 FT	1.5 m; 4.9 FT
	VOLUME, STOWED POSITION	3 m^3; 106 FT^3	0.44 m^3; 15.5 FT^3	COMBINED 0.65 m^3; 23.0 FT^3		8.8 m^3; 310 FT^3	0.65 m^3; 23.0 FT^3	0.84 m^3; 29.6 FT^3	0.4 m^3; 14.1 FT^3	0.5 m^3; 17.6 FT^3
	WEIGHT	300 kg; 660 LB	85 kg; 187 LB	COMBINED 80 kg; 176 LB		2,700 kg; 5,950 LB	290 kg; 640 LB	300 kg; 660 LB	200 kg; 440 LB	90 kg; 198 LB
INSTRUMENTATION DEVICES		SLITLESS SPECTROHELIOGRAPH PLATE CAMERA	GRAZING-INCIDENCE SPECTROGRAPH PLATE CAMERA, GRAZING INCIDENCE	CINE FRAME CAMERA, 35 mm X-RAY IMAGE INTENSIFIER PLUS VIDICON	CRYSTAL SPECTROMETER X-RAY GRAZING INCIDENCE SPECTROMETER	N/A	N/A	N/A	N/A	N/A
INSTRUMENT ACTIVITY FROM WHICH DERIVED		ATM EXPERIMENT S053	(NEW)	ATM EXPERIMENT S056	(NEW)	EMR EXPERIMENT NO. 9	EMR EXPERIMENT NO. 3	EMR EXPERIMENT NO. 5	EMR EXPERIMENT NO. 5	EMR EXPERIMENT NO. 8
DEVELOPMENT PREREQUISITES		ATM EXPERIMENT S053	ATM EXPERIMENTS S054 AND S056	ATM EXPERIMENT S056	ATM EXPERIMENT S054 OR S056	EMR EXPERIMENT NO. 9	EMR EXPERIMENT NO. 3	EMR EXPERIMENT NO. 5	EMR EXPERIMENT NO. 5	EMR EXPERIMENT NO. 8
DEVELOPMENT (PHASE D) COST		$3.5 MILLION	$5.7 MILLION	$4.5 MILLION	$4.8 MILLION	$2.8 MILLION	$2.8 MILLION	$2.1 MILLION	$2.1 MILLION	$6.3 MILLION
CRITICAL SUPPORTING RESEARCH AND TECHNOLOGY		FINE-RULING-FREQUENCY DIFFRACTION GRATINGS RULING OF GRATINGS ON ASPHERICS HIGH-REFLECTIVE COATING OF XUV FABRICATION OF NON-CIRCULAR ASPHERICS	GRAZING INCIDENCE ALIGNMENT TECHNIQUES	GRAZING INCIDENCE IMAGING ANALYSIS X-RAY GRAZING INCIDENCE SURFACE FINISHES	X-RAY GRAZING INCIDENCE SURFACE FINISHES	—	—	—	—	—

		LATE TIME PERIOD									
INSTRUMENT CATEGORY		RADIO TELESCOPE	OPTICAL TELESCOPES							RADIATION COUNTERS	
			NORMAL INCIDENCE					GRAZING INCIDENCE			
			STELLAR		SOLAR			STELLAR	SOLAR		
INSTRUMENT NAME		KILOMETER WAVE ORBITING TELESCOPE (KWOT)	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		41	35	13	46	05	07	19	09	25	27
APPLICABLE AREA OF ASTRONOMY		LONG-WAVE RADIO IMAGERY, SPECTROSCOPY, AND POLARIMETRY	IMAGERY AND SPECTROSCOPY OF FAINT SOURCES	UV SKY SURVEY	UV-VISIBLE IMAGERY AND SPECTROSCOPY	XUV SPECTROSCOPY	XUV SPECTROHELIOGRAPHY	X-RAY IMAGERY AND SPECTROSCOPY	XUV HIGH RESOLUTION SPECTROSCOPY	X-RAY AND GAMMA RAY SPECTROSCOPY AND PHOTOMETRY	COSMIC RAY FLUX, SPECTROSCOPY, AND POSITRON/ELECTRON RATIO
COLLECTOR	APERTURE	10 km	3.04 m	1.0 m	1.5 m	0.5 m	0.125 m	1.0 m	0.5 m	N/A	N/A
	EFFECTIVE FOCAL LENGTH	N/A	45 m	4.0 m	75 m	6.0 m	2.5 m	10.0 m	6.0 m	N/A	N/A
	EFFECTIVE COLLECTING AREA	N/A	63,200 cm^2	7,850 cm^2	17,200 cm^2	1,360 cm^2	122 cm^2	500 cm^2	500 cm^2	1,000 cm^2	500 cm^2
	SPECTRAL RANGE	0.1 MHz TO 10 MHz	900 Å TO 12,000 Å	1,000 Å TO 5,000 Å	<1,300 Å TO >12,000 Å	170 Å TO > 1,500 Å	304 Å TO 1,216 Å	2 Å TO 100 Å	170 Å TO > 650 Å	10 keV TO 20 MeV	20 MeV TO 100 GeV
	ANGULAR RESOLUTION	1.7°	0.04 $\widehat{SEC}$ AT 5,000 Å	0.1 $\widehat{SEC}$ AT 4,000 Å	0.1 $\widehat{SEC}$ AT 6,200 Å	0.5 $\widehat{SEC}$ AT 800 Å	1 $\widehat{SEC}$ AT 600 Å	5 $\widehat{SEC}$ AT 6 Å	0.5 $\widehat{SEC}$ AT 300 Å	3°	8 $\widehat{MIN}$
	FINE GUIDANCE RESOLUTION	N/A	± 0.005 $\widehat{SEC}$	± 0.05 $\widehat{SEC}$	± 0.05 $\widehat{SEC}$	± 0.05 $\widehat{SEC}$	± 0.02 $\widehat{SEC}$	± 0.25 $\widehat{SEC}$	± 0.02 $\widehat{SEC}$	N/A	± 15 $\widehat{SEC}$
	FIELD OF VIEW	80°	15 $\widehat{MIN}$	5°	1.1 $\widehat{MIN}$	2 $\widehat{MIN}$	10 $\widehat{MIN}$	10 $\widehat{MIN}$	2 $\widehat{MIN}$	6°	60°
	TOTAL SIGNAL COUNT	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	10^{-5} PHOTON SEC^{-1} · keV^{-1}	10^{-5} PARTICLE SEC^{-1} · MeV^{-1}
	EXPECTED COUNT IN TOTAL BAND	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2 PHOTON/SEC TO 20 PHOTON/SEC	0.05 ELECTRON/SEC TO 50 ELECTRON/SEC AT 0.1 GeV
	SPECTRAL RESOLUTION	NOT AVAIL.	0.5 Å AT 2,000 Å	N/A	0.002 Å AT 3,000 Å	0.02 Å AT 800 Å	0.015 Å AT 600 Å	6% AT 2Å	0.1 Å AT 304 Å	3 keV AT 1 MeV 8 keV AT 20 MeV	10% AT 1 GeV
COLLECTOR WITH INSTRUMENTATION DEVICES	LENGTH, STOWED POSITION	3.1 m; 10.2 FT	15.6 m; 51.2 FT	9.1 m; 29.6 FT	12.3 m; 40.4 FT	9 m; 29.6 FT	3.4 m; 11.3 FT	5.7 m; 18.8 FT	6.4 m; 21.0 FT	1.2 m; 3.9 FT	3.7 m; 12.1 FT
	VOLUME, STOWED POSITION	1.5 m^3; 53.5 FT^3	270 m^3; 9,520 FT^3	53 m^3; 1,870 FT^3	32.5 m^3; 1,150 FT^3	10.8 m^3; 38.1 FT^3	3 m^3; 106 FT^3	200 m^3; 7,050 FT^3	2.3 m^3; 81 FT^3	0.4 m^3; 14.1 FT^3	9 m^3; 318 FT^3
	WEIGHT	640 kg; 1,410 LB	12,000 kg; 26,500 LB	930 kg; 2,050 LB	1,600 kg; 3,530 LB	1,800 kg; 3,970 LB	320 kg; 710 LB	1,220 kg; 2,690 LB	400 kg; 880 LB	350 kg; 770 LB	800 kg; 1,760 LB
INSTRUMENTATION DEVICES		WIDE-BAND RADIOMETRY RECEIVER	NORMAL-INCIDENCE SPECTROGRAPH PLATE CAMERA FILTER ASSEMBLY 2-POWER FIELD LENS VIDICON	PLATE CAMERA FILTER ASSEMBLY	ECHELLE SPECTROGRAPH NARROW-BAND LYOT FILTER PLATE CAMERA MAGNETOGRAPH	NORMAL-INCIDENCE SPECTROGRAPH SLITLESS SPECTROHELIOGRAPH PLATE CAMERA	SLITLESS SPECTROHELIOGRAPH PLATE CAMERA	PLATE CAMERA, GRAZING INCIDENCE CRYSTAL SPECTROMETER X-RAY IMAGE INTENSIFIER CHANNEL SPECTROMETER	GRAZING INCIDENCE SPECTROGRAPH PLATE CAMERA, GRAZING INCIDENCE	N/A	N/A
INSTRUMENT ACTIVITY FROM WHICH DERIVED		KWOT	MANNED ORBITAL TELESCOPE (MOT)	(NEW)	ATM SOLAR TELESCOPE (JPL)	ATM EXPERIMENT S055	ATM EXPERIMENT S053	LARGE SPACE STRUCTURES EXPERIMENT STUDY	(NEW)	EMR EXPERIMENT NO. 7	(NEW)
DEVELOPMENT PREREQUISITES		KWOT FEASIBILITY STUDIES	MOT FEASIBILITY STUDIES 1-M DIFF-LIM INSTR NO. 34	0.3-M SCHMIDT INSTR NO. 33	0.8-M SOLAR INSTR NO. 44	ATM EXPERIMENT S055 0.2-M (OFF-AXIS) INSTR NO. 4	ATM EXPERIMENT S053 0.25-M SP'HEL'GRAPH INSTR NO. 6	X-RAY TELESCOPE STUDIES 0.25-M X-RAY INSTR NO. 39	ATM EXPERIMENTS S054 AND S056 0.25-M XUV INSTR NO. 8	EMR EXPERIMENT NO. 7	FEASIBILITY STUDIES
DEVELOPMENT (PHASE D) COST		$118.3 MILLION	$258.6 MILLION	$34.7 MILLION	$8.6 MILLION	$5.9 MILLION	$3.5 MILLION	$6.8 MILLION	$6.6 MILLION	$1.7 MILLION	$2.0 MILLION
CRITICAL SUPPORTING RESEARCH AND TECHNOLOGY		—	LARGE DIFFRACTION-LIMITED-QUALITY OPTICS	—	—	—	—	—	—	—	—

