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Volume II

Final Report

September 1972

Book 1
Astronomy Sortie Program Technical Report

Astronomy Sortie Missions Definition Study

MARTIN MARIETTA

Itek

Bendix

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Book 1

ASTRONOMY SORTIE MISSIONS DEFINITION STUDY

ASTRONOMY SORTIE PROGRAM TECHNICAL REPORT

Prepared for:

National Aeronautics and Space Administration
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FOREWORD

This document is submitted in accordance with the Data Procurement Document Number 282, Data Requirement Number MA-04 under the George C. Marshall Space Flight Center Contract NAS 8-28144.

This is the second of four volumes of the *Astronomy Sortie Missions Definition Study Final Report*. This volume contains the results of the concept definition and evaluation task.

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PREFACE

The realization of a fully operational Space Shuttle will open the door for unparalled research opportunities in space astronomy. One mode of operation currently envisioned for the Space Shuttle is the short-duration sortie mission. The sortie mission would consist of a low earth orbit of approximately seven days' duration. During this seven days, research would be conducted by an experiment crew utilizing a scientific payload located in the Space Shuttle cargo bay.

For research in astronomy, the Space Shuttle sortie mission offers significant advantages. Several of the more important are (1) the ability to escape the Earth's atmosphere and, therefore, open up the entire electromagnetic spectrum to research, (2) the elimination of atmospheric pertubations and, thus, the ability to use the spatial resolution of the telescopes, which is currently limited to approximately one-half arc-second for ground-based telescopes, and (3) the ability to continually observe the sun during the seven-day mission without obscurations. Combining these scientific advantages with the large payload capability of the Space Shuttle, the low-cost operation of the Space Shuttle, the availability of an experiment crew on-orbit with the experiments, the frequent space flight opportunities, and the ability to return the experiment to Earth for refurbishment and retrofit offer the scientific community a unique opportunity for further research in the field of astronomy.

While the opportunities for advances in space astronomy research are clear, it is evident that significant planning is required by NASA to ensure an orderly and timely program that not only satisfies the astronomy objectives but also provides the most return for the smallest investment. The primary purpose of this study was to provide NASA with an overview of the astronomy sortie mission requirements.

The specific objectives of the study were to:

1) Evaluate the responsiveness of the sortie mission concept to stated scientific objectives;

2) Develop conceptual designs and interfaces for sortie missions including telescopes, mounts, controls, displays, and support equipment;

3) Develop a system concept encompassing the sortie mission from mission planning through postflight engineering and scientific documentation;

4) Provide development schedules, and supporting research and technology requirements for Shuttle Sortie hardware.

The approach used in performing the study consisted of the following sequence:

1) Analyzing and conceptually designing the alternative candidate astronomy sortie mission program that maximized the utilization of common features;

2) Analyzing the astronomy sortie mission program to ensure compatibility between interfacing systems, evaluating overall performance and ensuring mission responsiveness, and developing a complete mission profile;

3) Analyzing the support subsystems to a depth sufficient to establish feasibility, compatibility with other subsystems, adequate performance, physical characteristics, interface definition, reliability level, and compatibility with manned operations;

4) Conceptually designing the selected astronomy sortie mission program, which included defining the significant design features, dimensions and interfaces on layout drawings, and defining the telescope system physical characteristics and support requirements;

5) Providing development schedules and supporting research and technology requirements.

The final report of the study is contained in four volumes of which this volume is Volume II, Book 1. They are:

Volume 1 - *Astronomy Sortie Missions Definition Study Final Report: Executive Summary*

This volume summarizes the significant achievements and activities of the study effort.

Volume II - *Astronomy Sortie Missions Definition Study Final Report:*

Book 1 - *Astronomy Sortie Program Technical Report*

Book 1 of this volme includes the definition of telescope requirements, preliminary mission and system definitions, identification of alternative sortie programs, definition of alternative sortie programs, evaluation of the alternative sortie programs, and selection of the recommended astronomy sortie mission program. This volume identifies the various concepts approached and documents the rationale for the concept and approaches selected for further consideration.

Volume II - *Astronomy Sortie Missions Definition Study Final Report:*

Book 2 - *Appendix*

Book 2 of this volume contains the *B*aseline *E*xperiment *D*efination *D*ocuments (BEDDs) that were prepared for each of the experiments considered during the study.

Volume III - *Astronomy Sortie Missions Definition Study Final Report:*

Book 1 - *Design Analyses and Trade Studies*

Book 1 of this volume includes the results of the design analyses and tradeoff studies conducted for candidate concepts during the selection of recommended configurations as well as of the design analyses and tradeoff studies conducted for the selected concept.

Volume III - *Astronomy Sortie Missions Definition Study Final Report*

Book 2 - *Appendix*

Book 2 of this volume contains the backup or supporting data for the design analyses and tradeoff studies that are summarized in Volume III, Book 1.

Volume IV - *Astronomy Sortie Missions Definition Study Final Report: Program Development Requirements*

This volume contains the planning data for subsequent phases and includes the gross project planning requirements; schedules, milestones, and networks; and supporting research and technology.

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I. INTRODUCTION

This volume summarizes the work performed during the first three months of the study to arrive at a baseline astronomy sortie mission concept. The baseline concept defined was the basis for the more detailed analyses performed in subsequent work.

During most studies, the guidelines and ground rules at the start of the study are very often modified as the study progresses. This study was no exception, and many of the guidelines and ground rules that are identified in this volume were either modified or deleted in subsequent work. To provide continuity between this volume and the remaining volumes of the report, a special chapter, Chapter VIII, was added to this volume to identify the major changes in the astronomy sortie mission concept that was recommended as a result of the first three months of the study.

In addition to the changes in the guidelines and ground rules, the information in this volume is considered preliminary in nature. In many cases, the analyses documented in this volume were expanded in subsequent work and therefore more detail is available in other volumes of the report.

This volume includes (1) definition of the telescopes and arrays, (2) preliminary definition of missions and systems, (3) identification, definition, and evaluation of alternative sortie programs, (4) the recommended astronomy sortie program, and (5) the astronomy sortie program concept that was approved as a baseline for the remainder of the study.

The general results of the first three months of this study were that the astronomy sortie mission concept is feasible and that the program identified would provide significant advances in the astronomical knowledge of the universe.

The primary changes that were made in the telescope and array definitions were the use of film for the recording devices instead of the electronic imaging specified in the reference documentation, and the repackaging of the instruments to make them more compatible with the sortie mode of operation.

The preliminary mission analyses indicated that the orbital requirements for a seven-day mission are quite different than those for a long-duration satellite. This occurs because the long duration effects of the sun, moon, and Earth positions and the effect of orbital regression are not nearly as important for the seven-day mission. This allows more flexibility in selecting orbital altitudes, orbital inclinations, and launch dates to satisfy the experiment requirements.

The operations concept defined for the astronomy sortie program utilizes three major areas for payload-oriented activities. A Payload Integration Center (PIC) located at MSFC provides the sustaining engineering for the life of the program and has the responsibility of delivering flight-ready payloads to the Shuttle launch site and refurbishing and maintaining these payloads for the life of the program. The Space Astronomy Control Facility (no location specified) would be responsible for all experiment operations and for coordinating space astronomy activities with ground-based observatories. The Shuttle launch site would be responsible for loading the flight-ready payload into the Shuttle, monitoring and coordinating on-orbit activities with the Shuttle, and offloading the payload at completion of the mission.

The astronomy sortie mission configurations defined were very dependent on the Space Shuttle and Sortie Lab capabilities and constraints. The analysis indicated that these two interfacing systems would have more effect on the final design and operation of the telescopes, arrays, and support hardware than any other single factor.

II. EXPERIMENT DEFINITION

The NASA *Blue Book* (Ref II-1) has identified a group of optical, X-ray, and high-energy instruments for use in space that would significantly advance the astronomical knowledge of the universe. Some of these instruments are candidates for use on the Space Shuttle operated in the sortie mode (one-week missions with instruments remaining attached to the cargo bay). Shuttle sortie operations offer the possibility of a very productive astronomy program because the scientific instruments (spectrographs, radiometers, etc) can be tailored to the objectives of each flight, and because scientific crewmen will be on board to evaluate and alter the progress of the observations. Shuttle sortie operations will also reduce total costs by reducing hardware complexity (reliability goals of only one week instead of several years will be required) and by allowing common support functions (gimbals, C&D consoles, etc) for all instruments.

The baseline experiments for the astronomy sortie missions definition study were provided by the NASA-MSFC COR. Solar-oriented experiments for the study included:

1) 65-cm (modified to 100-cm aperture during the study) photoheliograph (PHG);

2) 25-cm XUV spectroheliograph (SHG);

3) 50-cm X-ray telescope (XRT);

4) 2.45-cm inner coronagraph (IC) and 4.0-cm outer coronagraph (OC).

The Stellar experiments baselined included:

1) 120-cm Stratoscope III (SIII);

2) 100-cm infrared telescope (IRT);

3) High-energy X-ray and gamma-ray arrays.

The first task in the study was to review the experiment definition, contained in the available documentation, with special emphasis on aspects that would particularly affect the astronomy sortie missions definition study. Itek was responsible for defining the optical telescopes and Bendix was responsible for the X-ray telescope and the high-energy X-ray and gamma-ray arrays.

In the performance of this task it was assumed that the reference document values of aperture, focal ratio, and field of view were accurate representations of the scientists' requirements. Other parameters, such as obscuration, pointing, and guiding, were examined and modified according to best engineering judgment. This judgment was based on past experience or first-order calculations for such factors as format, plate scale, obscuration, and wavefront error. Modulation transfer function (MTF) analysis was used to establish the allowable guide errors and the expected resolution.

The choice between film and electronic image tubes was not included in this study. This choice involves such a breadth of disparate considerations that it should properly be the subject of its own investigation. For the analyses in this study it was assumed that a very high resolution film would be utilized. While this film may be too slow for many astronomical purposes, it comes close to ultimate system resolution than any other sensor that might be considered. Exposure times also were not studied, but it was assumed that exposures would be long compared to the period of image motion.

Baseline performance and packaging parameters for the baseline experiments were taken from the documentation included in the references at the end of this chapter, modified where necessary.

The study also benefited from discussions with Dr. Mayfield at Aerospace Corporation on the various solar instruments, and with several NASA-Ames personnel about the IRT. Although it was expected to work closely with NASA-MSFC on the development of the balloon version of the SIII, the schedule permitted a minimum interchange of concepts or data.

A *Baseline Experiment Definition Document* (BEDD) was prepared for each of the telescopes and arrays. These BEDDs are contained in the Appendix (Book 2) of this volume and include the experiment objectives, requirements, interfaces, time-lines and programmatic considerations.

A. ASSUMPTIONS

Simplifying assumptions and ground rules were used during the study since the study emphasis was on the sortie mission concept rather than on the individual optical systems. The detailed designs of the telescopes and arrays are the subject of other studies being performed by various NASA centers.

1. Resolutions

It was assumed that all instruments would be required, at least occasionally, to produce their highest possible resolution. This means that obscuration, wavefront error (WFE), and image motion must all be minimized. Obscuration is generally a function of the optical design and field of view; in this study the Blue Book values were used where possible. State of the art values for WFE and image motion were used even though such perfection is expensive to achieve. (A later study should consider the tradeoff of performance with cost to ensure that highest performance is justified.)

The assumption that the highest resolution must be provided should be considered in the light of the sortie missions and how they fit with other NASA space astronomy programs. Both the 100-cm PHG and the 120-cm SIII will be operated in the same time span with the large solar observatory (LSO) and the large space telescope (LST). It is reasonable to consider whether the sortie missions might not better be directed toward patrols and surveys, or to test new instrumentation or observational concepts. If so, then perhaps the expensive high-quality optics and the complicated and costly subsystems needed for best image stability could be dispensed with.

For the optical telescopes, resolution was defined on the basis of system MTF, which includes the effects of obscuration, WFE, image motion, and sensor. If ω_r line pairs per arc-second is the spatial frequency at which the MTF is 30%, then the resolution is ω_r^{-1} arc-s/line pair.

2. Sensors

The two major contenders for sensors on the various telescope are film and electronic image tubes. (The IRT is a case in itself because only electronic detectors respond over the extreme spectral range.) This choice between film and image tube depends on considerations of scientist quick response, data handling, relay satellites, weight, and cost. Film was used in the analyses because it offers the highest resolution and is available in large sizes, it therefore came closest to achieving highest resolution over the large fields of view required.

The effect of this choice of film for the sortie missions may be considerable. Image tubes would require either a large volume of onboard data storage or a high-capacity data link. The dimensions of the telescopes would probably increase because longer focal lengths would be required to match the poorer image tube resolution. The longer focal length and the limited format size of the tube combine to severely restrict the field of view so more exposures are required to cover a given area of the sky. On the other hand, each exposure can be shorter (at least for point sources) because image tubes have far higher quantum efficiencies than films.

3. Exposures

The length of exposure was not a part of this study. It was assumed that exposures generally would include many cycles of image motion.

4. Image Motion

It was assumed that image motion would have a Gaussian distribution, and the MTF analysis was treated accordingly. The specification on allowable image motion, or guide error, is based on an estimate of how much MTF degradation is acceptable. In general, an approximately 15% loss of MTF was allowed, which corresponds to about 10% worse angular resolution, compared to the zero-motion case.

5. Optical Parameters

In all cases published values of aperture and field of view were utilized when possible, and f/numbers were changed only when an obvious typographical mistake had been made. The result is that these systems are not necessarily optimized to match sensor to optics. Such optimization should properly wait until the sensor has been chosen.

6. MTF Analysis

An MTF analysis of each optical telescope was made because it graphically shows what factors limit system performance. In each case the analysis started with the MTF of a perfect optical system with its cutoff angular frequency at D/λ line pairs per radian, where D is the aperture diameter and λ is the specified wavelength. The next step demonstrated the effect of central obscuration. This degrades performance most at central frequencies, but raises the MTF near cutoff. The effect of wavefront error (WFE) on MTF was introduced next, again with greatest influence at central frequencies. The WFE arises from limitations in the design and manufacturing process, and from imperfect alignment of the optics due to thermal deformations.

Next, the MTF of the sensor was introduced. Film was used for all but the infrared telescope (IRT). At very high resolution film (Kodak 3404) was used for this purpose because it shows what the ultimate resolution of the system, as defined, could be. The film MTF is shown in Fig. II-1. In general, a slower system with longer focal length could improve resolution, but this would still further lengthen the exposure times.

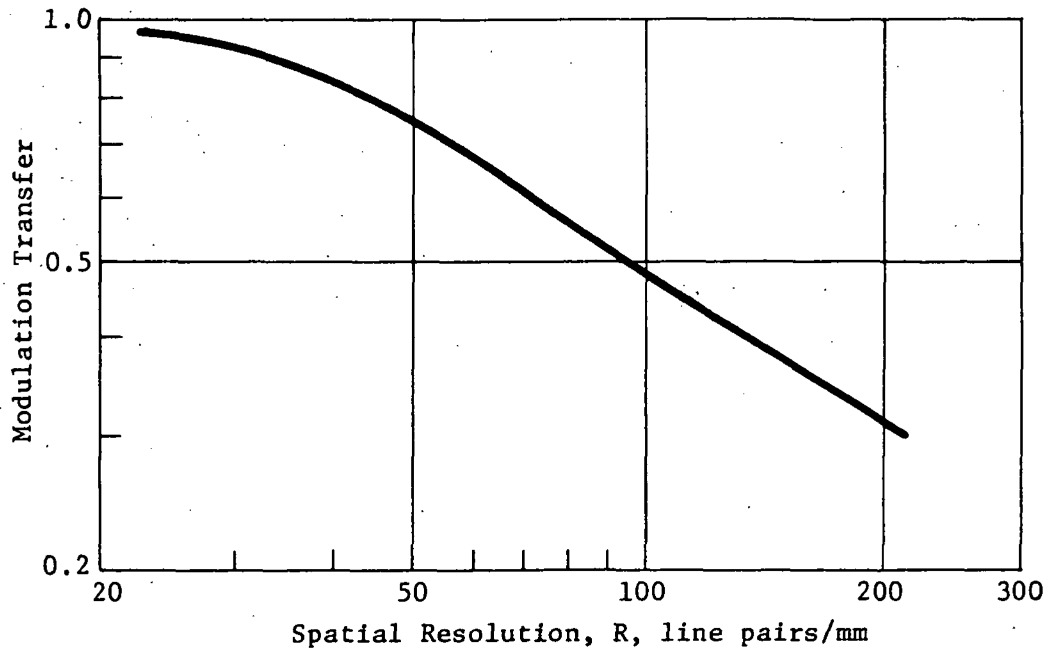


Fig. II-1 MTF of High-Resolution Film (Kodak 3404)

The last factor introduced in the MTF analysis was the image motion that results from errors of guiding, vibration in the structure, or relative motion between the guide stars and data star (differential velocity aberration). Although a Gaussian image motion function was assumed, for the small values used there is little difference between Gaussian and sine, linear, or bistable error functions.

From the MTF analysis it can be determined which factors have the greatest influence on system performance, what the specification for image motion should be, and what the system resolution will be. However, there are no "go/no-go" type criteria for setting image motion tolerance or resolution. The tolerance is only a matter of judgment as to what "looks" like a lot of MTF degradation. Only detailed analysis of implementation and cost for image stabilization can determine a reasonable set point.