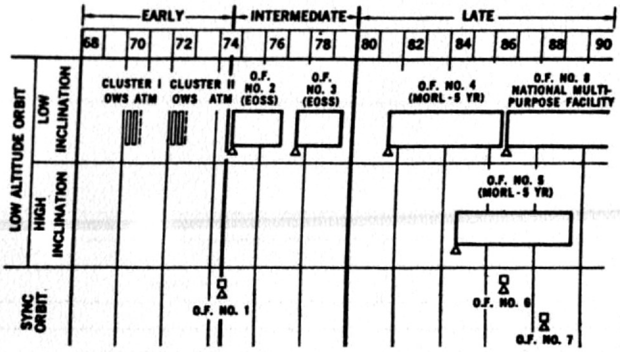


Figure 9. Mission Plan Forecast

The orbital facilities (O.F.) suggested by NASA/MSFC included two Earth orbital space station (EOSS) class 2-year, six-man space stations in low-altitude (200-nmi), low-inclination (30° to 50°) orbits in the intermediate period. The stations were visualized as evolving into 5-year, six- to nine-man manned orbital research laboratory (MORL) class stations in low-altitude, low-inclination, and polar orbits; then, into a long-duration, national multipurpose facility in a low-inclination, low-altitude orbit, all in the late period. Also considered were a series of short duration, non-resuppliable missions to synchronous orbit. The orbital facilities utilized have been numbered from one to eight, in approximate order of launch sequence. Missions 2 through 5 utilized Titan III-M-launched six-man logistics systems with a resupply frequency of 120 days. Some unmanned Titan III-M logistics vehicles are also available for special equipment delivery.

Note that this study, being primarily requirements-oriented, was concerned with the impact of manned orbital astronomy on multipurpose space stations. Because these space stations will probably simultaneously support many different types of scientific and applications missions as yet undefined, the study described some of the critical interactions between astronomy requirements and space system resources (e.g., skilled crewmen, electrical power, logistics capability, and data management). Therefore, the space stations were treated as representing a class of available technology, rather than as fixed configurations to be modified specifically for astronomy. The study concentrated more heavily on the 1974 to 1979 period (with 2-year space-station missions) because of its greater potential impact on current NASA planning activities.

SELECTION OF OPERATING MODES

The analysis first examined the advantages and disadvantages of the alternatives for housing and operating instruments in the various orbital facilities. The alternatives explored can be classified into three general categories:

1. Integrated–The instrument is attached to, and wholly dependent on, the manned space-station subsystems (propulsion, power, data management, crew systems).
2. Semidetached (intermittently-detached)–The instrument module can operate for limited times, independently (free-floating) of the manned space station and must have all subsystems required to support itself as an independent satellite. This module's normal mode of operation is attached to the space station.
3. Detached–The instrument's mode of operation is as an independent, free-floating satellite, station-keeping with the manned space station and dependent on it for maintenance, repair, resupply of consumables (e.g., propellants and film), modifications of instruments, possibly some data management, communication, and experiment program sequencing commands.

To determine general guidelines in optimal operations-mode (integrated, semi-detached, detached) selection, the instruments were divided into three general classes: radio, optical (IR-visible-UV-XUV--longer than 1 Å), and high-energy radiation (X-ray to cosmic ray--shorter than 1 Å).

Radio Telescopes

Earth-based and low-altitude radio telescopes are limited in their usefulness below roughly 30 MHz by the reflection, absorption, refraction, and polarization rotation effects of the ionosphere. These limitations increase in severity with decreasing frequency, becoming intolerable at frequencies below 5 MHz. The most highly ionized part of the ionosphere is the F-region. Above the F-region ionization maximum, the electron density falls, to merge eventually with that of the plasma surrounding the sun. A long-wave radio astronomy antenna placed above the F-region can both receive signals from outside the Earth, and be freed from radio noise generated on Earth by the shielding of the ionosphere.

The orbit altitude should be such that the local number of electrons must be $\leq 9\ \text{cm}^{-3}$ and the plasma frequency ($f \cong 9\ H_e{}^{1/2}$ kHz) must be ≤ 0.5 times the minimum operating frequency (50 kHz). These conditions exist only above the 12,500-mi (20,000-km) altitude.

Besides the requirements for very-high-altitude orbits, which would seriously limit the time available for manned operations, radio noise interference can be expected to increase near any manned spacecraft. For these reasons, an unmanned, detached antenna configuration was suggested as the normal operating mode for radio astronomy.

High-Energy Radiation Counters

Because high-energy radiation devices can tolerate coarse attitude control and are not subject to appreciable degradation by spacecraft effluents, it appeared that this class of instrumentation could be integrated into the basic space-station configuration, or operated while attached to the station, without the need for sophisticated mounting provisions.

Optical Telescopes

The selection criteria for the operations mode of the optical group were less obvious and it was necessary to examine the factors which could influence operations-mode selection for the optical instruments in greater detail.

Selection and recommendations for optical telescope operations modes were based on (1) scientific and technical performance, as affected by such factors as optical environment contamination, radiation effects, attitude hold (dynamic isolation), thermal stability, and data management; (2) operations, as affected by flexibility for modifications, maintainability, reliability, useful life, multipurpose mission impact, discretionary payload, and schedule flexibility; and (3) cost. In general, the optical group of instruments was characterized by precise attitude-hold requirements (1 arc sec or lower) and sensitivity to spacecraft effluent environment.

Of all the factors considered, optical environment contamination and data management appeared to have the most potential impact on mode selection, and thus warrant separate discussion.

Optical Environment Contamination–The contaminants expected from an Earth-orbiting space station of the 1974 era are summarized in Figure 10. The contaminants shown are for normal operations. Failure cases or unusual situations might change these estimates significantly. The revised tabulation column shows the contamination elements after some minimum-effort space station modifications. EVA would contribute approximately 1 to 9 lb of additional contaminants (largely water) per man-hour of activity. All of the contaminants shown, except propellants, contribute to an essentially steady-state, comet-shaped cloud around the space station.

RCS propellant ejection does not appear to cause a significant problem. The local density near the thrusters would reach the level of the normal density within 1 to 100 sec. The mean clearing time probably would be on the order of 10 sec. With suitable placement of instrument packages with respect to thrusters, even short-period obscurations could be greatly reduced.

Because the water molecules near the station would have a lower velocity than the gaseous contaminants, most of the surrounding cloud would consist of water; this poses perhaps the greatest problem in limiting observations for several reasons. First, an

		AS DESIGNED (LB/DAY)	REVISED (LB/DAY)
1	ATMOSPHERE LEAKAGE	5	1
2	ATMOSPHERE DUMP	7	5
3	LOGISTICS ATMOSPHERE LEAKAGE	1	1
4	PROPELLANT (P/RCS) EXHAUST	13	13
5	URINE DUMP	28	–
6	FECAL WATER DUMP	2	2
7	CO_2 DUMP	15	15

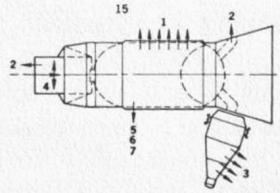


Figure 10. Contaminants Released by EOSS

artificial background brightness would be generated by light scattering off the ice crystals formed from the water vapor. Figure 11 presents the relative brightness of the background as compared to sun surface brightness ($B/B_{\odot}$) which could be expected at various separation distances from the space station. Note that the relative background brightness shown is for a viewing angle with respect to the sun of 60° and is seen to be approximately 4×10^{-13} sun-surface brightness. The level of background brightness is reached at a separation distance of approximately 2,700 ft.

Note that estimates of separation distance requirements are very dependent upon the assumptions made as to the amount of water vapor converted to ice crystals. For less than 100% conversion of water to ice crystals of approximately micron size, the relative background brightness will be reduced and the total background brightness will reach that of the natural background at a smaller separation distance. Determination of the severity of this potential problem must await in situ observations.

Because of the potential increase in artificial-brightness background, bagging of the urine water is proposed to reduce the water dumped. Negligible light absorption and scattering in the UV are expected from the molecular contamination; however, the potential deposition of contaminants on optical surfaces should be minimized. Therefore, any other easily attained modifications to the vehicle design which would reduce the effluents should be made. It should be emphasized that the magnitude of the effluent problem is hardware peculiar. Proper vehicular design can go a long way toward solving this potential problem.

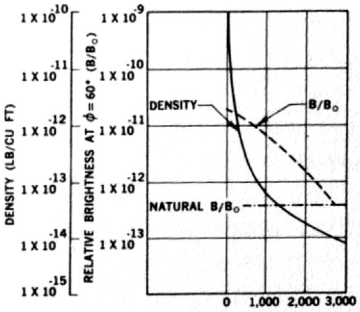


Figure 11. Density and Relative Brightness Effects as a Function of Separation Distance from Space Station

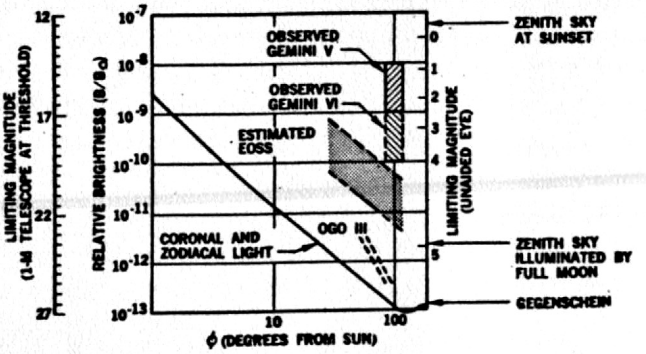


Figure 12. Radiance Distribution Comparison

To place the contamination problem in perspective, Figure 12 presents a comparison of data from Gemini V, VI, OGO III, and a proposed EOSS. The coronal and zodiacal light establishes the relative background brightness of the natural environment in the plane of the ecliptic. The upper boundary of the background brightness about the EOSS is the maximum expected from sunlight scattering off ice crystals for the original EOSS contaminant effluent rate. (Molecular scattering and absorption are assumed to be negligible and propellant exhaust is too quickly dissipated to be significant.) The lower boundary is the maximum background brightness expected by the revised EOSS effluent rate.

The background brightness for Gemini V and VI were determined by the magnitude of the stars that could be observed with the unaided eye during daytime. Other factors, besides a contamination cloud about the vehicles, may have contributed to the relatively high background brightness. Such factors may have included scattered sunlight reflected from other positions of the vehicle, lack of dark adaptation of the eye, and absorption/diffusion through the viewing port. Limiting visual-magnitude scale for viewing through diffraction - limited f/30 telescope of 1-m aperture with a stability of 0.1 arc sec is also included to show the potential effect on the detection and observation of faint objects.

OGO III data are included as representative of the background brightness to be expected around an unmanned satellite or module.

From these data, it would appear that optical instrumentation operating from a remote module would alleviate the potential problem of restricted visibility.

Data Management--The approaches to data collection considered during the study were (1) the use of direct facility-to-ground data transmission and (2) film recording, storage, and return via data return capsules or crew-rotation logistics vehicles.

Typical examples of data-generation rates can be cited. Spectroscopic surveys and flux determination of discrete gamma-ray sources were estimated to produce 3.7 x 10^6 bits per day of data. High-resolution cinemagnetography of the sun was estimated to produce 144 x 10^6 bits per day. UV spectroscopy of stellar chromospheres in late type, plus some O and B stars would generate 1,600 x 10^6 bits per day. Depending on the number of such activities to be accomplished by the orbital facility, the total data rate in bits per day could, of course, be considerably higher. In the case of direct transmission, data requirements for both coarse survey activities and for detailed object observations were considered. The facility-to-ground observation data-rate requirements as a function of bit rate and the data quantities are depicted in Figure 13. The figure shows that the Corpus Christi and Cape Kennedy ground stations can accommodate some survey observations at the standard 51.2-kbits/sec rate. However, five stations would be required for more comprehensive survey observations using this rate, and object-oriented observations cannot be handled, even assuming a data compaction ratio of 10:1. The maximum real-time rate that can be used with existing equipment on the Manned Space Flight Network is 200 kbits/sec. Since station performance data, navigation information, and data collected from other experiments will also be transmitted, 1-Mbit/sec downlink data rate is considered necessary for the orbital facility.

The alternative to direct transmission would be to make greater use of film techniques including on-board storage and later retrieval. In this case, a potential problem is the sensitivity of film to the space radiation environment. Exposure of photographic emulsions to radiation can produce varying effects, depending upon the type and energy level of the radiation as well as the characteristics of the film. The most serious effect of radiation exposure is an increase in film background density. The sensitivity of film density, i.e., the fog level, to radiation exposure is presented in Figure 14 for several representative astronomical films. In general, the higher the sensitivity of the film is to light, the more susceptible it is to radiation fogging. To estimate spacecraft shielding weights and determine mission sensitivity to orbital parameters, a maximum fog density of 0.2 was selected. The shield thickness required for the nominal mission (120 days between resupply, 200-nmi altitude, and 50° inclination) was determined by comparing the dose tolerance criteria of the film with the dose rate data of the environment. Table 2 presents aluminum and water-shield thickness required to protect representative astronomical films and a film suitable for solar work. These computations were based on flux rates corresponding to the solar minimum period. For the solar maximum period, it was determined that the orbit altitude could be increased to 260 nmi to maintain the same shield thickness. Note that the 103-0 film or its equivalent is extremely difficult to protect for a period of 120 days because of the

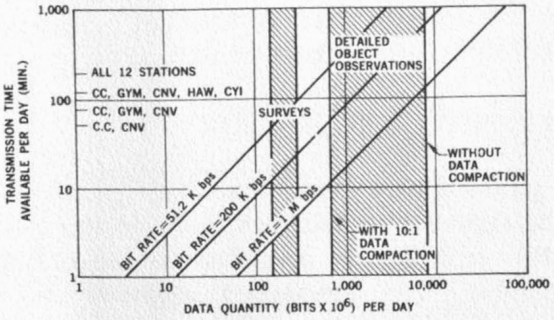


Figure 13. Observation Data Rate Requirements

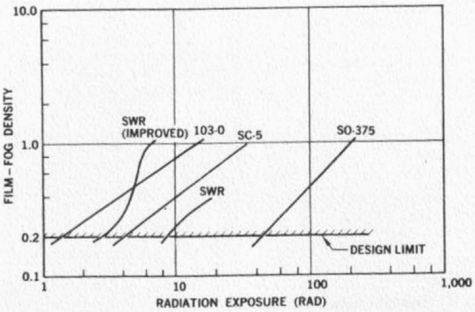


Figure 14. Film Sensitivity to Radiation

Table 2 Film Shielding Requirements (120-Day Mission, 200 nmi and 50° Inclination)

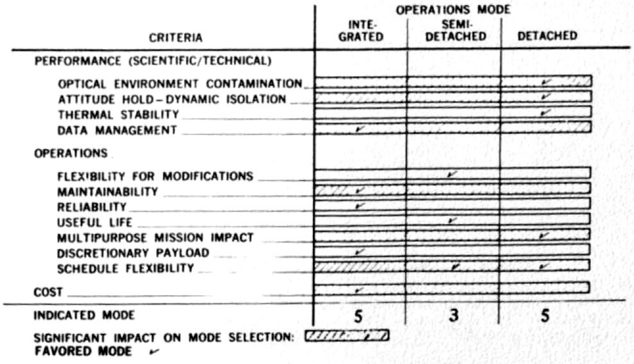
Film Type	Dose Tolerance (rad)	Shield Thickness (gm/cm^2) Aluminum	H_2O
103-0	1.5	66	54
SWR (improved)	2.7	49	40
SC-5	4.1	37	30
SWR	8.5	18	14
SO-375 (solar)	44.0	5	4

estimated 1.5-rad dose tolerance. A possible solution to the overall film radiation problem is the storage of the film at low or cryogenic temperature. A reduction of the storage temperature by 100°C could reduce the sensitivity of the film by as much as 75% (Reference 7). This suggests a possible space "Ice Box" using radiators or active cooling-systems to reduce storage film temperatures.

Because the storage volume on-board the module will be smaller than that of the space station and because the storage periods are significantly different, there is an optimum distribution of shield weights between the two spacecraft. Because approximately 10,000 lb of water will be carried on-board the space station for ecological purposes, a feasible approach to shielding would be to utilize the on-board water to provide protection for the film.

It would appear that film-storage and protection for those instruments and sensors using film techniques can best be met when the instruments are integrated into the parent space station.