System resolution depends on the objects being observed and the scene contrast. Astronomers look at point targets and continous-tone objects (stars, nebulae, solar granulation, or corona) with a wide range of contrasts. For this reason it is difficult to use one number to specify the resolution of each of the six optical telescopes in this study. An arbitrary point was chosen at which the MTF is 30% since this is usually in the midfrequency range.

The specification wavelength of all but the spectroheliograph (SHG) and IRT is 632.8 nm because optical systems are generally tested at this laser line. With the advent of ultraviolet lasers it may be possible to test at shorter wavelengths. The WFE expressed as wavelengths (λ) rms will be larger, but the cutoff angular frequency (D/λ) will also be larger. The result is that system resolution may or may not be worst, depending on the balance of MTF degrading factors.

B. PHOTOHELIOGRAPH (PGH)

The PHG on the Shuttle will provide man's most detailed observation of solar features until the 150-cm large solar observatory (LSO) becomes operational in the 1980's. The PHG will be supplied with a variety of cameras and spectrometers to suit most observational programs, though it apperas probable that individual sortie missions will be dedicated to a particular type of observation. The missions will be flown in highly inclined orbits so the sun may be viewed almost continuously.

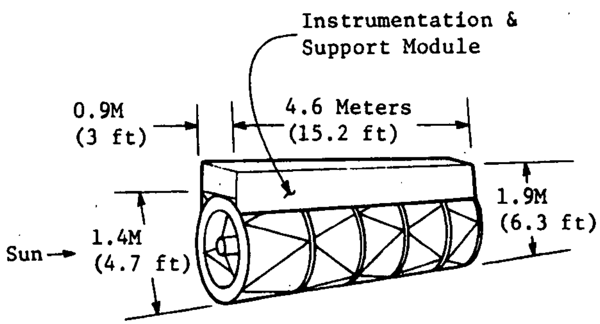
Figure II-2 summarizes the 100-cm photoheliograph that was baselined for this study. This PHG is a "scaled-up" version of the 65-cm instrument defined by BBRC under NASA Contract NAS8-30190. (Ref II-2) Since the 65-cm PHG was the original baseline for the study, the BEDD contained in the Appendix (Book 2) reflects the 65-cm PHG.

The accommodation requirements identified in Fig. II-2 are those that would be imposed on the carrier vehicle and do not reflect the capabilities of systems internal to the telescope. An example of this is the pointing stability requirements of 2.5 arc-s; this stability does not reflect the internal system that provides the ultimate stability of 0.03 arc-s rms that would be necessary to satisfy the telescope angular resolution of 0.3 arc-s/line pair.

1. <u>PHG Design</u>

The PHG in this study was based on a scaled-up version of the 65-cm design. Some rearrangement of the component parts was feasible because the design was no longer limited by the ATM envelope. This allowed a little closer coupling between the optical telescope assembly (OTA) and scientific instrument package (SIP), and also allowed the SIP to grow to accommodate a greater range of scientific instruments.

The basic 65-cm design grew to a 100-cm aperture, 1.4x1.9x4.6 m (56x75x182 in.) baseline [Fig. II-3(a)]. (The SIP does not necessarily scale with aperture; it was assumed here that there is no scaling.) For comparison, the 150-cm PHG currently being investigated by Itek (Ref II-3) was scaled to 100 cm. Figure II-3(b) shows that the in-line arrangement of the OTA and the SIP results in a very long package. By putting the SIP beside the OTA (decreasing the effective vertex back focus by several meters), the Itek package is only slightly larger than the baseline [Fig. II-3 (c)]. Therefore, it was concluded that while the baseline may be a slightly optimistic estimate of the final PHG hardware, it is suitable for this study. The PHG weight estimate was determined by scaling the 65-cm values. The original 65-cm estimate of 240 kg for the OTA and 150 kg for the SIP and support was first increased to a total of 440 kg to allow for a possibly more complex SIP. There are no universal rules of thumb for scaling the weight of a complex optical system; some components are invariant and others vary as the aperture cubed. Since the 65-cm weights were not itemized, a square-law scale was used, giving a 1000-kg baseline weight. This agrees well with the 900-kg estimate derived by scaling each items in Itek's 150-cm PHG weight table according to an appropriate scaling law. The flight weight of the PHG may vary by as much as 100 kg if each mission is dedicated to a particular type of observation.



Performance Characteristics

• Type	Gregorian
• Aperture	100 cm
• Obscuration	27%
• Spectral Coverage	200 to 700 mn (2000 to 7000Å)
• F/Number	F/3.85 Primary; F/50 Overall
• Field of View	8.7×10^{-4} Rad (3.0 arc-min)
• Format	44 mm
• Scale	20×10^{-6} Rad/mm (4.1 Arc-S/mm)
• Angular Resolution	1.45×10^{-6} Rad (0.3 Arc-S)
• Spectral Resolution	
Broadband Camera	10 to 50 mn (100 to 500Å)
H-Alpha Camera	25 pm (0.25Å)
Spectrograph	2.0 pm (0.02Å)
• Wavelength Specification	632.8 nm (6328Å)

Fig. II-2 100-cm Photoheliograph

Objectives

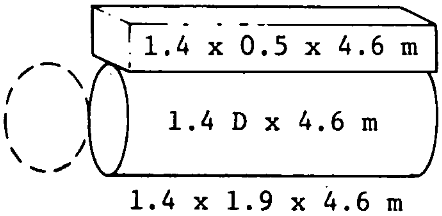
- High-Resolution Observation of the Sun in the 200 -to 700-Nanometer (2000 to 7000Å) Spectral Range
- Correlated Profiles of the Fine Solar Granulation Structure with Moderate Spectral and Angular Resolution
- Determination of Quantities of Elements in the Sun

Instrument Detectors

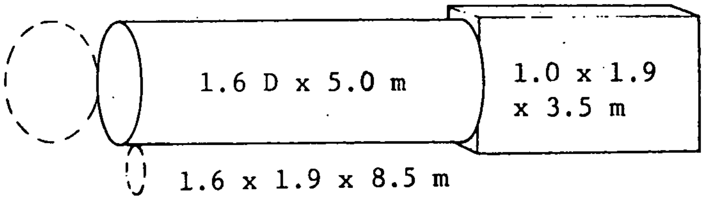
- Broadband Film Camera (2000 to 2500Å; 4000 to 7000Å)
- Hydrogen-Alpha Camera (6563Å)
- Dual-Range Spectrograph (2000 to 3000Å; 3000 to 7000Å)

Accommodation Requirements

• Size (Overall)	4.6 x 1.9 x 1.4 m(15.2 x 6.3 x 4.7 ft)
• Weight	1000 kg (2200 lb)
• Power	50 W Average; 80 W Peak
• Thermal	294°K Operating Environment; 283°K Cooling Fluid for Primary Shroud
• Data	35-mm Film Camera Broadband; 18,000 Frames Hydrogen-Alpha: 24,000 Frames Spectrograph: 3600 Frames Digital - 5100 bps Sunside 400 bps Darkside
• Controls & Displays	Panel Area; 0.23 m^2 (356 $in.^2$) Weight; 52.1 kg (116 lb) Power; 77 W
• Crew Requirements	13.3 Hr/Day - Operation
• Pointing Accuracy	2.4×10^{-5} Rad (5.0 Arc-S) (Instrument 0.3 Arc-S rms)
• Pointing Stability	$1.2.1 \times 10^{-5}$ Rad (2.5 Arc-S) (Instrument 0.03 Arc-S rms)
• Orbit	Continuous Sun

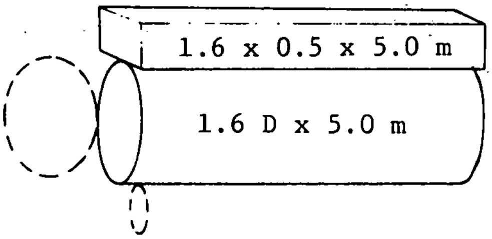


(a) PHG Baseline Scaled from 65-cm Instrument (Ref II-1)



(b) Itek's 150-cm PHG Scaled to 100 cm (Ref II-3)

<u>Note</u>: During operation, the doors will be extended and will increase the length and width by approximately 0.6 m.



(c) Itek's PHG Repackaged and Scaled for Shuttle

Fig. II-3 Comparison of Several PHG Packages

The 65-cm power estimate of 16 W average, 35 W peak greatly depends on the sensor chosen, since each image tube would consume 30 W average, 40 W peak. Itek has not yet developed a power profile for its 150-cm PHG, but it appears that no power would be required for thermal management in a twilight orbit. Further analysis may show it advisable to provide perhaps 150 W of thermal control (for the 100-cm PHG) to cover such contingencies as prolonged periods with the doors closed. Such periods could occur if an excessive contamination cloud appeared.

If the 65-cm PHG is scaled to 100-cm with constant f/number and field, then the format becomes 44 mm, which is nonstandard. In the MTF analysis it will be seen that a faster telescope may be possible without loss of resolution, and this could put the format back to a standard format.

2. PHG MFT Analysis

The MTF curves in Fig. II-4 show the performance of perfect optics degraded successively by obscuration, wavefront error, and film response. The 27% obscuration predicted is close to the 20 to 25% estimate for the Itek 150-cm PHG. The film is seen to produce a negligible effect on performance, which would indicate that a somewhat faster telescope could have been designed if this very slow film were to be used. However, a faster film could also be used to match the optics.

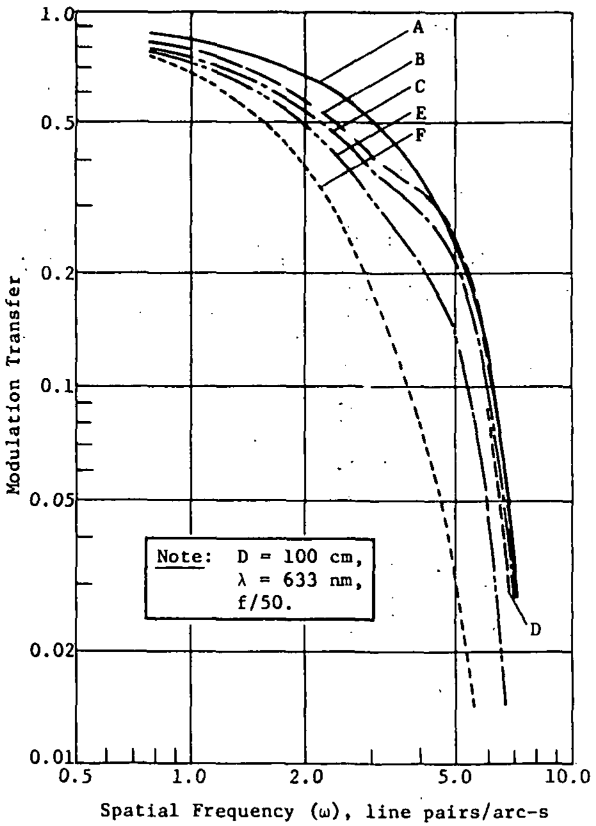
The effects of two values of random image motion are shown; it was assumed that the motion is Gaussian. There is no clear criterion by which to set a specification for allowable image motion; it is just a question of how much MTF loss is thought to be allowable and what it takes to achieve image stability. On the basis of Fig. II-4, however, it appears that the specification should be no larger than 0.03 arc-s rms.

In Itek's work on the 150-cm PHG for NASA-MSFC, the solar object modulation function was estimated. Figure II-5 shows the adopted function at 600 nm. It is based on a correlation of 670°K/arc-s surface gradients with observed modulation of solar granules. In the sortie study, system resolution was defined as the spatial frequency giving 30% modulation. From Fig. II-5 this gives 3.2 line pairs per arc-s. The source modulation at this frequency (Fig. II-6) is 10%, so that the image modulation is 3%. This corresponds to a very common definition of minimum-detectable images on film. It is therefore concluded that in this case, the 30% MTF criterion for resolution is suitable.

3. PHG Pointing and Guiding

To stabilize the image to 0.03 arc-s rms, it will be necessary to do internal guiding since the fine gimbals proposed for sortie missions cannot achieve 0.03 arc-s. Fine guiding will be achieved with a real-scene sensor driving a small folding flat.

If only a field camera were to serve as instrumentation, the pointing accuracy requirement could be quite loose (e.g., 5 arc-seconds). However, a spectrograph will also be used, and it should be possible to place its entrance slit to a pointing accuracy requirement of about 0.3 arc-second, rms, which is near the system resolution.



Legend:

A	Perfect Optics
B	27% Obscuration x Curve A
C	0.05λ rms WFE x Curve B
D	High-Resolution Film x Curve C
E	0.03-arc-s rms Image Motion x Curve D
F	0.06-arc-s rms Image Motion x Curve D

Fig. II-4 MTF Analysis of PHG

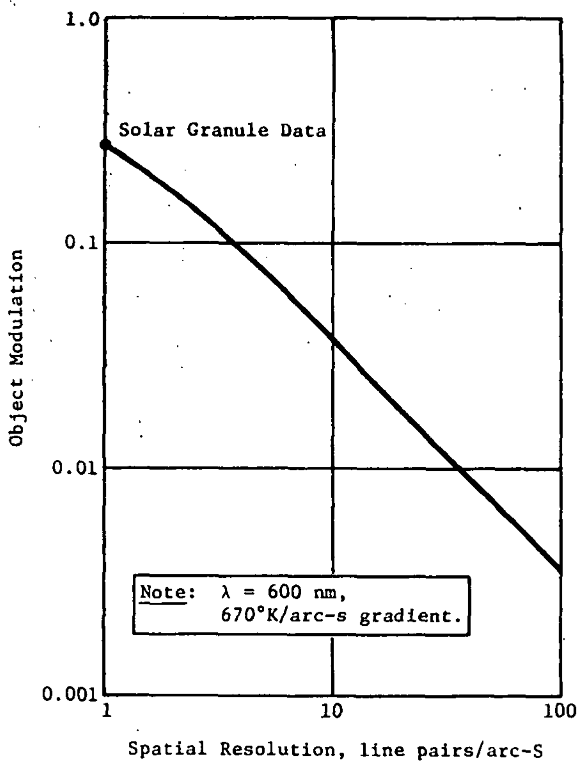
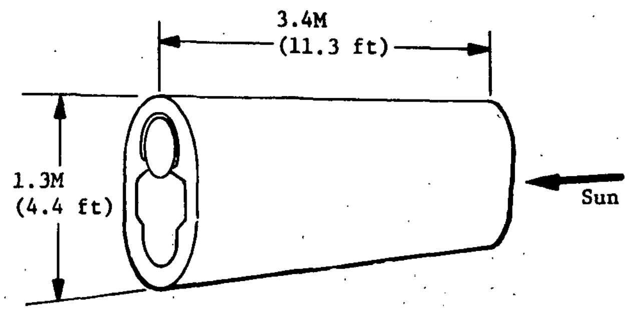


Fig. II-5 Continuum Modulation of the Sun



Objectives

- Observation of the Solar Disk in Bright-Line (XUV) Wavelengths between 17 and 65 nm (170 and 650Å)

Instrument Detectors

- Slitless Spectroheliograph
- Aspect Sensors (Field Viewing & Image Monitoring)

Performance Characteristics

• Type	Prime Focus
• Aperture	25 cm
• Obscuration	0
• Spectral Coverage	17 to 65 nm (170 to 650Å)
• F/Number	F/12 Primary (and System)
• Field of View	9.3×10^{-3} Rad (32 arc-min)
• Format	28-500 mm
• Scale	3.34×10^{-4} Rad/mm (69 arc-s/mm)
• Angular Resolution	5.8×10^{-6} Rad (-1.2 arc-s)
• Spectral Resolution	1.5 pm (0.015Å)
• Wavelength Specification	17 nm (170Å)

Accommodation Requirements

• Size (Overall)	3.4 x 1.3 x 0.76 M (11.3 x 4.4 (11.3 x 4.4 x 2.5 ft)
• Weight	430 kg (954 lb)
• Power	50 W Average; 60 W Peak (Film Changing and Calibration)
• Thermal	294°K Operating Environment
• Data	35-mm Film Camera One Image every 3 Minutes Digital - 60 bps Sunside, 10 bps Darkside
• Controls & Displays	Panel Area; 0.164 m^2 (254 $in.^2$) Weight; 41 kg (91 lb) Power; 70 W
• Crew Requirements	3.1 Hr/Day Operation
• Pointing Accuracy	73×10^{-6} Rad (15 Arc-S)
• Pointing Stability	0.49×10^{-6} Rad (0.1 Arc-S)
• Orbit	Continuous Sun

Fig. II-6 25-cm XUV Spectroheliograph

C. XUV SPECTROHELIOGRAPH (SHG)

The SHG is an extreme ultraviolet instrument operated essentially as a slitless spectrograph. It records a monochromatic image of the entire sun in each emission line. It is conceived of as a patrol camera, taking pictures every 3 minutes until solar activity occurs, when the rate goes to one every 30 seconds. The SHG is one of several solar instruments that can be flown with the PHG. Figure II-6 summarizes the SHG baseline used for this study.

1. SHG Design

The SHG is based on the Blue Book and OASF (Ref II-4) designs. While the two differ internally, they have the same package size and interface specifications. Since the OASF design has only one reflection and uses a photographic sensor, it seems preferable for sortie operation. Figure II-7 shows the packaging and optical configuration for the SHG. It also shows an alternative packaging configuration that is possible should space become critical.