Mode Selection--Figure 15 summarizes the criteria which were investigated in attempting to evaluate the potential of integrated, semi-detached, and detached modes of operation for the optical instruments. Each mode carries certain advantages and penalties. As discussed above, the potential problem of environment contamination favors detached module operation. The potential need to store data on film, to avoid saturating the data transmission capabilities, favors integrated operation (in view of the potential for better shielding provisions using ecological water). Dynamic isolation of instruments can be achieved in any operational mode but may be easier to accomplish in a detached module. Detached and semi-detached modes obviously offer advantages in improved schedule flexibility (equipment does not need to be launched with a space station) and reduced impact on station operations when several different observation programs must be accomplished simultaneously. Although no one factor could be determined which would make one mode of operation mandatory, examination of the factors considered to be most critical by the study team (i.e., environment contamination, dynamic isolation, data management, maintainability/reliability, multipurpose mission impact, and schedule flexibility) suggested that a detached module concept for housing optical instruments offered considerable potential and should be explored in further depth.



CRITERIA	OPERATIONS MODE INTEGRATED	SEMI-DETACHED	DETACHED
PERFORMANCE (SCIENTIFIC/TECHNICAL)			
OPTICAL ENVIRONMENT CONTAMINATION			✓
ATTITUDE HOLD-DYNAMIC ISOLATION			✓
THERMAL STABILITY			✓
DATA MANAGEMENT	✓		
OPERATIONS			
FLEXIBILITY FOR MODIFICATIONS		✓	
MAINTAINABILITY	✓		
RELIABILITY	✓		
USEFUL LIFE		✓	
MULTIPURPOSE MISSION IMPACT			✓
DISCRETIONARY PAYLOAD	✓		
SCHEDULE FLEXIBILITY		✓	✓
COST	✓		
INDICATED MODE	5	3	5

SIGNIFICANT IMPACT ON MODE SELECTION: ▨
FAVORED MODE ✓

Figure 15. Operations Mode Comparison (Optical Telescopes)

Besides the specific considerations related to optical telescopes, it might also be noted that the detached module concept provides considerable flexibility to the more general mission plan of the multipurpose orbital facility for many of the same reasons. By accommodating different equipment development and launch schedules and being able to simultaneously respond to many different observational requirements, multiple instrument modules can be used to efficiently meet the needs of other scientific disciplines as well as those of astronomy.

INSTRUMENT INTEGRATION

The generic classes of instruments proposed for each of the eight orbital facilities is shown in Figure 16, together with various operations modes and launch alternatives. The observation programs and their associated instruments generally evolve from simpler survey or gross data-collection tasks to detailed

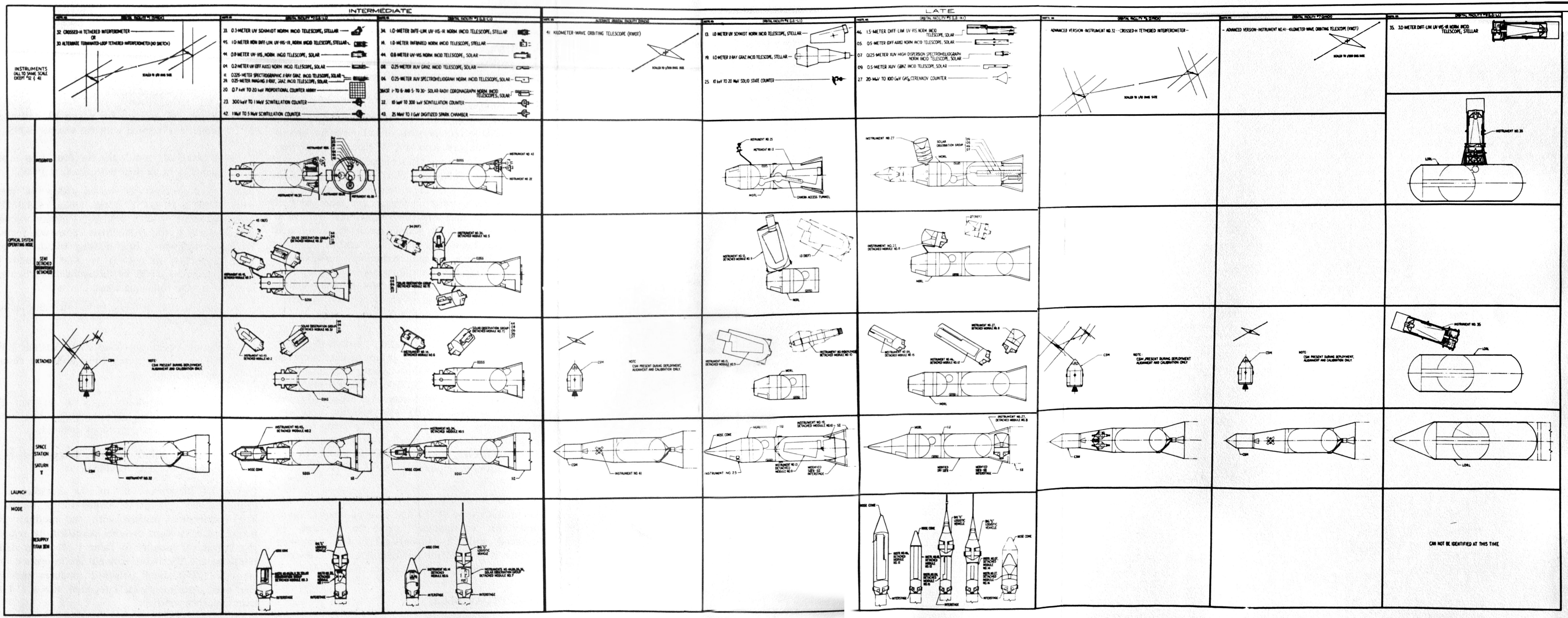


Figure 16. Concept Alternatives

observations of faint, small sources requiring larger apertures or more sensitive detectors. The demands on orbital-facility resources correspondingly evolve to more precise pointing, greater data-handling capability, stricter thermal control, less optical environment contamination, and specialized orbits for long-term uninterrupted viewing of celestial objects. This growth is reflected in the distribution of instruments among the orbital facilities.

The synchronous missions (No. 1, 6, and 7) are utilized in this plan only for radio astronomy because of the unique requirements of radio observations. A Saturn V-launched Apollo CSM-class vehicle delivers a Crossed-H Antenna (Reference 8) or a Kilometer Wave Orbiting Telescope (KWOT) to orbit (Reference 9). If man is present, crew duties might involve radio telescope deployment, checkout, and monitoring of initial operations. The crew would then return to Earth after 14 to 28 days, leaving the automated instruments behind. A possible alternative would be to conduct the entire radio astronomy mission in an unmanned mode. Determination of the optimal degree of involvement of the crew in these synchronous missions was beyond the scope of the current study.

The low-altitude, low-inclination missions (No. 2, 3, 4, and 8) support evolving groups of instruments in other regions of the electromagnetic spectrum, from gamma-ray detectors through IR telescopes. It is anticipated that other instruments besides the 3-m telescope (Reference 10) will probably orbit with the national multipurpose facility (No. 8). The design of other instruments for use in this time period, however, must wait for the results of the earlier astronomy programs.

The polar mission (No. 5) is to be placed in a sun-synchronous orbit (98°) and offers a unique opportunity for continuous viewing to an array of advanced solar instruments. The Gas Cerenkov Counter is planned for polar orbit to allow observation of cosmic-ray electrons down to 0.1 GeV.

CONCEPTUAL DESIGN

The conceptual-design phase of the study concentrated on the accommodation of instruments associated with EOSS missions of the intermediate time period. Four representative instrument housing concepts were developed:

1. The three high-energy radiation counters to be integrated into the first EOSS.
2. A detached module for a 1-m diffraction-limited UV-visible-IR stellar telescope (the advance Princeton telescope) to be orbited with the second EOSS.
3. A detached module for a 1-m IR stellar telescope, also orbited with the second EOSS.
4. A detached module for the four solar instruments to be orbited with the first EOSS.

Each design concept was evolved within the framework of the total OASF system which includes the host spacecraft, launch systems, logistics systems, and supporting ground facilities. Effort was focused on the instruments, their housing (modules), and their supporting subsystems, so that demands on critical resources could be determined. Particularly sensitive are the following areas:

1. Mission compatibility (orbit altitude, inclination, timing).
2. Station operation (orientation, attitude hold, effluent control, crew time, and data storage and handling).
3. Logistics capability (not a problem for astronomy alone, but potentially troublesome with multipurpose missions demands).
4. Ground facilities capability (experiment management and data handling).

Figure 17 illustrates one of the EOSS-class of orbital facility concepts developed during the study. The instruments utilized with the modules and parent space station can be identified by relating the instrument number to Table 1. The 1-m stellar telescope and the 0.3-m Schmidt are integrated into separate 120-in.-diam detached modules and the four solar instruments are integrated into a 154-in.-diam detached module.

As previously described, the high-energy detectors have fairly gross attitude-hold requirements (on the

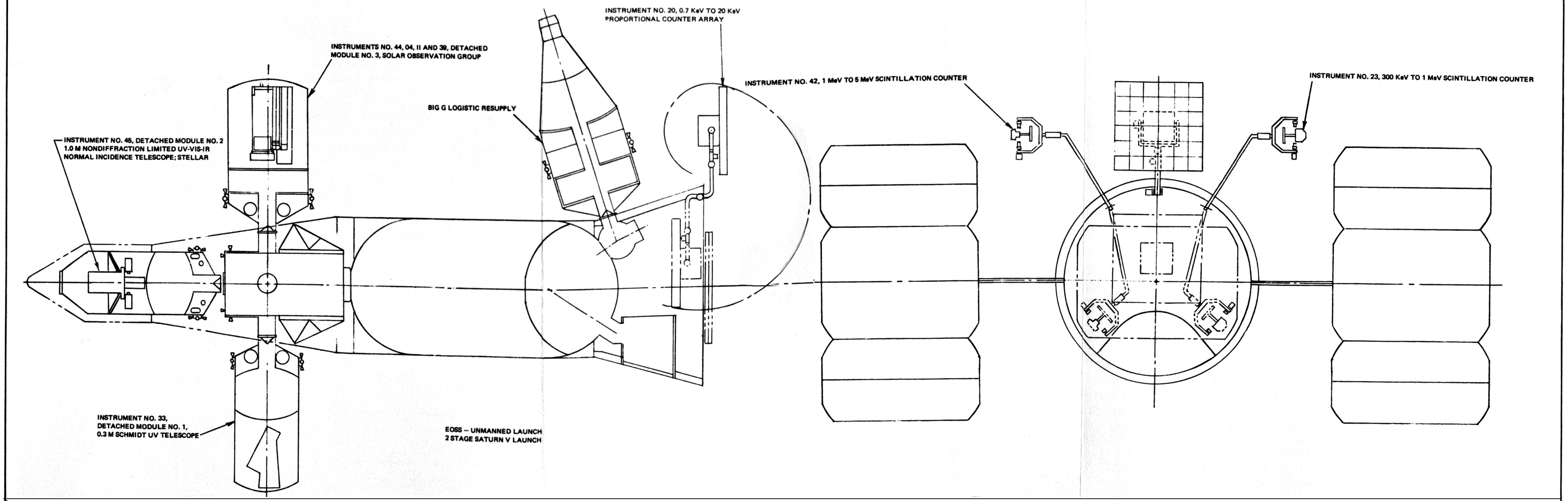


Figure 17. Orbital Facility No. 2

order of 1°) and do not appear to be sensitive to the space station effluent cloud; therefore, they are good candidates for integration into the space station. Each detector is stowed in the interstage area, as shown in Figure 17 during launch. After orbit is achieved, and the space station solar panels deployed, boom arms swing the detectors out. Two-axis gimbals with torque motor controls provide pointing capability independent of space station orientation.

Direct personnel access via astronaut EVA is required to replace failed components. The detectors are generally fairly reliable systems with little maintenance or repair anticipated. However, since they do utilize star trackers or television/guide telescopes to monitor their field of view, and the scintillation counters utilize photomultipliers, more frequent access to these devices may be required.

The detached module for the 1-m diffraction-limited UV-visible-IR stellar telescope (Figure 18) is typical of all the selected astronomy modules and has been designed to facilitate the use of man for alignment, checkout, maintenance, repair, and modification or replacement of equipment. It is anticipated that crewmen will only inhabit the modules when they are docked to the space station because a clearly defined need did not exist for man in the module during the actual operation of the optical telescopes.

The pressure shell is divided into the equipment section (manned compartment when docked to EOSS), instrument (sensor) section, and collector (optics) section. Hatches provide access between compartments. A maintenance and test console, which also mounts all the telescope-associated electronics that can be separated from the sensor mounting platen, is located in the equipment section. Guidance and control, communication, and data-management electronics are housed in separate bays of the same console. All electronic components are cold-plate mounted and the radiator is an integral part of the external shroud. This section also houses the control moment gyros (CMG's). Umbilical panels are located in the tunnel for use of EOSS power and environmental control and life support systems while docked.

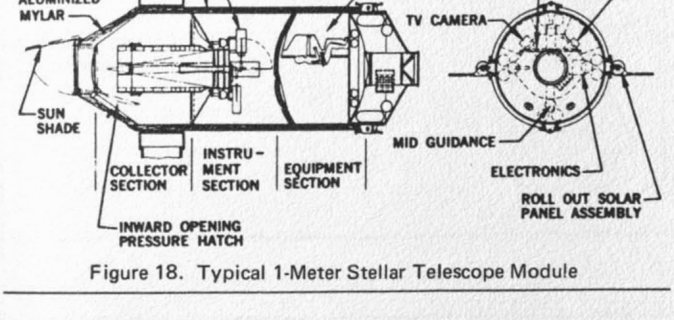


Figure 18. Typical 1-Meter Stellar Telescope Module

The portion of the module from the forward dome of the equipment section aft, is standard for all the 120-in.-diam astronomy modules because most of the spacecraft provisions in this area of the module satisfy common requirements.

A single length of waffled cylinder is used for the pressure shell forward of the equipment section. This cylinder is compartmented into separately pressurizable sections by the telescope support cone and the instrument mounting platen. The platen section outside the mirror diameter contains the precision pads for mounting the sensor equipment. Radial mounting of this equipment was selected to facilitate ease of access to any item. The outer section of the platen also contains the mounting provisions for six magnetic pushers of a magnetic suspension system.

During operation away from the space station, an average power level of 350 W is provided by an oriented solar-cell/battery system using two 15- x 3.3-ft rollout arrays and nickel cadmium batteries.

Attitude control is provided by CMG's which are periodically desaturated by magnetic torquers or reaction jets. The fine attitude sensor is provided by the instrument itself. Separate star trackers on the detached module are used during the acquisition phase to determine gross fields of view.

The propulsion/reaction control system (P/RCS) has four modules of six bipropellant thrusters (MMH and N_2O_4). The system is sized for 120 days without resupply, to match projected logistic flight frequencies.

MISSION CONSTRAINTS

As discussed in Volume IV (DAC-58144), the synchronous orbit is most desirable for general observations of the celestial sphere. From synchronous orbit, any portion of the celestial sphere can be continuously viewed for periods of at least 24 hours. In lower altitudes, a 98° orbit provides continuous viewing for most of the ecliptic plane, relatively small portions of the galactic plane, and short viewing periods for both the center of the Galaxy and the galactic poles. A 50° orbit provides limited continuous-viewing capability for a small portion of the ecliptic plane, and for the plane, poles and center of the Galaxy. Each of the low Earth orbits can view all of the celestial sphere for short periods of time.

Long-duration solar viewing can be obtained only in a sun synchronous, or near-polar orbit. For each orbit altitude, there is only one orbit inclination that yields the required precession of 0.986°/day to achieve a sun synchronous orbit. Deviations from this ideal would reduce the time for continuous viewing. For example at 200 nmi, the optimal orbit would be 98°. In this orbit, however, only about 210 days would be available for continuous viewing, assuming a 100-km critical atmosphere height; this reduces to less than 30 days of continuous viewing in a 200-nmi orbit at inclinations of 90°. Longer periods of continuous viewing would be possible in higher-altitude orbits (above 500 nmi).

Against the ideal orbital-operation requirements for astronomy, the considerations of launch vehicle performance and the competing demands anticipated on manned space facilities must be weighed. For multimission space stations, especially those dealing with Earth-centered observations, high-inclination orbits in the region of 50° or greater appear to offer significant advantages. To place these factors in perspective for space astronomy, celestial object visibility requirements, orbit-inclination payload limitations, and radiation effects on film and high-energy detectors were examined for the various candidate orbits.

Orbit-inclination payload limitations are imposed by range-safety constraints and launch-site latitudes. Maximum payload capability (due-east launch) is a function of orbit inclination for low-altitude (below 500 nmi) Earth orbits. ETR range-safety constraints require that the launch azimuth be between 44° and 110°. Thus, for in-plane launches, orbit inclinations must lie between 28.7° (minimum inclination set by the latitude of the launch site) and 52° (maximum inclination achievable at the 44° launch azimuth). Higher (or lower) orbit inclinations may be obtained through in-orbit plane changes and doglegging during boost.

One method of achieving a polar orbit from ETR is doglegging over Cuba and Panama. Payload achievable by this mode is plotted as a function of inclination over the region of interest (90° to 100°) in Figure 19. This mode consists of launching at an azimuth of 145° and, after first-stage separation, doglegging west. Polar orbits can be achieved with little problem if launch facilities are available at WTR. Range safety at WTR limits the launch azimuth to the range between 170° and 301°. Allowable orbit inclinations for in-plane launches can, therefore, vary from 81° posigrade, to 34° retrograde. The payload capability to the 98° orbit using an in-plane launch, is reduced by only 23% from that of the due east launch.