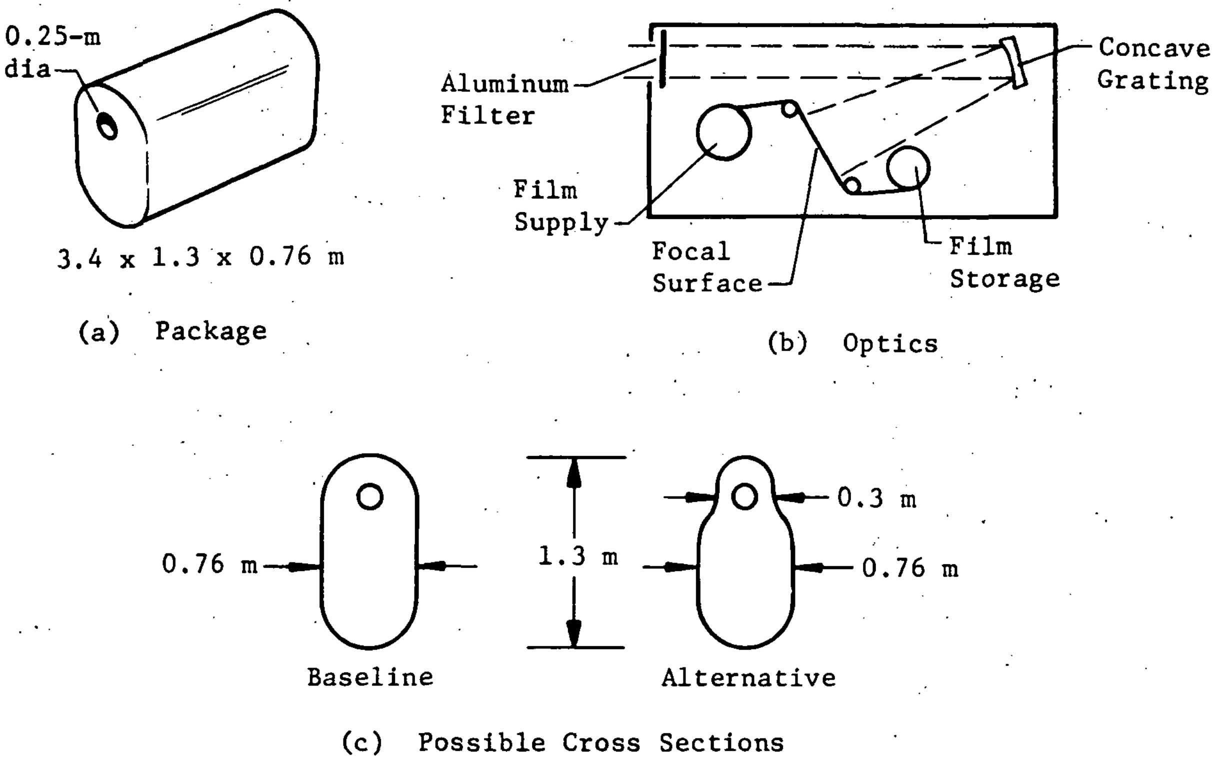


Fig. II-7 SHG Configuration

The 430-kg weight given in the Blue Book has been adopted. A simple film system would ordinarily weigh less than an electronic image tube, but the low gelatin content of XUV film forces special handling techniques that increase the weight.

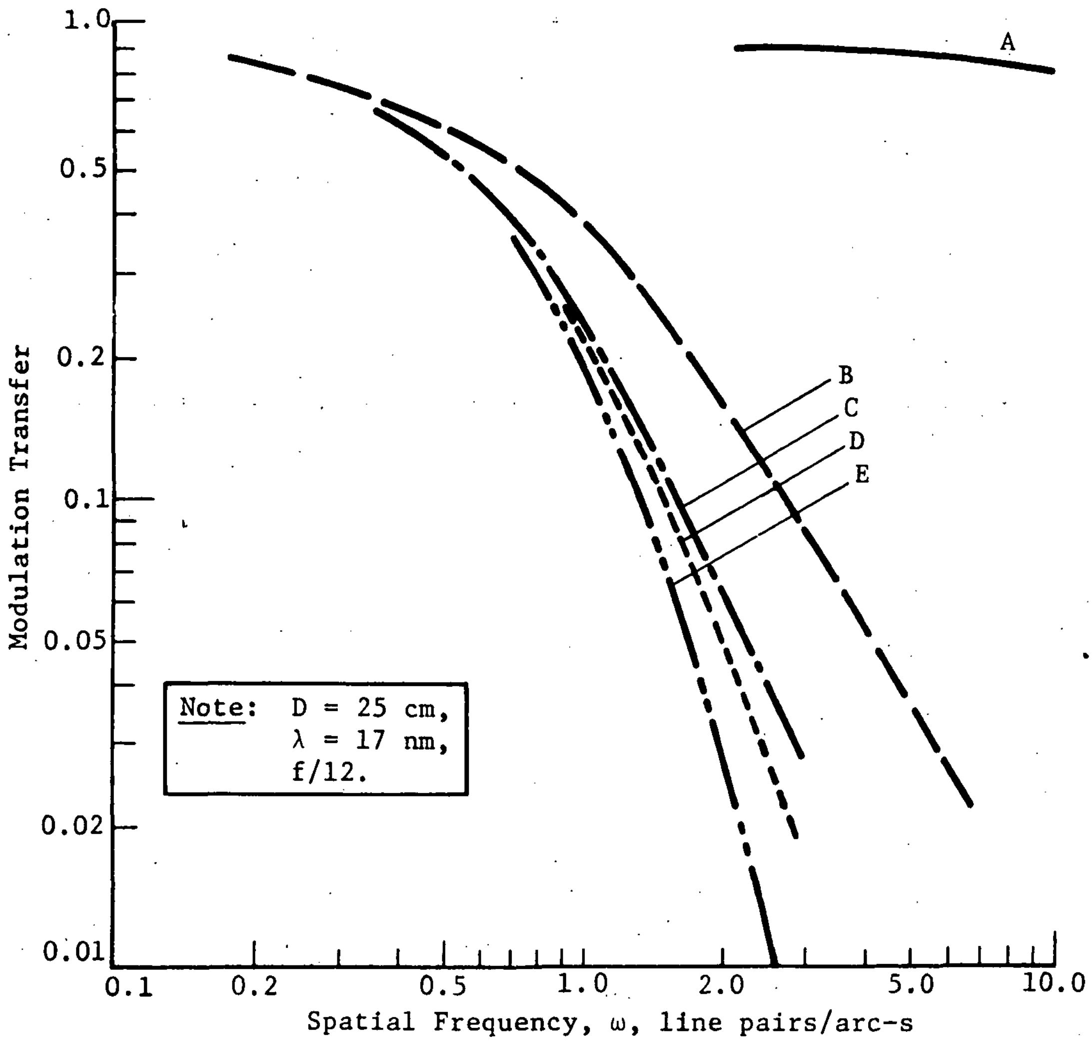
The Blue Book-suggested average and peak electrical power are 55 and 70 W for an image tube version of the SHG. A film version requires power only to move the film (10 W) and operate the calibration sources (5 W). Since these are very low duty cycle events, the average power is negligible. However, to provide some growth capability and to allow some power for thermal control, the average power requirement has been set at 50 W with a peak power of 60 W.

2. SHG MTF Analysis

The MTF curves of the SHG are given in Fig. II-8. A WFE of 0.05λ rms at 17 nm. This assumes that an aspheric grating is developed, because conventional gratings produce large amounts of astigmatism. Even the asphere will give good images for only one wavelength. It was also assumed that the filter introduces negligible WFE. When WFE exceeds about 0.1λ rms, its effect on MTF depends on the source of error--spherical, coma, or astigmatism. Lacking other data it was assumed that the 2λ rms WFE would be composed of equal portions of each error type. Figure II-8 shows that WFE greatly degrades perfect performance, and that the film further reduced performance significantly. A slower system (larger f/number) would improve resolution, but light levels are so low at these wavelengths we do not recommended this approach.

The same film MTF curve was used for this analysis as was used in the other ultraviolet-visual instruments, though in fact a special low-gelatin material will be required in the SHG. It was not determined what MTF the special film might have, or even whether it might be better or worst than the conventional materials.

From Fig. II-8 it can be seen that at least 0.1 arc-s rms image motion can be tolerated. When the SHG is analyzed in detail, the WFE may be found to be worse than estimated above, in which case the image motion might be relaxed considerably. The 0.1 arc-s rms is proposed as a worst-case possibility.



Legend:

A	Perfect Optics
B	2.0λ rms WFE x Curve A
C	High-Resolution Film x Curve B
D	0.05-arc-s rms Image Motion x Curve C
E	0.1-arc-s rms Image Motion x Curve C

Fig. II-8 MTF Analysis of SHG

3. SHG Pointing and Guiding

Although the pointing accuracy required for SHG need be only 15 arc-s rms, the MTF analysis showed that the image motion should be kept to 0.1 arc-s rms. It would be difficult to achieve this stability with an internal closed-loop system because of the short wavelengths involved, so the requirement must be met by the main gimbal system.

4. Thermal Considerations

Since there has been no optical analysis of the SHG, allowable thermal deformations are not presently known. However, if it is assumed that soak temperatures have little effect on performance but that the thermal gradient is important, that the principal effect of a gradient is "hot-dogging" of the structure, and that the deformation tolerance is determined by movement of the sensor, the allowable transverse gradient in the SHG can be esimated.

The deformation, δ, of a uniform structure due to a transverse gradient is given by

$$\delta = \alpha L^2 \Delta T / 2D.$$

If it is assumed that the coefficient of expantion is $\alpha = 10^{-6}/°C$, the length between mirror and sensor is $L = 2$ m, and the structural width is $D = 1.3$ m, the MTF curves in Fig. II-8 show that we will probably operate near a film response of 75% for low-contrast targets; this corresponds to 50 line pairs/mm. Thermal effects would be considered negligible if they moved the film less than 0.1 resolution element, or 2 μm. This then sets a gradient limit of 1.3°C in one direction; it is 0.9°C across the tube. The gradient is a problem only if it changes during an exposure, which may last many seconds. Such rapid temperature changes are not likely to occur.

The SHG is a closed system. The aluminum filter at the aperture passes less than 10^{-10} of the solar energy ($\lambda < 67$ nm, 5800°K blackbody). Transverse gradients will be introduced only through the outer skin of the tube and through the mounting surface. It will be necessary to supply some heat to the interior to make up heat losses because the SHG should be operated at 294°K. This heat could be introduced with electrical heaters (perhaps 50 W total). Alternatively, a small solar absorber could be placed at the front of the tube to control soak temperatures, and an electric heater of small wattage could control gradients. This latter alternative would be attractive, however, only in a power-limited mission. Therefore a 50-W load on the electrical system has been assumed for thermal control.

D. X-RAY TELESCOPE (XRT)

The X-ray telescope will observe solar phenomena in the 2 to 100 Å wavelength region with high spatial, spectral, and temperal resolution. Figure II-9 summarizes the XRT baseline used for this study.

1. XRT Design

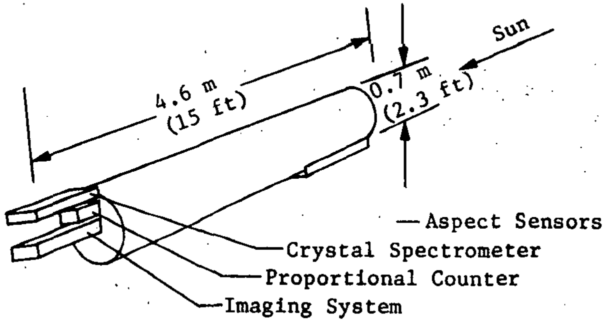
The XRT defined in the Blue Book has an aperture of 50 cm and an overall length of 7.15 m (23.5 ft). To accommodate the XRT to the sortie mission, it was necessary to reduce the overall length of the telescope to 4.6 m (15 ft). It was assumed that the grazing angles identified in the Blue Book satisfied the scientific objectives and that it was desirable to maintain these angles. Therefore the aperture of the XRT was reduced to 32 cm to maintain the X-ray grazing angles. The weight of the XRT was reduced to reflect the changes in the aperture and length.

A film system was adopted for this study in place of the electronic imaging device identified in the Blue Book.

The performance characteristics for the XRT were based on the Blue Book definition and the ATM experiment S054 (Ref II-5) definition.

2. XRT Pointing and Guiding

The pointing accuracy requirement for the XRT was relaxed to 20 arc-s since the experiment crew could be utilized to close the pointing loop. The requirement for guiding error was set at 0.1 arc-s since the resolution at the center of the field would be approximately 0.5 arc-s.



Performance Characteristics

● Type	Grazing Incidence
● Aperture	32 cm
● Spectral Coverage	0.2 to 10 nm (2 to 100Å)
● F/Number	F/10 Overall
● Field of View	2.9×10^{-3} Rad (10 Arc-M)
● Format	14.6 mm
● Scale	2×10^{-4} Rad/mm (41.2 Arc-S/mm)
● Angular Resolution	
Imaging System	Less than 5×10^{-6} Rad (1 Arc-S)
Crystal Spectrometer	10 to 50×10^{-6} Rad (2 to 10 Arc-S)
Proportional Counter	10 to 50×10^{-6} Rad (2 to 10 Arc-S)
● Spectral Resolution ($\lambda/\Delta\lambda$)	
Imaging System	Less than 2
Crystal Spectrometer	Greater than 2×10^{3}
Proportional Counter	Less than 2
● Temporal Resolution	
Imaging System	Greater than 0.01 S
Crystal Spectrometer	Greater than 100 S
Proportional Counter	Less than 0.01 S

Fig. II-9 32-cm X-ray Focusing Telescope

Objectives

- Observe Solar X-ray Phenomena in the 0.2- to 10-nm (2 to 100Å) Wavelength Region.
- Obtain Solar X-ray Data with High Spatial, Spectral, and Temporal Resolution

Instrument Detectors

- Imaging System (X-ray to Visible Light Image Converting)
- Crystal Spectrometer (Spectral Resolution)
- Proportional Counter (Temporal Resolution)
- Aspect Sensors (H-Alpha and X-Ray)

Accommodation Requirements

● Size (Overall)	4.6 x 0.7M-dia (15 x 2.3 ft)
● Weight	392 kg (862 lb)
● Power	160 W Average, 230 W Peak
● Thermal	294°K
● Data	Film Camera (Imaging System) Digital 10 kbps (Spectrometer/ Counter)
● Control & Display	Panel Area 0.26 m^2 (402 $in.^2$) Weight 80.6 kg (179 lb) Power 99 W
● Crew Requirements	25% Quiet or Active Sun; 95% during Flare
● Pointing Accuracy	1×10^{-4} Rad (20 Arc-S)
● Pointing Stability	0.49×10^{-6} Rad (0.1 Arc-S)
● Orbit	Continuous Sun

E. CORONAGRAPHS (CORs)

Two coronagraphs will be available for use with the PHG--the inner coronagraph (IC) views to six solar radii and the outer coronagraph (OC) to 30. These are essentially white-light instruments operated as patrol cameras. Like thy SHG, the coronagraph assembly (COR) will normally take a picture every 3 mintues, but can go to 30-second rate when solar activity is occurring. Figure II-10 summarizes the COR baseline.

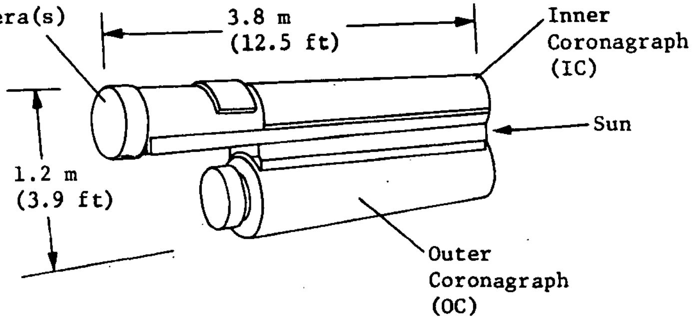
1. COR Design

The COR is based on the Blue Book and OASF (Ref II-4) concepts with one modification. Two mirrors were introduced into the IC optical path in the Blue Book version, evidently to shorten the instrument. These mirrors can only degrade performance by extra scattering and WFE, and the large cargo bay of the Shuttle will accommodate the telescope without the need for folded optics. Therefore the IC was extended 0.2 m for a total length of 3.8 m (including cameras). This sets the COR length. The width is set by the OC diameter of 0.7 m, exclusive of mounts, etc. The Blue Book height of 1.4 m depends on the hardware used to join the IC and OC and to mount the assembly to its gimbal. Since a decrease of 0.2 m is feasible, 1.2 m was used.

The COR weight is taken from the Blue Book; a small increase results from added tube length when the IC is unfolded, but the tube diameter can be kept constant and no mirror brackets are needed so the net weight change is negligible.

The Blue Book calls for coronagraph spectral coverage from 400 to 1000 nm, which indicates an infrared-sensitive film. These films generally have a moderate to low resolving power. Also, solar astronomers do not find the near-infrared particularly interesting. For these reasons a 400- to 700-nm coverage was specified. Two different film sizes are used in the OASF concept. In keeping with our graound rule for this study, the suggested formats have been retained, but at a later date it would seem logical to standardize on one format for as many of the sortie instruments as possible.