In low-inclination, low-altitude circular orbits, the primary radiation hazard to film is from energetic protons above 40 MeV. The sensitivity of this radiation environment to the inclination of an orbiting spacecraft is illustrated for orbit altitudes of 200 and 300 nmi (Reference 11) (Figure 20). As shown, the accumulated dose is relatively insensitive to the inclination of the orbit in the range of 50° to 90° inclination. In this inclination and altitude range, the dose will be accrued when the spacecraft passes through the South Atlantic anomaly, where the magnetic field is weak and particle fluxes correspondingly high. At inclinations below 25°, the

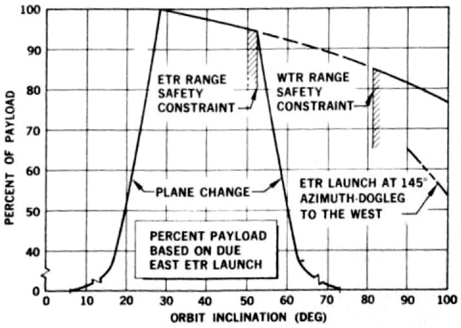


Figure 19. Payload Degradation

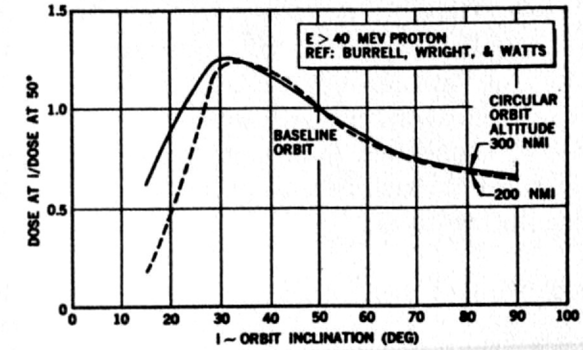


Figure 20. Sensitivity of Trapped Radiation to Orbit Inclination (Integrated Proton Dose)

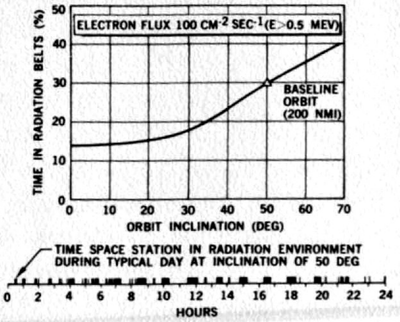


Figure 21. Effect of Orbit Inclination on High Energy Radiation Observation Time Available

orbit will no longer pass through the anomaly, and proton dose rates will decrease quite rapidly with decreasing inclination. To limit potential film damage, it appears that orbital inclinations below 25° or above 50° would be preferred.

A further orbital consideration is the functioning of the high-energy radiation counters, which are designed to resolve X-ray and gamma-ray sources. These instruments will be adversely affected by the large charged particle fluxes of the space environment. With a nominal orbit of 200-nmi altitude and an inclination of 50°, the primary constituents of the environment of concern are the geomagnetically trapped protons and electrons. These particles, when impinging upon the counters or surrounding shielding, either create an inherent noise in the instrument, thereby reducing a signal detection, or, shut off the instrument via anticoincidence detection.

To evaluate the potential problem of operating in the nominal orbit, the trapped radiation environment was examined to determine what fraction (averaged) of the nominal orbit would pass through the high flux regions. Of primary concern was the South Atlantic anomaly where the fluxes reach large values at low altitudes.

With the assumption that the X-ray and gamma-ray detectors would be inoperative at a flux density of 100 particles/cm^2 sec, or more, the time of potential instrument utilization was determined. As shown in Figure 21, the nominal orbit would require shutdown of the instrument on the average of 30% of the time, thus leaving approximately 70% of the orbit for potential instrument operation. Lowering of the orbit inclination would maximize instrument utilization time to approximately 85%.

Within the 70% average orbit period, the high-energy radiation detectors remain susceptible to the reduced trapped-particle flux and the related anticoincident shutdown is important in determining overall instrument performance. Three high-energy radiation instruments considered for Orbital Astronomy Facility No. 2 (see Figure 17) are identified in Table 3, along with the corresponding operating energy range and critical condition for anticoincidence shutdown. Also identified in this table are a summary of electron flux data and the corresponding instrument dead time of the 70% orbit period. Of the three instruments, the proportional counter was determined to be most critical, with a shutoff period of less than 2% and 1% from the electron and proton flux, respectively.

From considerations of celestial object visibility, launch-vehicle performance, film irradiation, and high-energy detector protection from radiation, it is concluded that a nominal inclination in the region of 40° to 50° would be acceptable for general astronomy-oriented missions.

EVOLUTIONARY PLAN DEVELOPMENT

Elements that were developed as part of the evolutionary plan included the following:

1. An implementation schedule which displays the calendar-time-dependent relationships of critical Supporting Research and Technology (SR&T) activities to the four phases of Phased Project Planning for the orbital facilities.

Table 3 Mission No. 2 – High-Energy Radiation Counters Observation Time (70% of Orbit)

Energy Range	Counter Name	Critical View Angle (Steradians)	Resolution Time (sec)	Electron		Time Off (%)
				Energy	Flux	
0.7 keV- 20 keV	Proportional	10^{-3}	10^{-4}	23 KeV	190 counts/ sec over 900 cm^2	2
300 keV- 1 MeV	Scintillation	2π	10^{-7}	0.46 MeV	12,500 counts/ sec over 230 cm^2	0.2
1 MeV- 5 MeV	Scintillation	2π	10^{-7}	0.75 MeV	6,000 counts/ sec over 180 cm^2	0.1

2. Development plans for the astronomy-peculiar major hardware elements (instruments and detached modules) with critical predecessor relationships delineated.

3. An astronomy-oriented supporting research and technology program for instruments, detached modules, and space stations, time-phased with the implementation plan and showing the interactions among various technologies.

4. An analysis of the impact of the proposed manned orbital astronomy program on present and planned NASA ground facilities, with emphasis on launch and mission control facilities.

5. Proposed operational concepts to relieve the projected burden on present mission and experiment management facilities.

6. Engineering estimates of total program cost, accumulated on the basis of Phase Project Planning (PPP) techniques. Costs are allocated to program breakdown structure elements and are time-phased with the implementation schedule.

The overall schedule for a manned orbital astronomy program is summarized in Figure 22. It includes schedules for SR&T and PPP phases relating to both the intermediate (1974 to 1979) and late (1980 to 1990) time periods. For planning, it was assumed that Task C of the OASF Study satisfied a Phase A output requirement, and the timing sequences assigned to the SR&T and PPP phases are predicated on this assumption.

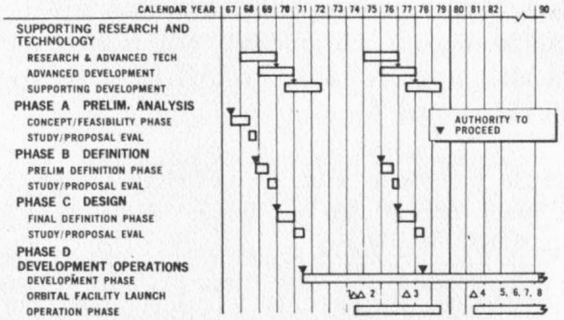


Figure 22. OASF Program Implement Schedule

The development period is shown extending nearly to the end of flight operations because of continuing instrument evolution. The operations phase starts early in 1973 with the fabrication of hardware for the first orbital facility and terminates for the intermediate period in mid-1979. The late-period operation phase starts with the fourth orbital facility launch in mid-1981 and terminates in the mid-1990's with the end of the manned orbital telescope (MOT) 5-year mission.

An example of the astronomy related program funding that might be required for the intermediate time period is summarized in Figure 23. The time scale is indicated for illustrative purposes only.

The funding distribution for system definition represents a total expenditure of $26 million which includes Phase A ($0.45 million), Phase B ($8.8 million), and Phase C ($17 million).

For the intermediate period, the distribution of development funds would be visualized to extend over 7.5 years. Of the total, 90% would be spent by June 1974, the time of the first orbital facility

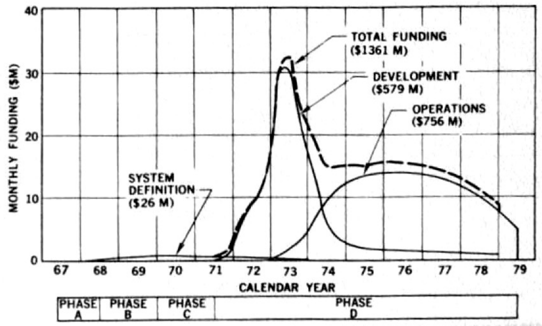


Figure 23. Project Funding

launch. The remaining 10% is needed for development to update and modify the instruments and detached modules being utilized in orbit, together with O.F. 2 and 3.

Because the Phase B and C activities related to the late time period can be expected to start in the mid-1970's, the total program funding curves for the intermediate and late time periods will overlap in the 1974 to 1980 period. Although funding estimates for the later periods are more nebulous (because many of the operational requirements will be predicated on research results obtained during the earlier periods), comparable implementation schedules can be foreseen for the more advanced orbital facilities. This would suggest the requirement for a continuing level of funding comparable to that illustrated in Figure 23, throughout the 1974 to 1990 time period.

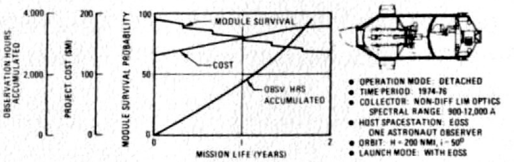
The development funding curve was prepared from the Manned Orbital Research Laboratory (MORL) and other NASA-derived space station cost data and correlated with Air Force Weapon System Planning and Cost (WSPAC) curves.

Attention should be called to the fact that the present concept of mission control in support of the Apollo program allows only limited support of multiple or simultaneous space missions. The mission control capacity in the 1974 to 1990 period may prove to be a limiting constraint, unless expanded capability is provided. Such expansion is not reflected in the funding curves of Figure 23. The present mission control complex at Houston is limited to simultaneous multiple-mission support for two missions with: (1) restricted capability because instantaneous data circuit switching is not available; (2) a Mission Operation Control Room (MOCR) turnaround time of 14 days; (3) real-time computer power adequate for only two simultaneous Apollo class missions; and (4) control rooms adequate for only two simultaneous missions, with no time sharing of critical operations.

To validate the program plans developed in this study, computer simulation of alternative missions* was used to check the sensitivity of each orbital facility concept to various research requirements and work loads and to estimate the operational costs associated with these missions. As an example of the analysis conducted, Figure 24 summarizes a case study for a 1-m non-diffraction-limited UV-visible-IR stellar telescope operating in a detached module. In this example, the observation tasks identified for this instrument together with task times (number of observations required multiplied by the average time per observation) provided the input data.

The results (day of completion) are shown for the case in which only one astronaut-observer is utilized in the astronomy observation program. In this sample case, the major restriction on observations resulted from not always having an astronaut-observer available on-board EOSS to select a field of view or to monitor the observations.

In the table of Figure 24, the probability of module survival to the day of task completion is listed for each task. The reliability of the instrument, module,



- OPERATION MODE: DETACHED
- TIME PERIOD: 1974-76
- COLLECTOR: NON-DIFF LIM OPTICS
  SPECTRAL RANGE: 900-12,000 A
- HOST SPACESTATION: EOSS
  ONE ASTRONAUT OBSERVER
- ORBIT: H = 200 NMI, i = 50°
- LAUNCH MODE: WITH EOSS

TASK NO.	TASK TITLE	TASK TIME (HOURS)	DAY OF COMPLETION	PROB OF COMPLETION
002	WIDEBAND UV PHOTOMETRY OF STARS	1750	349	0.82
028	UV SPECTROSCOPY OF PLANETARY NEBULAE	100	369	0.78
037	SEARCH FOR O_2 IN PLANETARY ATMOSPHERES	40	377	0.78
027	UV SPECTROPHOTOMETRY OF O&B STARS	125	399	0.77
039	UV POLARIMETRY FOR INTERSTELLAR DUST	75	411	0.77
030	ABSOLUTE STELLAR SPECTROPHOTOMETRY	75	423	0.76
031	MEASURE LARGE DOPPLER SHIFTS IN O&B STARS	180	470	0.76
032	MEASURE LUMINOSITY SENSITIVE UV LINES	180	470	0.76
033	SEARCH FOR INTERSTELLAR H_2	20	473	0.76
034	UV SPECTROSCOPY OF STELLAR CHROMOSPHERES	375	521	0.72
035	UV SPECTROSCOPY FOR CHEMICAL ABUNDANCES	450	640	0.68
036	UV SPECTROSCOPY FOR INTERSTELLAR ABSORPTION	450	640	0.68

Figure 24. Program Accomplishment Summary

***Computer simulation facilities and programs were generously made available to the OASF Study team by the MORL Studies Office at NASA's Langley Research Center.**

space station, launch vehicle, logistics systems, and the probability of successful module rendezvous with the space station were included in calculating the module-survival probability.

Total recurring and nonrecurring costs associated with the 1-m non-diffraction-limited stellar telescope module are plotted. Instrument and detached module backup flight hardware and launch services costs are included. In this example, total project cost at the end of the second year is $178 million.

Based upon the analyses conducted, (similar to the example cited above) it was concluded that the evolutionary program plan summarized in Figures 22 and 23 was a valid representation of a feasible working plan.

SUPPORTING RESEARCH AND TECHNOLOGY

The estimation of development times and costs, as described above, was based, among other factors, upon a systematic review of the supporting research and technology (SR&T) requirements for instruments and facilities as identified during the study. A summary of the SR&T requirements is presented in Volume V. The OASF requirements in general appear to be within the present technology or reasonably anticipated extensions thereof. However, those areas of SR&T where emphasis would be most advisable are identified in Volume V and are summarized below.

Key research and technology items related to sensor development were found to be:

UV AND XUV IMAGING TUBES

Image tubes with a spatial resolution of 100 to 200 line pairs/mm and sensitivity down to 1 Å (the shortward limit of anticipated imaging systems) would be desirable. Because image tubes are two to five orders of magnitude more sensitive than photographic film down to at least 2,000 Å, it may be expected that they would be more sensitive than photographic film at any of the shorter wavelengths. Image tube development of these specifications, with appropriate instrument modification, could eliminate the need for photographic film in many instruments.

Applicable instruments (see Table 1) are: 4, 5, 6, 7, 13, 33, 34, 35, 44, 45, and 46 (normal-incidence optical telescopes) and 8, 9, 11, 19, and 39 (grazing-incidence optical telescopes).

IR IMAGING DEVICE

Present imaging equipment, such as film and vidicons, has negligible sensitivity at wavelengths longward of 1μ. This sensitivity vanishes completely at about 1.3μ. IR imaging devices of adequate resolution for use with a 1-m aperture IR telescope are required in the wavelength region from 1μ to $1{,}000\mu$.

The applicable instrument (see Table 1) is: 14 (normal-incidence optical telescope).

GRATING RULING TECHNIQUES

For high-dispersion spectrography (0.02 to 1 Å/mm) in the extreme ultraviolet (XUV) region, very high ruling frequency is required. The present technology of about 2,400 lines/mm will have to be extended to 3,400 lines/mm.

Applicable instruments (see Table 1) are: 6, 7, 33, 44, and 46 (normal-incidence optical telescopes).

HIGH-RESOLUTION FILM

Although the current film capabilities of 40 to 70 line pairs/mm are adequate for the larger ground-based telescopes, film with a resolution of 200 line pairs/mm would be required for the angular resolutions achievable in space and would enable a 60% increase in distance penetration to remote stars.

Applicable instruments (see Table 1) are: 13, 34, 35, and 46 (normal-incidence optical telescopes).

FILM HANDLING

Research is needed to: develop techniques to overcome electrostatic charge buildup and fog-producing spark discharge on roll film in hard vacuum; develop flexible film substrata of higher dimensional stability than are now available; and develop criteria for film-transport mechanisms suitable for roll film in hard vacuum to avoid emulsion cracking and flaking.

Applicable instruments (see Table 1) are: 4, 5, 6, 7, 13, 33, 35, 36, 37, 44, 45, and 46 (normal-incidence optical telescopes) and 8, 9, 11, 19, and 39 (grazing-incidence optical telescopes).

PROTECTION OF FILM FROM RADIATION DAMAGE

To select films for specific observations and to match these films to optical equipment performance, the degree of fogging from radiation must be predictable. Analysis of film radiation damage is required to include the testing of a large spectrum of films with all particle species (protons, electrons, alphas, etc.) and energy ranges anticipated in the natural space environment.

Film-sensitivity-control techniques must be investigated, including cryogenic storage, to protect film against radiation damage.

Applicable to O.F. 2, 3, 4, 5, and 8.

THERMAL CONTROL OF IR DETECTORS

IR telescope design calls for the cooling of IR detectors to temperatures more than an order of magnitude lower than that of the basic telescope environment, which itself is about 77°K. Techniques for mounting the detector unit (at 1.5°K to 4°K) to the structure of the basic telescope (at 77°K) by a high-thermal-impedance interface are required. Development of a small, reliable cryogenic refrigerator and of a small cryogenic pump is required. Development is required of suitable plumbing for liquid helium, with particular emphasis on swivel and flexible joints, so as to isolate from the telescope any vibration in the cryogenic pump or other equipment. Storage techniques for liquid helium for up to 120 days are required.

The applicable instrument (see Table 1) is: 14 (normal-incidence optical telescope).

XUV FILTER TECHNOLOGY

Development is required in XUV filter technology to provide structurally sturdy transmission filters of about a 100 Å bandpass in the region from 170 Å longward. Such techniques as the use of metal mesh, organic substrates, and temporary structural protection until a high-vacuum, zero-gravity environment is attained, must be investigated.

Applicable instruments (see Table 1) are: 4, 5, 6, and 7 (normal-incidence optical telescopes), and 8 and 9 (grazing-incidence optical telescopes).

IR FILTERS

The atmosphere is opaque to wavelengths between 25μ and 1,000μ, making this region attractive for useful IR observations that can be carried out only from orbit. To perform even low-resolution spectroscopy in this region, filters are required. Both wideband (1- to 2-octave) and narrowband ($\Delta\lambda/\lambda \approx 1\%$) filters for the range longward of 50μ should be developed.