The f/2.25 optics cited for the OC in Figure II-10 differs from the OASF f/1.85 and the Blue Book f/12.9 values. However, the latter two numbers are inconsistent with such other specifications as focal length, plate scale, or format.



Objectives

- Observe White-Light Emission of Outward Moving Plasma Clouds
- Detect Outward Moving Disturbances along Coronal Streams
- Determine Quantities of Matter in Coronal Streams
- Determine Phase Velocities of Disturbances

Instrument Detectors

- Film Camera - IC (1 to 6 Solar Radii)
- Film Camera - OC (5 to 30 Solar Radii)

Performance Characteristics

● Type	Refractor
● Aperture	2.45 cm (IC) 4.0 cm (OC)
● Obscuration	18% (IC) 26% (OC)
● Spectral Coverage	400 to 700 nm (4000 to 7000Å)
● F/Number	F/12.9 - IC F/2.25 - OC
● Field of View	0.057 Rad (3.25°) - IC 0.26 Rad (15°) - OC
● Format	18 mm - IC 24 mm - OC
● Scale	31.7 x 10^{-4} Rad/mm 11 (arc-min/mm) - IC 1.11 x 10^{-2} Rad/mm (38 arc-min/mm) - OC
● Angular Resolution	68 x 10^{-6} Rad 14 (arc-s) - IC 97 x 10^{-6} Rad (20 arc-scc) - OC
● Wavelength Specification	732.8 nm (6328Å)

Accommodation Requirements (Inner and Outer Coronagraph Assembly

● Size	3.8M x 1.2M x 0.7M (12.5 ft x 3.9 ft x 2.1 ft)
● Weight	430 kg (954 lb)
● Power	40 W Average; 32 W Peak
● Thermal	294°K Operating Environment
● Data	35-mm Film Cameras One Exposure every 3 Minutes on Sun Side for Each Coronagraph Digital - 110 bps Sunside, 10 bps Darkside
● Controls & Displays	Panel Area: .0.15 M^2 (234 in.^{2}) Weight: 36.4 kg (81 lb) Power: 65 W
● Crew Requirements	2.0 Hr/Day Operation
● Pointing Accuracy	9.7 x 10^{-6} Rad (2 arc-s)
● Pointing Stability	4.9 x 10^{-6} Rad (1 arc-s)
● Orbit	Continuous Sun
● (Operation)	(Limited Gimbals or Flexure Mounts to Allow Assembly Axis to be Solar-Disk-Centered if other Instruments are Oriented to Spots on the Sun)

Fig. II-10 Inner and Outer Coronagraphs

The Blue Book power requirement has been reduced because film cameras are being used in place of the electronic imaging devices. However, there does appear to be a need for electrical heaters to control temperatures. This results in a small net change from the Blue Book values.

2. COR MTF Analysis

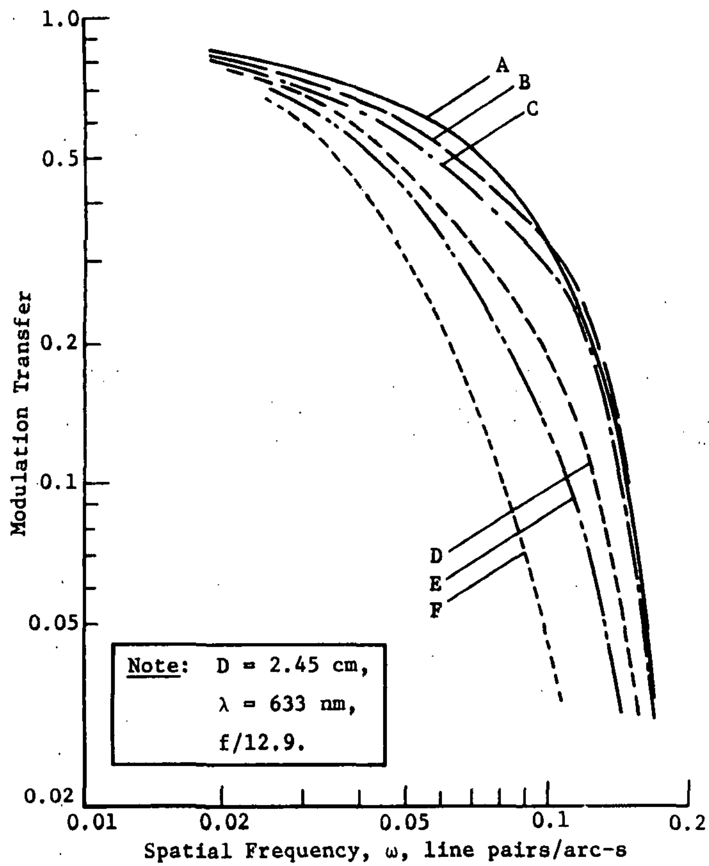
The MTF curves in Fig. II-11 and II-12 show how perfect optics are degraded by obscuration, WFE, film response, and two levels of image motion. The amount of obscuration was taken from the Blue Book. The design goal of 0.05λ rms may be difficult to achieve over the whole spectrum and field. Even if achieved, it appears that the 12 arc-s rms IC resolution of the Blue Book may not be achieved at low contrast. It will readily be achieved at higher contrasts.

It is evident that the 9-cm focal length of the OC is inadequate to fully utilize the resolution capability of the film. The simulation will become worst if a faster film or electronic image tube is used. On the other hand, there is so little light in the outer corona that it may not be practical to increase focal length by using slower optics. It may be that a larger aperture will be found to be the best solution. The Blue Book calls for a 30 arc-s resolution (ω = 0.033 line pairs/arc-s). Figure II-12 shows 40% MTF at this spatial frequency. This may not be adequate for the relatively low scene contrast found in the outer corona.

The MTF curves show that an image motion tolerance of about 1 arc-s rms for the COR is desirable.

3. COR Pointing and Guiding

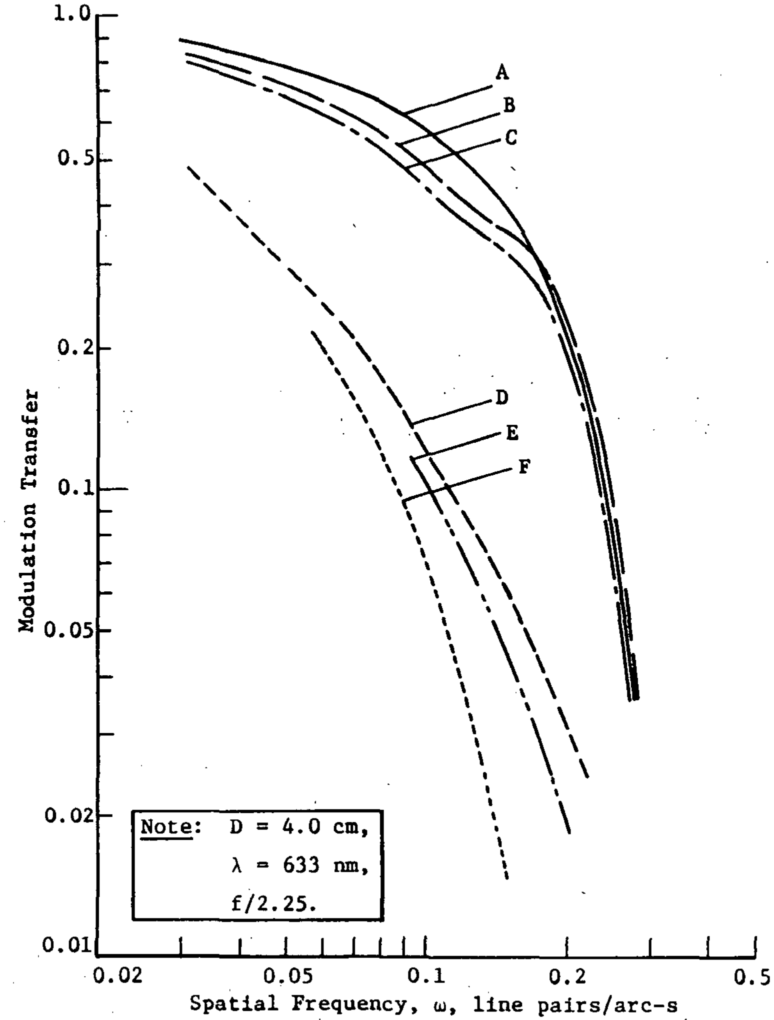
The pointing requirements for the COR are set by the IC. Solar astronomers would like to be able to view the corona to within 5 arc-s of the solar limb, although they realize that this will be difficult to achieve in practice. What is required is that the occulting disk must be centered on the sun with high precision. A pointing or guiding error, or a thermal deformation of the optical bench that holds the disk, could allow an edge of the sunlight to leak into the optics and completely mask the coronal image. Therefore a 2 arc-s pointing accuracy is identified. This should readily be achieved with appropriate internal sensors.



Legend:

A	Perfect Optics
B	18% Obscuration x Curve A
E	0.05λ rms WFE x Curve B
D	High-Resolution Film x Curve C
E	1.3 arc-s rms Image Motion x Curve D
F	2.6 arc-s rms Image Motion x Curve B

Fig. II-11 MTF Analysis of IC



Legend:

A	Perfect Optics
B	26% Obscuration x Curve A
C	0.05λ rms WFE x Curve B
D	High-Resolution Film x Curve C
E	0.8 arc-s rms Image Motion x Curve D
F	1.6 arc-s rms Image Motion x Curve D

Fig. II-12 MTF Analysis of OC

The large field of the OC results in the tightest roll stability specification of all six optical telescopes. The relation is

$$\rho = \frac{2\varepsilon/\theta}{4.85 \times 10^{-6}}$$

The field of view of the OC is θ = 15 deg = 5.4×10^4 arc-s. The total guide error allowed is 1 arc-s rms, so no more than ε = 0.5 arc-s rms should be budgeted to roll instability. This then specifies a roll stability of ρ = 4 arc-s for the instrument. The 0.5 arc-s rms error due to roll will be found only at the edge of the field. Since it decreases to zero at the center, the 4 arc-s specification could be relaxed a little if necessary.

4. COR Thermal Considerations

Although the Blue Book shows conceptual layouts of the two coronagraph optical system, there are no optical designs on which a thermal analysis could be based. It appears, however, that the lens assemblies and optical assemblies are so small that uncontrolled thermal gradients large enough to degrade the imagery are not anticipated.

Probably the tightest thermal specification in the COR comes from the decentering tolerance on the external occulting disk assembly in the IC. It is desirable to observe to within 5 arc-s of the solar limb, and 2 arc-s was established for pointing error. If 1 arc-s is assumed for thermally induced decenter error for the occulting disk, since it is the disk that determines how close to the solar limb observation can be made, then the allowable decenter for 1 arc-s error is δ = 10 μm in a spacing of L = 2.2 m.

If the IC tube is treated as a homogeneous cylinder with expansivity $\alpha = 10^{-6}$/°C and a uniform gradient ΔT (°C) is assumed across the D = 0.25 m tube, then to a first approximation

$$\delta = \alpha L^2 \Delta T / 2D$$

so that T = 1.1°C.

This is quite a tight tolerance for a transverse gradient in a structure that will be directly exposed to a space environemnt. Transverse gradients will probably result from the mounts joining the COR to a mounting structure and from the fact that one side of the coronagraph sees space or earth while the other sees the Shuttle or adjacent instruments. Basic calculations show that a small cyclic variation in heater power from 30 to 50 W may be required to remove gradients. Alternatively, the structure could be athermalized to the point that no thermal control would be needed.

F. STRATOSCOPE III (SIII)

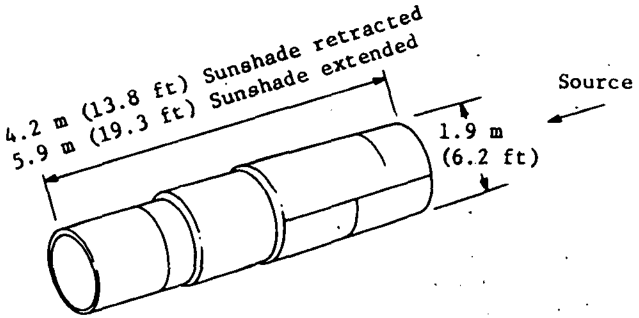
The SIII is the largest of the six optical telescopes considered in this study and, with the PHG, is best defined at this time. Several development sequences are associated with it. It will be a successor to the balloon-borne SIII (with as much commonality of design and hardware as possible) and it will be a predecessor to the 3-m LST (serving as an engineering model). However, it is also a research instrument in its own right. Its optical system is modeled on the Itek LST (Ref II-6, II-7, and II-8), with an f/1.1 primary mirror and an f/12 system. The scientific instrumentation has almost as broad a range of capabilities as those of the LST, but photographic materials will replace electronic sensors. Figure II-13 summarizes the SIII baseline used in this study. This baseline is compared with the current balloon-borne version in Section F.5.

1. SIII Design

The dimensions and weight of the SIII are scaled from Itek's analysis of the LST. The diameter of the tube does not scale directly with aperture because the light traps used for stray light control should be kept very deep. On the other hand, there is less need for meteor protection in the SIII. The length scales with aperture fairly well, but can vary greatly according to the scientific instrumentation. The basic telescope is 3.2 m long, but the spectrographs can add almost another full meter.

The weight estimate is based on a data developed for the LST. Each item was scaled based on engineering judgement. For instance, the heaviest single item is the primary mirror, whose weight might be expected to scale as the diameter cubed. However, the faceplates of the eggcrate mirror blank could not be built thinner due to manufacturing limitations, so a diameter squared scaling was indicated. The LST pressure bulkhead is not needed in the SIII because no on-orbit manned maintenance is planned, but a support ring had to be added for the scientific instrument package (SIP).

The extendible baffle adds 0.2 m in diameter and increases overall length by 1.7 m in use. It is conceivable that the Shuttle could always be flown to make the baffle unecessary, but only with restricted performance.



Performance Characteristics

• Type	Ritchey-Chretien
• Aperture	120 cm
• Obscuration	34%
• Spectral Coverage	90 to 2000 nm (900 to 20000Å)
• F/Number	F/2.2 Primary; F/12 Overall
• Field of View	17.5×10^{-4} Rad (6.0 arc-min)
• Format	50 mm
• Scale	67.9×10^{-6} Rad/mm (14 arc-s/mm)
• Angjlar Resolution	1.45×10^{-6} Rad (0.3 arc-s)
• Wavelength Specification	632.8 nanometers (6328Å)

Objectives

- Detailed Observation of Stellar Objects in the 90 to 2000 nm (900 to 20,000Å) Spectral Range
- Slitless Spectrography of Specific Features in Large-Emission Nebulae
- Direct Photography of Galaxies

Instrument Detectors

- Field Cameras (1150 to 6500Å)
- UV Spectrographs (1000 to 3000Å)
- IR Spectrographs (5000 to 20000Å)
- Polarimeters (900 to 4000Å)
- Aspect Sensor (Field Viewing)

Accommodation Requirements

Size (Overall)	4.2 x 1.9 m (13.8 x 6.2 ft)
Weight	1800 kg (4000 lb)
Power	140 W Average; 180 W Peak
Thermal	294°K Operating Environment
Data	35-mm Film Camera Digital, 2200 bps
Controls & Displays	Panel Area: 0.23 m^2 (356 in^2) Weight: 58 kg (129 lb) Power: 88 W
Crew Requirements	3.2 Hr/Day - Operation
Pointing Accuracy	9.7×10^{-6} Rad (2.0 arc-s) (Instrument 0.3 arc-s rms)
Pointing Stability	0.49×10^{-6} Rad (0.1 arc-s) (Instrument 0.02 arc-s rms)
Orbit	28.5° Inclination; 250 n mi Altitude
Operation	Line-of-Sight No Closer than 0.785 Rad (45°) to the Sun and 0.262 Rad (15°) to Earth

Fig. II-13 120-cm Stratoscope III

The weight of the scientific instruments for the SIII is based on the 770-kg instrumentation in the GSFC X-670-70-480 report (Ref II-7). Some structure in that report is redundant to the SIII structure, and some instruments can be reduced in number or size (e.g., use of film would obviate the need for f/96 cameras, though the MTF analysis shows that some relay power is desirable). It may even be desirable to select which instruments will go on each flight of SIII. (This would definitely be the mode of operation in balloon flights.) On the other hand, the SIII will require a two-star guider, and should carry focus, alignment, and figure sensors. Taking all these factors together, a 700-kg weight estimate for the experiments seems reasonable; this adds to the 1100 kg telescope to give an 1800-kg system.

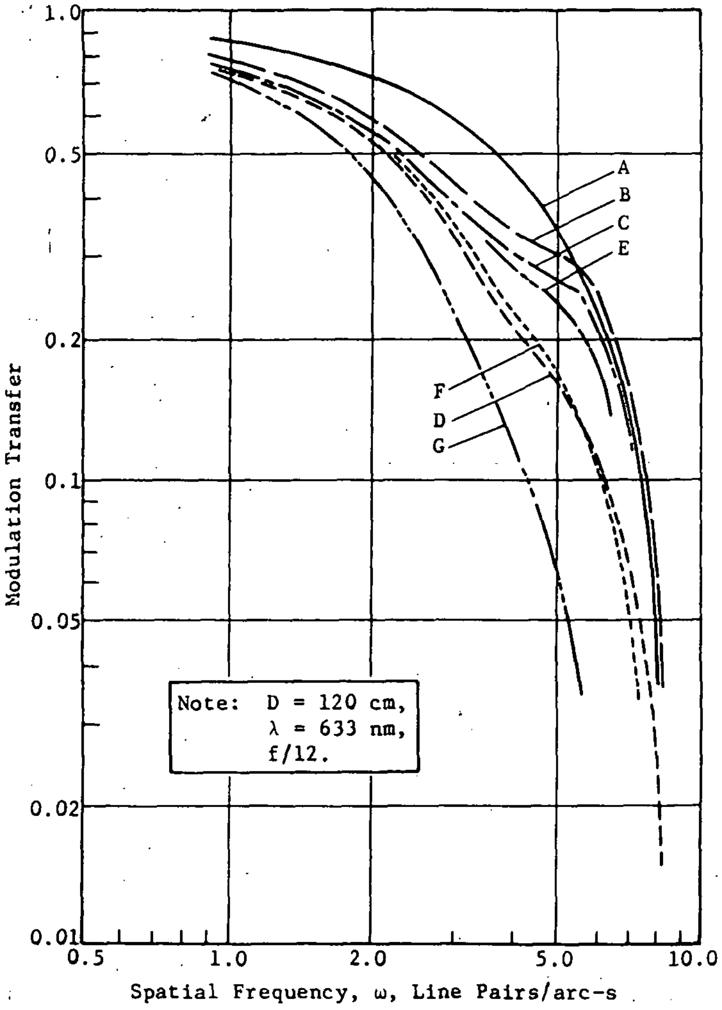
2. SIII MTF Analysis

The perfect MTF curve in Fig. II-14 has been degraded by the LST obscuration value of 34%. The availability of a large format with film may make a very wide field of view interesting even though the resolution at the edges would degrade; this would increase the amount of obscuration. The LST wavefront error of 0.05λ rms has also been used. The large degradation caused by the film shows that a relay is required to achieve the resolution inherent in the telescope image. This relay would convert the f/12 telescope to perhaps f/24. If the image stability specification is based on the f/12 image, some of the potential SIII capabilities would be sacrificed. Therefore, it was shown how image motion degrades the MTF of the image with a 2X relay in use. It appears that an 0.02 arc-s rms image stability will be adequate for the SIII.

3. SIII Pointing and Guiding

The pointing specification is determined by the small entrance aperture of the radiometers and spectrographs that make up the scientific instrumentation. Among the considerations that determine these apertures are signal-to-noise ratio, exclusion of sky light, and spectral resolution. LST analysis to date shows that the smallest aperture to be used will probably approximate the system resolution, so that the pointing specification will be 0.3 arc-s rms.

Since the image stability requirement of 0.02 arc-s rms is beyond the capabilities of the main gimbal system, internal closed-loop guidling will be required. This will cover the gap between the gimbal limit and the requirements of the SIII.



Legend:	
A	Perfect Optics
B	34% Obscuration x Curve A
C	0.05λ rms WFE x Curve B
D	High-Resolution Film x Curve C
E	Same as Curve D but at f/24
F	0.026 arc-s rms Image Motion x Curve E
G	0.053 arc-s rms Image Motion x Curve E

Fig. II-14 MTF Analysis of SIII

4. SIII Thermal Considerations

It would be desirable to have the sortie SIII be as close to the balloon SIII as possible in terms of hardware and operation. The balloon version will be run with warm optics and a cold tube. A full-aperture window is used to reduce wavefront errors resulting from heating of the residual atmosphere. It appears that preconditioning to the 215°K temperature of the atmosphere at an altitude of 25 km will not be necessary because the telescope tube can be left open to the air, thus giving good thermal contact. At altitude the tube would be sealed and evacuated. A total of 60 W is expected to be adequate for heating the mirrors and their mounts.

The sortie SIII can operate in much the same way except that it may be necessary to precondition to 225°K before launch. This will ensure that astronomical observations need not wait for temperature stability to be achieved. Again, 60 W will be adequate: 30 to heat the back of the primary missor, 20 to heat its mount, and 10 for the secondary mirror assembly.

Two other methods of handling the temperature probelm are feasible. An athermalized system would reduce the total power needed, but would merit the cost only if power were in short supply. Alternatively the structure could be heated so all critical components of the telescope are kept warm. This would require perhaps 120 W total and would be possible by wrapping the structure in superinsulation.

5. Comparison with Current SIII Concept

One of the ground rules set at the kickoff meeting of this study was that the 1.2 m sortie SIII system should be a scaled down version of the 3-m LST. The balloon-borne version of the SIII was to have only a field camera with image tube sensor, for scientific instrumentation, but the Shuttle version was more flexible. When the SIII project office at MSFC was set up, the optics were changed from the LST design to an f/3 and an f/20 telescope, and some other less drastic revisions were made. Because most of the instrument analysis was completed by then, this study considered the scaled-down version of the LST as the baseline.

Itek has recently completed an analysis of the balloon-borne SIII (weight critical) with the new ground rules; this new work is compared with the study baseline in Table II-1. Some comments are in order. The new f/numbers allow a modest reduction in obscuration. The required spectral range has been reduced, primarily because the balloon SIII cannot operate further into the ultraviolet. Because the image tube requires an f/100 image to realize the full resolving power of the optics, the data field is only 1.4 arc-min across even though a large sensor is used.

The difference in WFE is explained partly by the inclusion of an "effective WFE" due to image motion in the 0.1λ rms value and results partly from the desire for a lower cost system. The 0.05λ rms system is at the state of the art and therefore very expensive. Detailed analysis may show that the expense is unwarranted.

The ±2 arc-s pointing accuracy results from the ground rule that the balloon SIII will carry only a field camera and therefore need not be precisely pointed. The resolution capabilities of the new concept have not been determined because the sensor has not been specified. The change in plate scale reflects the slower telescope optics.

The recent concept has a total length of 7.0 m, which far exceeds this study baseline. The difference results from the following factors: (1) a 1.0 m greater distance is required between the primary and secondary mirrors due to slower optics; (2) an 0.8 m excess length is required for window and protective cover, which will not be used on the Shuttle; and (3) a 2.0-m-long scientific instrument was used rather than the 1-m instrument assumed in this study. With film, the relay can be very simple so that camera length is reduced. The spectrograph will be quite short since it will probably be a low-dispersion instrument (to complement the high-resolution spectrographs on the LST).

The difference in diameters comes from the extendible light shield required for Shuttle operation.

Thus the differences largely result from different assumptions of optics and instruments, and the largest impact is on pointing requirement and tube length.

Table II-1 Comparison of SIII Baseline

Type	This Study Ritchey-Chretien	Recent Concept Ritchey-Chretien
Aperture, cm	120	120
f/number	f/2.2 to f/12	f/3 to f/20
Obscuration, percent of diameter	34	30
Wavelength range, nm	90 to 2000	300 to 750
Wavelength specification, nm	633	633
Data field, arc-min	6 at f/24	1.4 at f/100
WFE, λ rms	0.05	0.1
Pointing, arc-s rms	0.3	±2
Guiding, arc-s rms	0.02	0.015
Resolution, arc-s/line pair	0.3	TBD*
Format, mm	50	50
Scale, arc-s/mm	14	8.6
Temperature, °K	294	294
Length, m	4.2	7.0
Diameter, m	1.9	1.7
Weight, kg	1800	1900
Power, W		
Average	140	TBD
Peak	180	TBD
Sensor	Film	Image tubes
Instruments	Field camera, spectrographs, photometers	Field camera

*TBD = To be determined.

G. INFRARED TELESCOPE (IRT)

The IRT will give astronomers their first long-term high-resolution view of the universe in wavelengths between 1 and 1000 μm. It may measure the residual temperature of the cosmic background or reveal the presence of nearby cool stars; it very likely will discover many new features of the unverse, just as it will solve many old problems.

The salient feature of the IRT is that the entire instrument is cooled to 28°K or below. The cryogenic support needed to achieve this temperature is greatly simplified by the sortie mode of operation, but it still drives the design in many cases. Figure II-15 summarizes the IRT baselin, and Volume III, Book 1 contains a more detailed definition based on subsequent analyses.

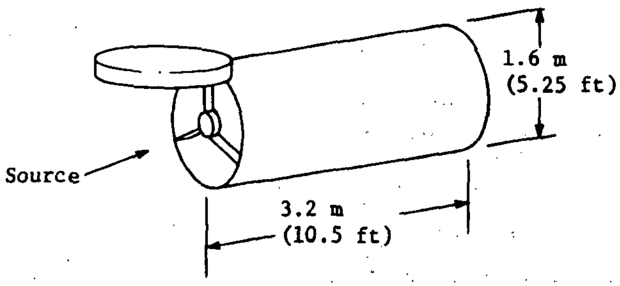
1. IRT Design

The IRT consists of a Cassegrain telwscope and scientific instrumentation surrounded by a tank of liquid neon (LNe) or colder cryogen. Although the Blue Book concept of a two-cryogen system using LNe for the structure and optics and LHe for the detectors was used, other cryogens should be investigated.

The 500-kg weight estimate for the IRT given in the Blue Book seems low since estimates for the 100-cm PHG was 1000 kg and for the 120-cm SIII was 1800 kg (including complex instrumentation in both cases). Although the tanks for cryogen storage will be part of the IRT structure, they will add to the overall weight. Therefore, a dry weight of 1000 kg was estimated for the IRT. To this must be added about 400 kg of LNe and perhaps 10 kg of LHe. These boil away to nothing at the end of the mission. With valves, vents, etc, the total weight is 1600 kg.

With the cryogens stored in place there is little or no electric power required for its management. The power required for multichannel sensors, amplifiers, multiplexing circuits, and the vidicon monitor is not expected to exceed more than 40 W average and 60 W peak.

The 1.2-m diameter x 2.7-m length of the IRT given in the Blue Book seems inconsistent with the requirement for a 100-cm-aperture system mounted in an evacuable dewar. A fast mirror is probably permissible because of the long wavelengths, but still the telescope alone will probably be about 2 m long. To this must be added instruments, structures, and dewar, so that the final size may be on the order of 1.6-m diameter x 3.2-m long.



Performance Characteristics

• Type	Cassegrain
• Aperture	100 cm
• Obscuration	25%
• Spectral Coverage	0.7 to 1000 Micrometers
• F/Number	F/1.5 Primary; F/10 Overall
• Field of View	14.5×10^{-4} Rad (5.0 arc-min)
• Format	15 mm
• Scale	1.02×10^{-4} Rad/mm (21 arc-s/mm)
• Angular Resolution	19.4×10^{-6} Rad (4.0 arc-s)
• Spectral Resolution	2500 ($\lambda/\Delta\lambda$); 1.6×10^{-4} Microns at 4 Microns
• Wavelength Specification	4 Microns

Fig. II-15 100-cm Infrared Telescope

Objectives

- Detailed Observation of IR Sources in the 0.7 to 1000 μm Spectral Region
- Determine Infrared Emission Mechanisms
- Determine IR Spectra Intensity and Spectral Characteristics for Comparison or Correlation with X-ray Spectra for same Sources

Instrument Detectors

- Interferometer (Spectroscopy - 0.7 to 1000 μ)
- Linear Detector Array (Radiometry - 5 to 100 μ)
- Aspect Sensor (Field Viewing and Guide Star Tracking)

Accommodation Requirements

• Size (Overall)	3.2 x 1.6M Dia (10.5 x 5.25 ft)
• Weight	1600 kg (3520 lb) - Including Cryogenic Support Units
• Power	40 W Average; 60 W Peak
• Thermal	27.6°K - Neon-Cooled Telescope 2.0°K - Helium-Cooled IR Detectors
• Data	Digital - 1300 bps Simultaneous Visible - Light Imaging
• Controls & Displays	Panel Area: .141 m^2 (218 in^2) Weight: 33.3 kg (74 lb) Power: 11 W
• Crew Requirements	8 Hr/Day - Operation
• Pointing Accuracy	19.4×10^{-6} Rad (4.0 arc-s)
• Pointing Stability	1.94×10^{-6} Rad (0.4 arc-s)
• *Orbit*	*Optimum Dark Time*
• Operation	Line-of-Sight No Closer than 1.57 Rad (90°) to the Sun and 0.785 Rad (45°) to Earth

2. IRT MTF Analysis

The MTF analysis (Fig. II-16) assumes 25% obscuration, which is reasonable for a fast primary mirror, moderate field, and good baffling. A 0.1λ rms wavefront error at 4 μm is used in the analysis. The telescope may be build to achieve 0.05λ rms at 0.6 μm. This would convert to 0.008λ rms at 4 μm were it not for the inevitable deformations that occur when the structure and optics are cooled to 28°K or below. Even the 0.1λ rms value could prove optimistic if, for instance, there is hysteresis in the materials during thermal cycling.

The spatial frequency response of the infrared sensor is taken to be a (sin x)/x function. It was assumed that 0.1 x 0.1-mm elements would be used. Smaller sensors are available for some spectral regions, but they are not generally used in large multi-element arrays for long wavelength observations.

It is clear that this sensor focal length combination significantly affects system performance. Analysis of the IRT system may show that a slower optical system would pay off in higher resolution even though the exposure may be longer. The decision depends, among other things, on the wavelengths of interest because at 40 μm the sensor has relatively little effect on MTF. Since 4-μm observations are feasible from the ground, and the short wavelengths are generally accessible from the NASA-Ames C-141 aircraft, this spectral region should not drive the IRT design too much. It was chosen in the first place because, being near the most difficult end of the spectral range of the IRT, it would indicate what sort of limits on performance might occur.

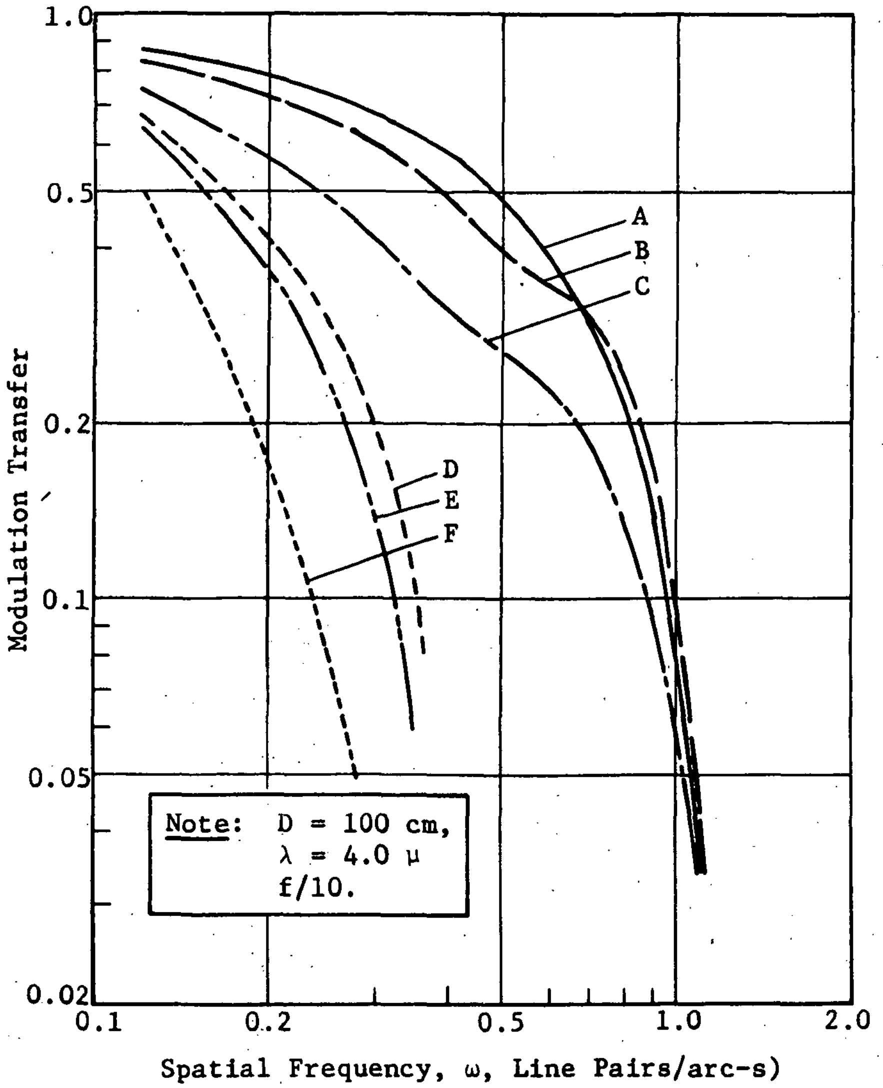
3. IRT Pointing and Guiding

The pointing specification of the IRT is set by the entrance aperture of the scientific instruments. This would be a hole in the case of a radiometer and a slit in the case of a conventional grating spectrometer. Ideally, it should be possible to put the entrance aperture onto a resolved object. From Fig. II-16 this is defined as about 4-arc s.

It will not be necessary to have internal guide error correction in the IRT because the pallet-mounted gimbal will have better than the 0.4-arc-s rms stability required. Guide error signals can be generated either by an auxiliary telescope or by folding the visual wavelengths in the IRT field to a guide head. The fold might be done with a dichroic mirror or by time-sharing using a mechanical modulator.