The applicable instrument (see Table 1) is: 14 (normal-incidence optical telescope).

SCINTILLATORS

Investigation is required of: the practicability of laminated plastic scintillators; the quantitative advantages of cooling photomultipliers and scintillators; and the value of liquid and gaseous scintillators.

Applicable instruments (see Table 1) are: 22, 23, 25, and 42 (high-energy radiation counters).

Key research and technology items related to energy collectors were found to be:

MIRROR STRUCTURES

Angular resolutions of 0.1 arc sec for 1-m-diameter mirrors and 0.04 arc sec for 3-m-diameter mirrors are desired in the UV and visible regions, e.g., ~5,000 A. Various candidate base materials have been identified: aluminum, beryllium, glass-ceramics, and fused silica (fused quartz). Materials research is required to determine the physical and structural properties and characteristics of these materials.

Applicable instruments (see Table 1) are: 13, 14, 34, 35, 44, 45, and 46 (normal-incidence optical telescopes).

DIFFRACTION-LIMITED MIRROR QUALITY

Techniques for the manufacture of mirrors up to 1.5-m in diameter, are needed. In the visible wavelength (~5,000 Å), RMS surface smoothness as well as mirror configuration should be held to 1/50 of the wavelength, and pits and scratches of greater than one-wavelength dimension should be eliminated to avoid losses from scattering.

Applicable instruments (see Table 1) are: 13, 34, 35, 44, and 46 (normal-incidence optical telescopes).

HIGH MIRROR REFLECTIVITY

Various surface-finishing techniques, such as evaporation, substrata preparation, and cooling should be investigated to increase reflectance and precision of figure for normal-incidence and grazing-incidence reflectors in the UV and X-ray ranges. Present technology in surface finishing can reduce maximum surface roughness to about 3 Å in fused quartz. Metallic coatings are at best considerably rougher. Finishing techniques to attain a 1.25 Å maximum surface roughness for grazing-incidence mirrors up to 1 m in diameter are desired.

Applicable instruments (see Table 1) are: 4, 5, 6, 7, 13, 33, 34, 35, 44, 45, and 46 (normal-incidence optical telescopes), and 11, 19, and 39 (grazing-incidence optical telescopes).

ASPHERIC SCHMIDT CORRECTOR REFLECTORS

To provide folding at other than 180° and reflective correction for the Schmidt telescopes, an aspheric or elliptical symmetry is required. A 1-m mirror requires a figuring accuracy to about 500 Å. This factor involves a significant technology difference over currently available systems.

Applicable instruments (see Table 1) are: 6, 7, 13, and 33 (normal-incidence optical telescopes).

XUV COATING REFLECTIVITY

Present reflective coatings are capable of reflectivities near 20% to 25% for wavelengths between 500 Å and 900 Å. Below 500 Å, to about 150 Å reflectivities of about 3% are attainable. From 1,000 Å up, reflectivities starting at about 60% are being achieved. General improvements are desired. In the 500 Å to 900 Å range, improvements of 10% or more would be significant.

Applicable instruments (see Table 1) are: 4, 5, and 35 (normal-incidence optical telescopes).

GRAZING INCIDENCE STUDIES

Computerized ray tracing techniques applicable to families of reflector configurations, covering the entire (1° to 15°) range of grazing-incidence angles anticipated for X-ray and UV telescopes, are required.

Applicable instruments (see Table 1) are: 8, 9, 11, 19, and 39 (grazing-incidence optical telescopes).

OPTICAL ALIGNMENT IN SPACE

Techniques for evaluating the figure of primary mirrors, in their telescope mountings in space, to within 1/50 of a wavelength, and for evaluating the alignment between primary and secondary mirrors to within 5 to 10μ, are required.

Applicable instruments (see Table 1) are: 13, 14, 34, 35, 44, and 46 (normal-incidence optical telescopes) and 8, 9, 11, 19, and 39 (grazing-incidence optical telescopes).

Key research and technology items related to space operations in general were found to be:

EFFLUENTS

As missions, particularly those using optics, become longer and more sophisticated, optical-surface contamination or contamination in the form of artificial atmosphere, from material outgassing or space-station effluents, may present a serious problem. Analysis is required for: deposition on, and contamination of, optical surfaces by space-station effluents; effluent control through space-station design procedures; dispersion dynamics of effluent materials after they are released; and effects of effluent "clouds" on astronomical observing.

Applicable to O.F. 2, 3, 4, 5, and 8.

INSTRUMENT ISOLATION

Investigation is required of telescope suspension systems capable of isolating spacecraft perturbation from the fine-guidance telescope. Large diffraction-limited astronomical telescopes will require a high degree of pointing accuracy and pointing stability. While the stability of an Apollo class spacecraft in which man is free to move about is $\pm 1^{\circ}$, stability requirements for a 1-m diffraction-limited orbital telescope may be as much as five orders of magnitude more severe, or about 0.03 arc sec.

Applicable to O.F. 2, 3, 4, 5, and 8.

HUMAN PERFORMANCE

Research and development is required to: investigate and determine man/machine interface for telescope assembly, instrument calibration, optical alignment, and operation; analyze relative capability and training requirements for astronomers and astronauts; develop astronomy-oriented astronaut task data for operations and data handling and analysis; develop techniques for erecting large structures in space; evaluate man's visual performance in space; and develop optimum data display and control arrangements.

Applicable instruments (see Table 1) are: 30, 32, and 41 (radio telescopes) and all orbital facilities.

RENDEZVOUS AND DOCKING AIDS

Rendezvous and docking guidance devices are required that provide alignment, range, and range rate for distances under 50 ft.

Applicable to O.F. 2, 3, 4, 5, and 8.

DATA HANDLING

The large amount of data to be collected, stored, analyzed, and transmitted to Earth is well beyond the capability of current equipment.

Requirements exist for development of: data compression (not reduction) hardware suitable for use in orbit; broadband recording, adaptive data-processing systems, and scan conversion equipment for use in orbit; and photographic scanning equipment capable of operating rates an order of magnitude faster than presently available. It is also necessary to determine what data reduction, analysis, and interpretation should be conducted on-board the space stations and develop equipment compatible with space-station constraints. Consideration should be given to the use of a land-landing entry capsule for return of film records.

Applicable to O.F. 2, 3, 4, 5, and 8.

CONCLUSIONS

During the OASF Study, a time-phased, baseline astronomy research program was established to identify the general classes of measurement and mission requirements. From these requirements, groups of support instruments were developed which have the inherent flexibility of responding to the changing needs of research scientists.

Three time periods were used to categorize the evolving level of sophistication of manned space operation, in general, and astronomical research, in particular. These periods were designated early (1968 to 1974), intermediate (1974 to 1979), and late (1980 to 1990). The early period reflected the short-duration (30-day) Orbital Workshop-ATM mission capability. The intermediate time period reflected a more sophisticated 1- to 2-year space station. The late time period was predicated upon a six- to nine-man extended life (5-year) space station which could be anticipated as evolving into a national multipurpose facility in the late 1980's. These space facility concepts were treated as representing classes of available technology, rather than as fixed configurations modified specifically for astronomy.

The study concluded that the emphasis in the early time period should be primarily directed toward the development of operational capability with manned vehicles. Highest probability of significant scientific return could be realized if the OWS-ATM concept was directed toward obtaining a better understanding of the role and primary contributions of man before large-scale commitments are made to the more sophisticated facilities of the intermediate and late time periods. This early facility would also provide a needed platform to provide answers to the many technology-oriented questions upon which future design will be predicated if its general mission is oriented specifically toward exploratory manned space astronomy missions as in the ATM concept. Based upon early mission success, it can be anticipated that the first major long-term scientific facilities for astronomy would become available in the intermediate time period.

During the study, the following specific conclusions were reached:

- A total of 22 out of the 29 required instruments can be derived from current development activities.
- Instruments can be effectively isolated from crew-motion disturbances.
- Man will be primarily used for updating, maintenance, and repair. (Semiautomated data collection minimizes time demands on astronaut as an observer.)
- Radiation effects are minimized and payload capability maximized for orbital inclinations of 40° to 50°. Significant contributions to astronomy can be made from facilities operating in this region.
- Modules for optical instruments can be designed for pressurized crew access.
- Contamination effects are minimized by detached module operation.
- Detached modules, if accessible for manned maintenance, appear most effective and offer the greatest operational flexibility for high-resolution optical astronomy.
- Ground facilities for mission control and data management must be augmented to meet projected loads.

The major outputs of this effort have been (1) definition of OASF concepts, (2) an implementation schedule, (3) a supporting research and technology program, (4) development plans for all major equipment items (including orbital facilities) and master phasing charts, (5) a ground-facility impact analysis, and (6) engineering estimates of total system costs.

It is intended that the data generated in this study will provide at least a portion of the information needed by NASA upon which to base those management decisions vital to long-range program planning in this area of research.

* * *

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DOUGLAS MISSILE & SPACE SYSTEMS DIVISION

5301 Bolsa Avenue Huntington Beach, California 92646 (714) 897-0311

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