4. IRT Thermal Consideration

The thermal considerations for the IRT are covered in detail in Volume III-1, Book 1, of this report.



Legend:	
A	Perfect Optics
B	25% Obscuration x Curve A
C	0.1λ rms x Curve B
D	0.1-mm Sensor x Curve C
E	0.4 arc-s rms Image Motions x Curve D
F	1.0 arc-s rms Image Motion x Curve D

Fig. II-16 MTF Analysis of IRT

H. X-RAY ARRAYS

A total of five separate stellar X-ray arrays were defined for the astronomy sortie missions definition study. In general, the array definitions are either derivatives of the Blue Book or HEAO array definitions. Table II-2 summarizes the X-ray arrays, and each array is briefly discussed in subsequent paragraphs. In the definition of the arrays, information was obtained from Reference 10 thru 15, and these documents are not referred to in the text.

1. Wide-Coverage X-Ray Detector

This instrument surveys a complete hemisphere, on a continuous basis, for unusual transient X-ray emissions. The instrument can be used either as a support system to indicate that something unusual is occurring and where to look for it with other instruments with higher resolution and sensitivity, or it can be used to measure the background flux from a hemisphere.

The instrument should be considered as a new instrument, as compared to the Blue Book, since it has been completely redesigned into a large combination of individual modules that offer a detector area of at least 200 cm^2. The instrument consists of a large number of identical X-ray detector modules. Each module has a limited angular sensitivity, approximately 0.25 rad (15°) full-width half-maximum (FWHM), defined by a honeycomb collimator ahead of the X-ray-sensitive detector. The module overlaps partially with that of all adjacent modules to provide a means to estimate the direction of arrival of a burst of X-ray photons.

Each X-ray detection unit consists of a metallic-window proportional counter backed up with a scintillation detector. The combination is sensitive to photons in the energy range from 0.32 to 32 fJ (2 to 200 keV). The events detected by each module are sorted according to photon energy with pulse height analyzers, and combined with module identification code. Comparison is made with a threshold (adjustable by the observation crew) and with events detected in other moduels. When the preset threshold is exceeded, a console display alerts the observation crew.

The detector units are thermally protected so no detrimental effects result from direct exposure to solar radiation. The large increase in background count rates that takes place during crossings through the South Atlantic Anomaly and the "radiation belts" will result in automatic power-downs of the detector units. Normal sensitivity is restored when the flux drops back to normal levels.

Table II-2 X-Ray Arrays

Objectives:

1) Measure the flux, location and energy distribution of high-energy radiation in the range from 0.1 to 100 keV for each X-ray source and the diffuse X-ray component;

2) Measure angular dimensions and structure of selected X-ray sources.

PARAMETER / ARRAY	PERFORMANCE CHARACTERISTICS		ACCOMMODATION REQUIREMENTS										
								CONTROLS AND DISPLAYS				POINTING	
	ENERGY BAND, keV	FOV, rad (deg)	SIZE, m	WEIGHT, kg (lb)	POWER AVERAGE (PEAK)	THERMAL °K (GRADIENT)	DATA kbps	AREA, m^2 (in^2)	WEIGHT, kg (lb)	POWER, W	CREW hr/day	ACCURACY, rad (arc-min)	STABILITY, rad (arc-Min)
Wide-Coverage X-Ray Detector	2 to 100	3.14 (180)	2.0 dia x 1.2 high	250 (550)	120 W (170 W)	263-303 Integral Temperature Control	0.5 Continuous 1.0 at Initial Calibration	0.122 (174)	36 (80)	46	1.0	--	9×10^{-3} (31)
Large-Area X-Ray Detector	0.1 to 100	2×10^{-2} (1.15)	Six Modules, 1.2 x 0.6 x 0.5 Each	315 (695)	160 W (200 W)	291-295 (Less Than 2-Any Module)	4.3 X-Ray Source: 25 Peak-Pulsar	0.09 (140)	28.4 (63)	39	2.5	2×10^{-3} (6.8)	2×10^{-3} (6.8)
Large-Modulation Collimator	0.1 to 100	5×10^{-2} (2.87)	Six Modules, 1.2 x 0.6 x 0.85 Each	375 (826)	160 W (200 W)	291-295 (Less Than 1-Any Module)	4.3	0.097 (150)	28.8 (64)	38	12.0	Reference to 1 x 10^{-3} (3.4)	Scans - 0.05 rad/s to 0.005 rad/s (2.8°/s to 1.7 arc-min/s)
Collimated Plane Crystal Spectrometer	0.5 to 10	0.52 (30)	Three Modules 1.33 x 1.22 x 0.61 Each	261 (574)	70 W (112 W)	281-285 (Less Than 2-Any Module)	1.3	0.149 (231)	43.6 (97)	51	7.2	2.9×10^{-4} (1.0)	2.9×10^{-4} (1.0)
Narrowband Spectrometer-Polarimeter	5.95 to 8.37	1.75×10^{-2} (1)	Nine Modules, 0.75 dia x x 0.6 High, Each	543 (1197)	195 W (270 W)	281-285 (Less Than 2-Any Module)	1.2	0.119 (184)	30.6 (68)	41	3.6	1.5×10^{-3} (5)	2.9×10^{-4} (1.0)

2. Large-Area X-Ray Detector

This instrument will be used to perform measurements of the intensity, spectral distribution, and temporal variations of galatic and extragalactic X-ray sources.

The large-area X-ray detector consists of six mapping modules rather than the Blue Book combination of the three mapping modules plus three modulation collimator modules. An increase in instrument beamwidth from 1×10^{-2} rad (0.6°) to 2×10^{-2} rad (1.15°) involved a minor change that provided simpler instrument integration and pointing.

The detection of low-energy X-ray photons is performed with thin-window gas-filled proportional counters. For detection of photons in the high-energy X-ray range, the proportional counters are backed with scintillation detectors. The proportional counters exhibit good photon efficiency in the 0.2 to 6 keV (30 aJ to 1 fJ) range, with adequate sensitivity for photons of energies between 0.1 and 10 keV (16 aJ to 1.6 fJ). The scintillation counters are sensitive to photons with energies above 10 keV.

3. Large-Modulation Collimator

This instrument will be used to investigate the fine structure and angular dimensions of X-ray sources and the precise location of these sources in the celestial sphere to enable their identification with objects observed in optical wavelengths.

The large-modulation collimator is basically the same instrument as identified in the Blue Book, with the exception that it has been made a separate instrument instead of being combined with the mapping modules. The modulation collimator is considered as a separate array since it cannot acquire valid data if simply pointed to a source. It must scan. Grids on the modulation collimators and arranged so scanning in only one direction produces the desired type of information. The fine beamwidth of the modulation collimator pattern, not defined in the Blue Book, is specified at 3×10^{-4} rad (1 arc-min) full-width half-maximum (FWHM) for this study.

4. Collimated Plane Crystal Spectrometer

This instrument will be used to obtain high-resolution spectral information on known celestial X-ray sources in the 0.08 to 1.6 fJ (0.5 to 10 keV) energy range. Both point sources and extended sources will be observed.

The collimated plane crystal spectrometer defined in the Blue Book wav considered as a support unit to the large stellar X-ray telescope with a single module covering the wavelength from 0.1 to 0.6 nm (1 to 6 Å). This study uses a configuration similar to the HEAO-B instrument where three moduels with different crystal mosaics are used to cover an extended energy range (0.5 to 10 Å) in three slightly overlapping bands. The effective area of the proposed array is about three times that of the Blue Book unit.

The primary detector system consists of three Bragg crystal plates and gas proportional counters, each optimized for a specific energy range. A drive system allows the crystal plates to select any desired wavelength or scan a portion of the spectrum. The intensity of the X-rays diffracted by the crystals as a function of angle is detected by proportional-counter and pulse-height-analyzer systems.

5. Narrowband Spectrometer-Polarimeter

This instrument will measure the intensity and polarization of the emissions from X-ray sources, at two energies corresponding to continuum radiation, and at seven others corresponding to emission lines of ionized elements. The intensity measurements are critical to the determination of the temperature of the source, which is determined by comparing the intensity ratio at the two continuum energies, and by the ratios of line intensities of two ionization levels of the same element. Relative abundance of species are determined by line intensity ratios for different elements. The polarization measurements are critical to the determination of the mechanisms of X-ray flux generatiofrom the sources.

The narrowband spectrometer-polarimeter defined in the Blue Book is used for this study with no major differences other than the arrangement of the nine modules.

I. GAMMA-RAY ARRAYS

Two stellar gamma-ray arrays were defined for the astronomy sortie missions definition study. In general, the array definitions are either derivatives of the Blue Book or HEAO array definitions. In the definition of the arrays, information was obtained from References II-16 and II-17, and no reference is made to these documents in the text. Table II-3 summarizes the gamma-ray arrays, and each array is discussed briefly in the subsequent paragraphs.

Table II-3 Gamma-Ray Arrays

Objectives:

Measure the flux, location, and energy distribution of high-energy radiation in the range from 0.06 to 10 MeV for each gamma-ray source and the diffuse gamma-ray component.

PARAMETER / ARRAY	PERFORMANCE CHARACTERISTICS		ACCOMMODATION REQUIREMENTS										
								CONTROLS AND DISPLAYS				POINTING	
	ENERGY BAND, keV	FOV, rad (deg)	SIZE, m	WEIGHT, kg (lb)	POWER AVERAGE (PEAK)	THERMAL °K	DATA kbps	AREA, m^2 (in^2)	WEIGHT, kg (lb)	POWER, W	CREW hr/day	ACCURACY, rad (arc-min)	STABILITY, rad (arc-Min)
Gamma-Ray Spectrometer	0.06 to 10	1.25 (72)	0.7 x 0.34 x 0.34	155 (341)	30 W (Con-tinous)	281-285 Detector 30 to 90	2.2	0.104 (162)	28.8 (64)	39	7.2	2×10^{-2} (69)	0.3×10^{-2} (10.2)
Low-Background Gamma-Ray Detector	0.3 to 10	1.92 (110)	1.6 x 1.6 x 0.75	910 (2000)	70 W (111 W)	291-297	4.0	0.168 (260)	36 (80)	56	2.9	1.74×10^{-2} (60)	0.87×10^{-2} (30)

1. Gamma-Ray Spectrometer

Measurements have been performed on a large number of celestial sources in the X-ray range. This instrument will extend the range of measurements into higher energies. Specific objectives are to:

1) Perform an exploratory search for sources of X-ray and gamma-ray line emissions in the 0.6 to 10 MeV energy interval;

2) Determine the location, intensity, and detailed spectrum of X-ray and gamma-ray sources;

3) Search for new X-ray and gamma-ray sources;

4) Observe time variations in the intensity and spectral details of discrete X-ray and gamma-ray sources;

5) Study the origin, isotropy, and spectral details of the diffuse X-ray and gamma-ray background.

The gamma-ray spectrometer identified in the Blue Book and the instrument defined for this study have basically identical characteristics. For sortie missions, coolant is required for a limited time (days) rather than for six months, and the volume of cryogen is greatly reduced.

This instrument uses four lithium-drifted germanium [Ge(Li)] crystals as primary detectors for gamma-ray photons in the energy range from 0.06 to 10 MeV. These detectors can provide photon energy resolution as high as 0.1% at 1 MeV.

2. Low-Background Gamma-Ray Detector

This instrument will investigate the photon spectrum from point, diffuse, and line sources over the energy range from 0.3 to 10 MeV (0.048 to 1.6 aJ). The photon sensitivity and background signal rejection characteristics are designed to provide excellent scientific data return from observing missions of comparatively short duration, such as the astronomy sortie missions.

The low-background gamma-ray detector defined for this study has been returned to its original status of a gamma-ray instrument. The Blue Book instrument is primarily an X-ray instrument of rather low effective area and with a field-of-view on the same order as the large-area X-ray detector (1 to 1.5°). A field-of-view of 1.92 rad (110°) is specified for the gamma-ray detector. It covers the 0.3 to 10 MeV energy range, the cesium iodide and sodium iodide detectors become appreciablby heavier to achieve three of four radiation lengths.

The instrument consists of four identical detector modules mounted in a gimbal system by a mounting frame, plus an electronic package that should be located near the detector modules but not necessarily on the gimbal system. Seven separate scintillation crystal detectors are included in each module. The collimation shield for the six exterior scintillators restricts the sensitivity to a conical region of 0.5 rad (28°) full-width half-maximum (FWHM) angle. The central scintillator views a larger region, with 0.95 rad (55°) FWHM angular sensitivity. The "narrow" field of the exterior detectors is designed for observation of discrete or point sources, while the "wide" field of the central detector is optimized for the measurement of the diffuse component in the presence of the background resulting from energetic cosmic nuclei.

J. REFERENCES

II-1. *NASA Blue Book*, Vól II. NHB 7150.1, January 15, 1971.

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II-3. Itek's current work on the Large Solar Observatory (LSO).

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II-17. Dr. Laurence E. Peterson, Principal Investigator: *A Sky Survey Experiment for 0.3 to 10.0 MeV for Gamma-Ray Sources for HEAO-A.* University of California, San Diego, California, May 1970.

III. PRELIMINARY MISSION AND SYSTEM DEFINITIONS

Preliminary mission and system analyses were performed early in the study to provide sufficient data to enable an evaluation of the alternative programs being considered for the astronomy sortie missions. Since these preliminary analyses were the ground work for the study activities that are reported in the remaining volumes of this final report, much of the work documented in this chapter has been modified or deleted by subsequent analyses.

The preliminary mission and system definitions included (1) the establishment of an operations concept that encompassed the astronomy sortie mission from preflight planning through postflight data analysis, (2) development of functional time-lines for the baseline experiments for each phase of the sortie mission program, (3) identification of the preferred orbital parameters for each of the baseline experiments, (4) evaluation of the mission effectiveness for each of the baseline experiments, (5) identification of operations or phenomena that would influence the experiment design or interface definition, and (6) identification of activities that could effectively utilize the crew.

A. ASSUMPTIONS AND GUIDELINES

To limit the scope of this study, guidelines were provided by the NASA-MSFC COR and a number of assumptions were made by the study personnel. The more significant guidelines and assumptions are discussed in the following subsections.

1. Guidelines

The following guidelines were provided as a part of the study statement of work or by the NASA-MSFC COR:

1) The baseline flight schedule for the astronomy sortie payloads identified two flights per year in 1979 and grew to a maximum of eight flights per year in 1983 and continued at this rate through 1990;

2) Each sortie payload consisted of one telescope and a group of high-energy arrays. This guideline was deleted during subsequent work, but this volume does not reflect the deletion;

3) The RAM/pallet would be GFE to the astronomy sortie program and the definition would be based on the RAM Phase B study. This guideline was modified during subsequent work to reflect the sortie lab and pallet being defined by NASA-MSFC. However, this volume of the report does not feflect the sortie lab and pallet definitions since all work was performed using the RAM/pallet;

4) Two experiment crewmen would be available for on-orbit operations permitting a 24-hour day experiment operation;

5) Space Shuttle definition would be provided by NASA-MSFC.

6) Planned EVA would not be permitted. This guideline was later modified to allow two EVAs per mission.

2. Assumptions

Study personnel made the assumption that maximum use of previous or on-going studies was desirable.

B. OPERATIONS CONCEPT

One of the first tasks performed during the study was to establish an operations concept that encompassed the entire sortie mission. In developing the preliminary operations concept, other programs and study results were reviewed to identify the philosophy, resources, and techniques used and to determine their potential application in astronomy sortie missions.

The preliminary operational concept established for the astronomy sortie missions is shown in Figure III-1. This concept utilizes three major areas of payload-oriented activities--the Payload Integration Center (PIC), the Space Astronomy Control Facility (SACF), and the installations required for Shuttle mission operations and support.

The Payload Integration Center is responsible for a wide range of payload-sustaining engineering functions. The Space Astronomy Control Facility provides a focal point for coordinating space astronomy activities with established and continuing ground-based astronomy research. The principal investigators accommodated there will provide scientific support in all mission phases throughout the program.

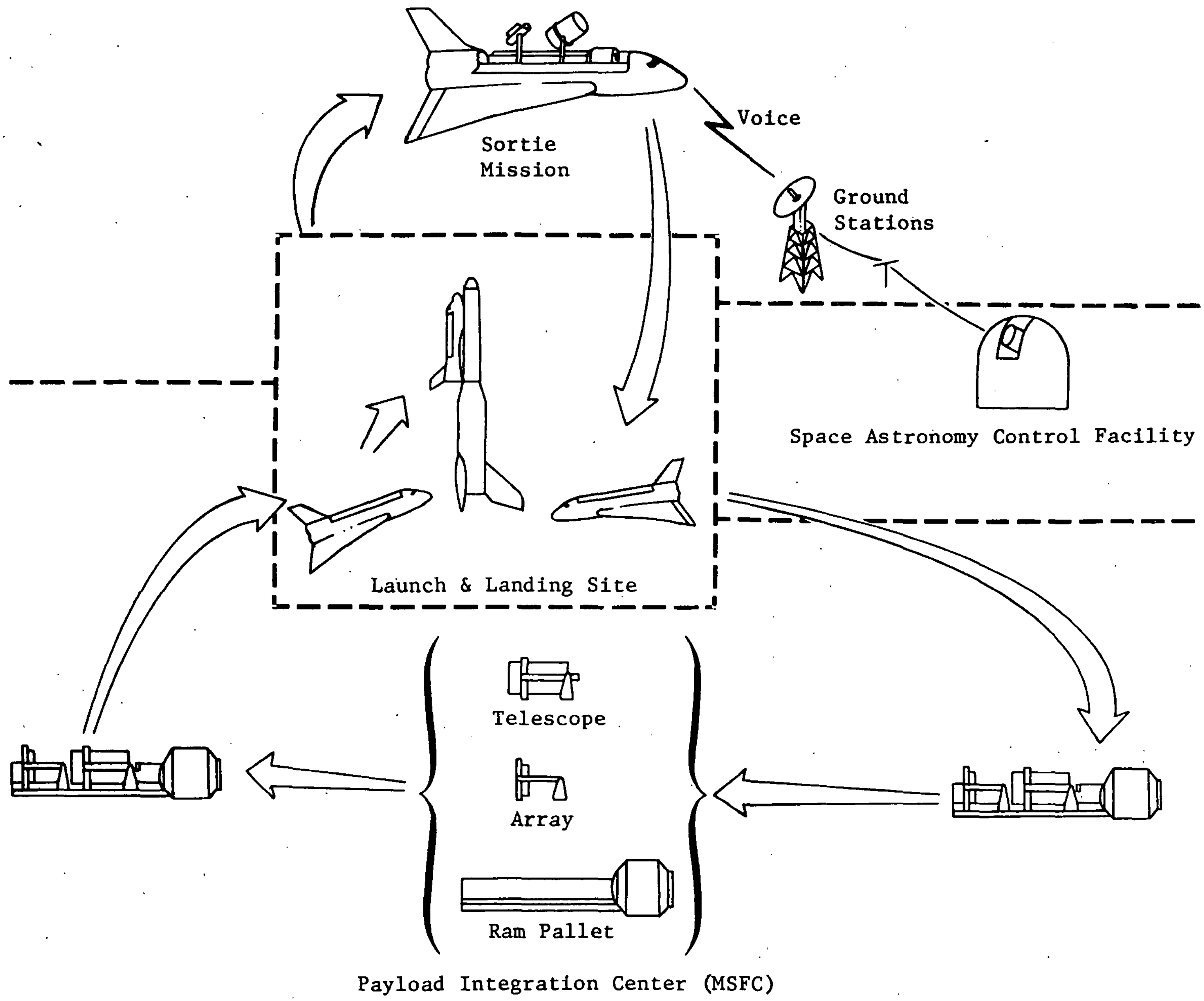


Fig. III-1 Preliminary Operations Concept

This operations concept interrelates the resources to be used in a manner that satisfies the astronomy sortie program. Provisions include (1) communications between the ground-support centers, (2) return of the payload for refurbishment, updating, and subsequent reflight, (3) coordination of many astronomers in using the telescopes as a national facility, and (4) capability of operating many missions defined in a baseline flight schedule.

To determine the type of operation techniques currently in existence or planned, four space astronomy programs were reviewed (Ref III-1 thru III-4). Table III-1 summarizes the operation techniques for these programs.

Table III-1 shows that each of the programs has ground personnel that are active in real-time, or near-real-time, mission planning, target selection, experiment operation, and experiment monitoring and evaluation. For the astronomy sortie missions it can be expected that similar ground operations will be required to support the on-orbit experiment crew and to coordinate the ground observatories and activities. Another factor that demonstrates the need for a ground crew to support the on-orbit experiment crew would be the operations of a ground observatory such as Kitt Peak National Observatory. At a ground observatory, when a scientist obtains time on the telescope to perform his particular experiment, he is supported by the permanent staff at the observatory should he need assistance during his experiment. The above reasoning led to the recommendation that a Space Astronomy Control Facility should be established.

The concept of a Payload Integration Center was based on the study *Implementation of Research and Applications Payloads at the Shuttle Launch Site* (Ref III-5). This study established the philosophy of achieving an integrated, flight-ready payload at a location other than the launch site. This location was defined as the center that was the owner and operator of the payload and, for this study, MSFC was baselined as the Payload Integration Center for astronomy sortie missions.

The functional responsibilities for each of the three major areas included in the preliminary operations concept are described in the subsequent paragraphs.

1. Payload Integration Center (MSFC)

Sustaining engineering for telescope, arrays, and RAM pallets is performed throughout the program at the Payload Integration Center (MSFC) for astronomy. Sustaining engineering includes a broad range of functions, requiring diverse and sophisticated equipment and crew skills.

Table III-1 Operations Techniques - Existing Programs

OPERATIONS CRITERIA	STRATOSCOPE	OAO	ATM	HEAO
Crew Requirements	Unmanned balloon carrier Flight director Photo recorder Navigator Thermal operations (2) Engineers & log recorder Focus analyzer Chief astronomer Assistant Astronomer (2) Tape recorder operator Power generator operator TV operator (2) Guards (2) plus part-time Project director TV engineer CCII operator (2) Project manager Engineer, ground station Engineer mechanic Power generator operator (24 people total)	Unmanned spacecraft Mission operations staff (7) Experimenters (5) Support computer personnel (2) Data processing center (5) Astronomer has direct (delayed) control (≈ 20 people total at GSFC, plus KSC & STANDAN)	3-man flight crew including commander, pilot, and scientist pilot. Each has flight plan scheduled duty to support experiments. Plan updated during mission. MSFC HOSC area: Operations support manager, Assistant for systems, Assistant for operations, Support coordinator, Assistant support coordinator, Personnel locator, Mission requirements review coordinator, Assistant mission requirements review coordinator Evaluation coordinator and Report coordinator and Support Action Centers have technical reps (12). Report Preparation Room has coordinators & reporters (5) Operations Support Room has Console Operators (6). Administration & Support area has all skills (≈ 110), plus people at KSC, MSC & MSFN.	Unmanned spacecraft project manager Project scientist Mission operations director Data processing engineer Mission operations manager Control center operations manager Control center operations manager PI operation personnel Tracking & data system manager Ground system manager Tracking & TM engineer Orbital Coordination Engineer Communication Engineer Remote control station programming manager Software manager (≈ 14 people in MCC at GSFC plus people in HOSC at MSFC; and at KSC and MSFN station)
Integrated space and ground systems using man in primary role	Continuous ground crew	Ground control during test phases	Manned space vehicle, coordinated with ground stations.	Ground control during test phases
Mission operations planning	Overnight mission, multi-discipline crew, real-time ground control	Intercenter computerized planning to accommodate viewing pattern changes.	Detailed flight plan, intercenter coordinated support, multidiscipline experiment coordination.	Intercenter computerized planning to accommodate viewing pattern changes
Preflight ground conditioning	Temperatures	Temperatures	Water, methanol.	Liquid propane, argon/CO_2 neon, helium, ethanol, methane
Direct ground-based astronomer control	Continuous	Through ground stations	Through ground stations.	Through ground stations
Attitude constraints	Controlled to accommodate target selection	Limited to control temperatures and solar panel positions	Solar inertial.	No constraints
Flight calibration	Remote controlled	Ground control.	Initial activation by IU or DCS; MSFN verification	Ground control
Restricted zones of viewing	None, mission performed overnight	90 deg excluded sun cone; 40 deg antisun restricted power cone.	Experiment-peculair.	None
Target selection and pointing	Targets chosen in advance by PI astronomer. Remote ground controlled pointing	Preflight determination of available targets by experimenter PI. Uplink commands from STADAN to program pointing	Flight crew selects data taking mode based on solar activity, observing program, and ground requests. Film exposed and data dump to ground for assessment at control center in MSC. Supported by HOSC at MSFC.	During station contact, spacecraft status transmitted to operations control center at GSFC. Command adjustments as desired through remote stations
Coordination requirements	NCAR Princeton University Observatory Contractors	GSFC KSC STADAN PIs Contractor	MSFC KSC MSC PIs MSFN Contractors	MSFC GSFC KSC PIs MSFN Contractors

Integration of the telescopes and arrays into the RAM and pallet requires physical mating of attachment points in the telescope mounts and alignment of optical axes with pointing reference axes. Detectors and cameras are calibrated and set up for operation. RAM and pallet subsystems are installed, activated, and checked out for operation. A combined systems test, exercising all subsystems and operating the telescopes and detectors in all modes possible in the 1-g environment, will be performed for flight qualification. Selected thermal and vacuum environments may be imposed on the payload in these tests.

The Payload Integration Center (MSFC) has a key role in providing experiment support at other facilities. A transient crew for each integrated payload travels with the payload to the launch site, retaining responsibility and performing operations for the experiments and RAM pallet until handover to the launch crew for loading in the orbiter. The transient crew then provides support to the launch site for all prelaunch operations.

Sustaining engineering operations involving the integrated payload in test and checkout exercises are used to provide flight crew training, including control simulations and procedure verifications.

Throughout the program, the Payload Integration Center (MSFC) provides for the modification and update of the telescopes, arrays, and RAM pallets. The activities necessary for this responsibility include logistics of flight and ground equipment and spares, configuration control, and engineering support.

2. Launch and Landing Site

The launch site crew is responsible for loading the payload in the orbiter, launch operations, and off-loading. Normally, loading is performed with the orbiter in the horizontal attitude; however, these payloads should be compatible with on-pad vertical removal and replacement.

After loading, the launch site crew performs launch operations during which these payloads are essentially passive, except for systems requiring environmental conditioning. During the on-orbit phases, the launch site will monitor flight operations, coordinate landing operations, and make preparations for payload recovery.

After offloading is performed by the launch site crew, the responsibility for the payload is immediately transferred to the Payload Integration Center (MSFC) transient crew.

3. Space Astronomy Control Facility

This facility is responsible for all experiment operations in the program and for coordinating space astronomy activities with established and continuing ground-based research. The facility has extensive capabilities in astronomy and accommodates principal investigators for support of all mission phases throughout the program.

The permanent crew at this facility and the experiment PIs provide preflight experiment mission plans, target selection observation periods, and operations for incorporation into detailed flight procedures. Update or modification of experiment operations during the on-orbit phase is provided through the voice link with the Shuttle orbiter. Scientific information obtained during the missions is returned to this facility for processing, analysis, interpretation, and storage.

C. TIME-LINES

Functional time-lines for each telescope were prepared, for the Payload Integration Center (PIC), Shuttle launch site, and the on-orbit phases of the mission. These time-lines were prepared to provide a basis for evaluating the responsiveness of the sortie mode of operation to the stated scientific objectives, and to determine the resources and facilities that would be required to support the astronomy sortie missions. The time-lines presented in this section are preliminary, and they have been considerably modified based on the more detailed analyses performed in subsequent work. The modified time-lines are presented in Volume III of this report. The time-lines presented in this section reflect the operations concept defined in Section B.

1. Payload Integration Center Time-Line

Figure III-2 presents a typical time-line for an astronomy payload at the Payload Integration Center (PIC) that would be located at MSFC. It indicates a total 212-hr turnaround time would be required from receipt of the payload at the PIC until the transfer of a new payload to the launch site.

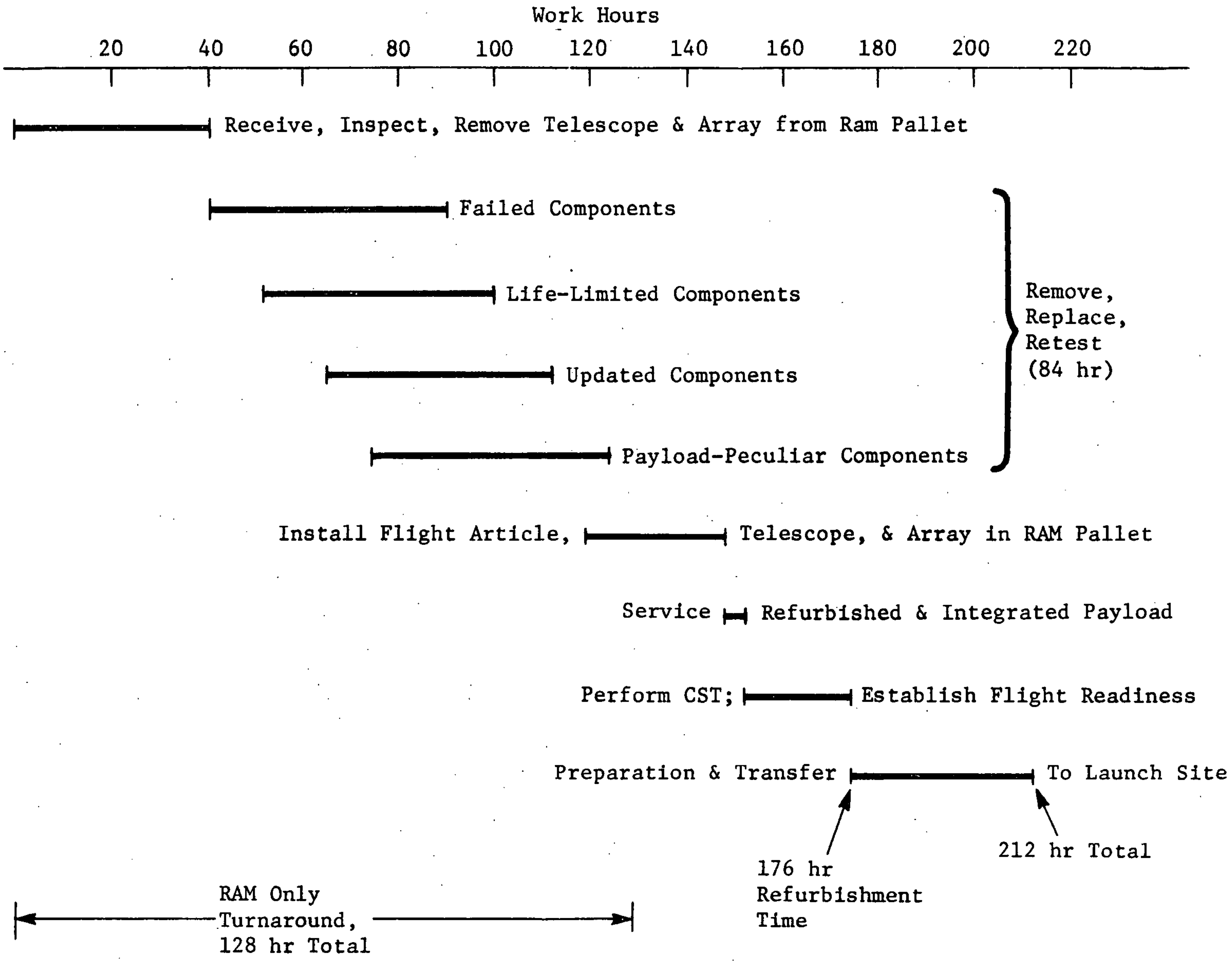


Fig. III-2 Typical Payload Integration Center Time-Line

The time-line shows that the time required to receive and inspect the payload at the PIC and to remove the telescope and arrays from the RAM and pallet would be 40 hr. After the telescopes and arrays are removed, a total of 84 hr would be required for refurbishment and update activities on the RAM and pallet. At the completion of this time, 128 hr total, the RAM would be ready for reuse should it be desirable to use the RAM for a discipline other than astronomy or to use the RAM for another astronomy payload already integrated with a pallet. The time-line shown assumes that the refurbished RAM and pallet would remain as a unit and would be integrated with a new telescope and array and flight readiness established. This would require an additional 48 hr, bringing the total refurbishment time to 176 hr. The hours shown on the figure are work hours and do not correspond to clock hours.

In derivation of the time-line, the following basic criteria were applicable:

1) Each payload is integrated and flight readiness is established at the Payload Integration Center (MSFC);

2) The RAM and pallet are not dedicated to any telescope and array combination, but will receive a different telescope and array after each mission;

3) The PIC crew is responsible for all activities shown on the time-line.

2. Launch Site Time-lines

Launch site schedules require merger of payload operations with orbiter processing when the orbiter is ready for loading. For these time-lines, a 212-hr Shuttle processing schedule was selected from five such schedules that were compared (Ref. 6 and 7). The selected schedule was based on a recoverable booster with drop-tank orbiter and is about the same as those for two other configurations. A substantially longer processing schedule for the Mark I Shuttle and a shorter version for the McDonnell Douglas SOAR study were among those considered but rejected for this analysis.

The launch site time-line for each of the telescopes was obtained from the study of the *Implementation of Research and Applications Payloads at the Shuttle Launch Site* (Ref 5), and are shown in Figures III-3 thru III-5.

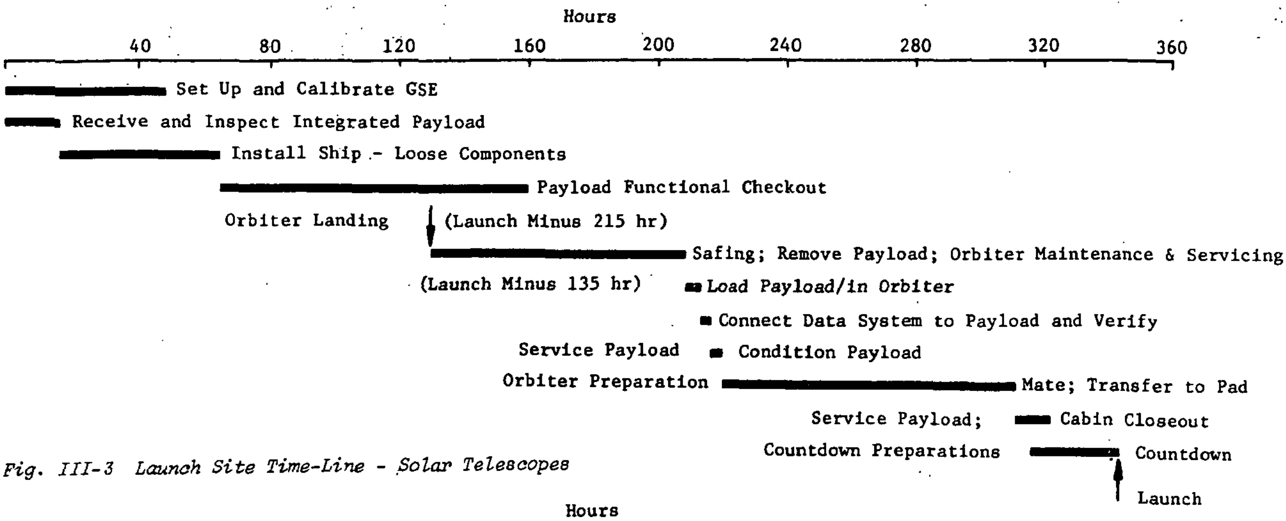


Fig. III-3 Launch Site Time-Line - Solar Telescopes

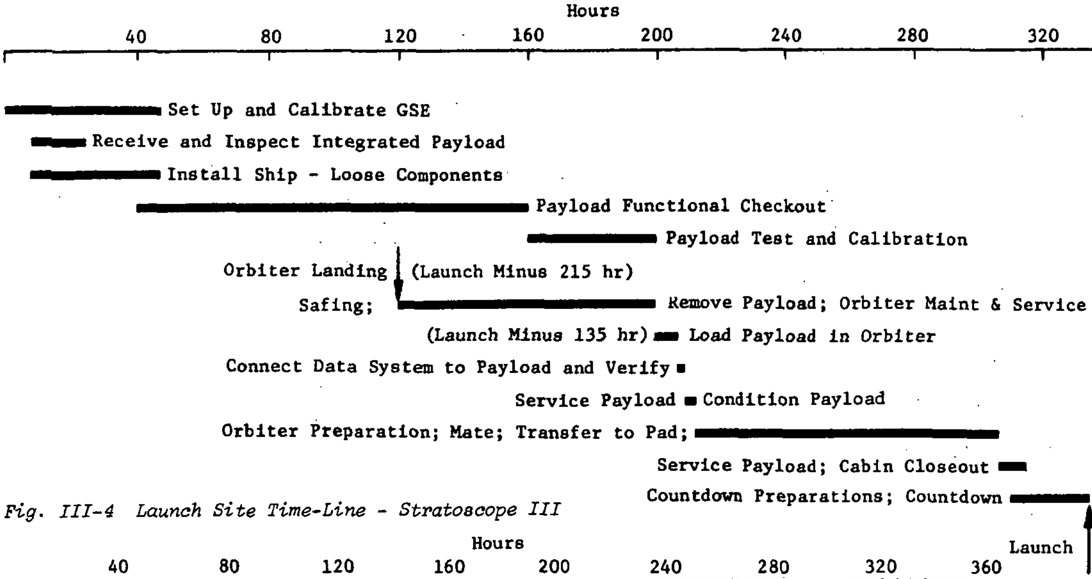


Fig. III-4 Launch Site Time-Line - Stratoscope III

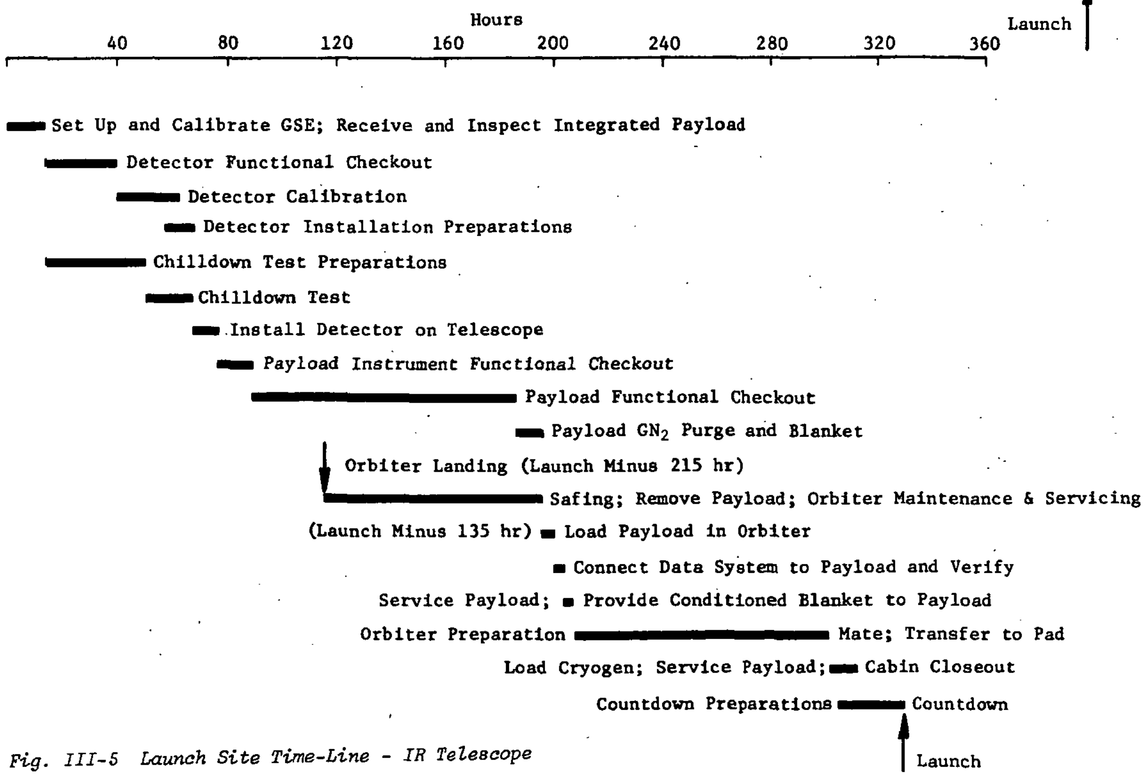


Fig. III-5 Launch Site Time-Line - IR Telescope

For the solar telescopes, the overall receipt-to-launch span is 343 hr, with merger of the payload with the orbiter occurring at launch minus 135 hr as shown in Figure III-3. A total of 12 hr is scheduled for loading the payload, including installation, data system connection, servicing, and hookup of conditioned blanket. From that time, the payload is inaccessible and requires no servicing except for maintaining the inert gas blanket on the entire payload. During "service cargo" and "cabin closeout" functions, environmental status and environmental conditions that have been encountered are verified, but payload servicing is not planned.

Figure III-4 presents the launch site time-line for Stratoscope III. The overall receipt-to-launch span is 335 hr, with merger of the payload with the orbiter at launch minus 135 hr. As for the solar telescopes, 12 hr are scheduled for loading in the orbiter and verification of installation. No on-pad servicing is planned.

The launch site time-line for the IR telescope is shown in Figure III-5. The overall receipt-to-launch span is 332 hr, with merger of the payload with the orbiter occurring at launch minus 135 hr. A total of 12 hr is scheduled for loading the payload, including installation, data system connection, servicing, and hookup of conditioned blanket. Then for 96 hr the payload is inaccessible until cryogens are loaded, and final servicing begins at about launch minus 24 hr.

Comparing the three launch site time-lines, the important difference between telescopes (noting that the span times are nearly the same) is the cryogenic test and loading required for the IR, which is unnecessary for the other telescopes. This cryogenic requirement dictates on-pad access for the IR telescope, but not the other telescopes. In other respects such as cleanliness, handling, and inert gas blankets, the requirements for all the payloads are similar.

In derivation of the launch site time-lines, the following criteria were used:

1) Telescope alignment and calibration will be performed at the Payload Integration Center (MSFC) and will not be repeated at the launch site unless environments allowable during transit are exceeded;

2) Some "ship loose" items will require installation at the Shuttle launch site.

3. <u>On-Orbit Time-Lines</u>

The on-orbit time-lines derived for the astronomy telescopes (Tables III-2 thru III-10) were based on the mission analysis results discussed in Section D, the baseline experiment definition documents (BEDDs) contained in the Appendix (Book 2) of this volume, and a reference Shuttle launch-to-orbit and deorbit-to-load profile extracted from existing Shuttle documentation (Ref 8).

In preparation of the on-orbit time-lines, such periodic preparation operations as pointing, alignment, calibration, detector selection, focusing, indexing, etc were considered to be manual functions initiated (and in many cases completely performed) by the experiment crewmen. Some of these functions require relatively long times to complete or must be repeated frequently. The periodic functions performed during usable observation time periods were identified as candidates for modification to automatic or semiautomatic functions to increase the amount of observation time available.

In derivation of the on-orbit time-lines, the following mission parameters and assumptions were used:

1) Total mission duration - 166 hrs 54 min for solar, and 166 hr 30 min for stellar launch to initiate deorbit;

2) Orbital period - 94.6 min;

3) On-orbit time to achieve thermal equilibrium assumes prelaunch conditioning;

4) Shuttle mission profile based on existing Shuttle documentation;

5) Repeatable on-orbit sequences extracted from BEDDs.

In addition to the above general mission parameters and assumptions, those that apply for the specific telescopes are given in Table III-11.

Table III-2 Mission Timeline - Photoheliograph

ELAPSED TIME,	EVENT
00:00	Liftoff
00:06.5	Insert into 50 x 100 n mi Orbit
00:50.1	Transfer to 100 x 200 n mi Orbit at First Apogee
01:35.8	Circularize at 200 n mi Orbit at First Apogee Stabilize, Check Out Orbiter Systems, Update Ephemeris, Open Orbiter Cargo Bay Doors, Verify Readiness to Proceed with Experiment Operations
02:00	Orbiter Coarse-Attitude Acquisition
02:30	Turn on Electrical and Thermal Control Subsystems
02:32	Turn on Control and Display Panel, Image Control Subsystem Servos, Camera, and Filter Control and Thermal Control Electronics
02:36	Turn on and Stabilize Telescope Thermal Control Fluid Systems and Spectral Filter Thermal Control
03:14	Release Telescope Launch Locks
03:16	Rotate Telescope to 90-deg Position and Lock
03:31	Pitch Telescope into Initial Operations Position
03:48	Release Launch Locks to Protect Primary and Secondary Mirror Assemblies
03:50	Open Aperture Door
03:52	Enable Alignment and Focus Servos and Achieve Thermal Equilibrium
04:02	Initiate Repeatable On-orbit Operations Sequence
...Typical Repeatable On-orbit Operations Sequence Requiring 522 min (8 hr 42 min) is Performed 18 Complete Times, Plus one Partial Cycle, Achieving 86 hr 24 min of Observation (See Table III-3), Ending at...	
164:24	Close Aperture Door
164:30	Secure Launch Locks to Protect Primary and Secondary Mirror Assemblies
164:42	Pitch Telescope into Stowed Position
165:42	Secure Telescope Launch Locks
165:46	Turn off Telescope Thermal Control Fluid Systems and Spectral Filter Thermal Control
165:48	Turn off Control and Display Panel, Image Control Subsystem Servos, Camera and Filter Control, and Thermal Control Electronics
165:52	Turn off Electrical and Thermal Control Subsystem
165:54	Check out Orbiter, Prepare for Return to Earth
166:54	Initiate Deorbit

Table III-3 Typical Repeatable On-Orbit Operations Sequence - Photoheliograph

MODE	FUNCTION/OPERATION	TIME, MINUTES 1	2	3	4	5	6	7	TOTAL
QUIET SUN	A. Select Target	3			3	3	3		12
	B. Point Telescope to Acquire Target	3			3	3	3		12
	C. Align Secondary Mirror Relative to Primary Mirror Transversely and in Tilt	6			6	6	6		24
	D. Adjust Focus, Moving Secondary Mirror and Cell Assembly Axially Along Optical Axis of Mirror	12			12	12	12		48
	E. Observe Target	18			18	18	18		72
ACTIVE SUN	F. Select Target	3	3	3			3	3	15
	G. Point Telescope to Acquire Target	3	3	3			3	3	15
	H. Align (same as C above)	6	6	6			6	6	30
	I. Adjust Focus (same as D above)	12	12	12			12	12	60
	J. Observe Target	30	30	30			30	30	150
FLARE	K. Select Target							3	3
	L. Point Telescope to Acquire Target							3	3
	M. Align (same as C above)							6	6
	N. Adjust Focus (same as D above)							12	12
	O. Observe Target							60	60
	TOTAL TIME FOR REPEATABLE SEQUENCE, MIN								552

Table III-4 Mission Timeline X-Ray - Focusing Telescope

ELAPSED TIME,	EVENT
00:00	Liftoff
00:06.5	Insert into 50 x 100 n mi Orbit
00:50.1	Transfer to 100 x 200 n mi Orbit at First Apogee
01:35.8	Circularize at 200 n mi Orbit at First Apogee. Stabilize, Check out Orbiter Systems, Update Ephemeris, Open Orbiter Cargo Bay Doors, Verify Readiness to Proceed with Experiment Operations
02:00	Orbiter Coarse-Attitude Acquisition
02:30	Turn on Electrical, Thermal Control, Pointing and Control, and Communication Subsystems
02:40	Turn on Control and Display Panels, Image Electronics, Camera Programming Electronics, Filter Wheel Control, Thermal Control Electronics, Photomultiplier Detector Electronics
02:50	Turn on Telescope Main Power Thermal Control Status Check. Aperture Door Position Control, Select Filter Wheel Position Select Detector
03:08	Select Imaging System Camera Frame Rate, Verify Image Intensifier High-voltage Control and Grating Position, Check Initiate and Stop Mode Operation
03:11	Check Crystal Spectrometer System Slit Size Control, Scan Range Control, Calibrate, Initiate and Stop Mode Operation
03:19	Check Proportional Counter High-voltage Control, Calibrate, Pulse Height Analyzer Resolution Width, Initiate and Stop Mode Operation
03:23	Turn H-alpha Slit Camera Power on, Filter Heater on and Status Check, High-voltage Control on
03:26	Check Photomultiplier Detector System High-voltage Power Control, Discriminator Level Control, Flare Alert Display
03:31	Turn on Solar X-ray Monitor Telescope Main Power Control, High-voltage Control, Brightness Control
03:33	H-alpha Monitor Telescope Main Power Control, High-voltage Control, Filter Heater Control, Verify Thermal Status
03:36	Release Telescope Launch Locks
03:38	Rotate Telescope to 90-deg Position and Lock
03:53	Pitch Telescope into Initial Operations Position
04:10	Initiate Repeatable On-orbit Operations Sequence
...Typical Repeatable On-orbit Operations Sequence Requiring 245 min (4 hr 5 min) is Performed 39 Complete Times, Plus one Partial Cycle, Achieving 105 hr 52 min of Observation (See Table III-6), Ending at...	
164:30	Pitch Telescope into Stowed Position
165:00	Rotate Telescope into Stowed Position
165:30	Secure Telescope Launch Locks
164:34	Turn off Control and Display Panels, Image Electronics, Camera Programming Electronics, Filter Wheel Control, Thermal Control Electronics, Photomultiplier, and Detector Electronics
165:44	Turn off Electrical, Thermal Control, Pointing and Control, and Communication Subsystems
165:54	Check out Orbiter, Prepare for Return to Earth
166:54	Initiate Deorbit

Table III-5 Typical Repeatable On-Orbit Operations Sequence, X-ray Focusing Telescope

MODE	FUNCTION / OPERATION	Time, Min 1	2	3	4	5	6	7	TOTAL
QUIET SUN	A. Select Target	3			3	3	3		12
	B. Point Telescope to Acquire Target	3			3	3	3		12
	C. Operate Imaging System	5			5	5	5		20
	D. Index to Crystal Spectrometer	1			1	1	1		4
	E. Operate Crystal Spectrometer	3			3	3	3		12
ACTIVE SUN	F. Select Target	3	3	3			3	3	15
	G. Point Telescope to Acquire Target	3	3	3			3	3	15
	H. Operate Crystal Spectrometer	3	3	3			3	3	15
	I. Index to Imaging System	1	1	1			1	1	5
	J. Operate Imaging System	5	5	5			5	5	25
	K. Index Grating In	1	1	1			1	1	5
	L. Operate Imaging System Plus Grating	5	5	5			5	5	25
	M. Index to Proportional Counter	1	1	1			1	1	5
	N. Operate Proportional Counter	1	1	1			1	1	5
	O. Index to Crystal Spectrometer	1	1	1			1	1	5
FLARE	P. Identify Target							1	1
	Q. Point Telescope to Acquire Target							3	3
	R. Index to Imaging System and Grating							1	1
	S. Operate Imaging System and Grating							60	60
	Total Time for Repeatable Sequence, min								245
	Repeatable Operations Time, min								162

Table III-6 Mission Timeline XUV Spectroheliograph

ELAPSED TIME,	EVENT
00:00	Liftoff
00:06.5	Insert into 50 x 100 n mi Orbit
00:50.1	Transfer to 100 x 200 n mi Orbit at First Apogee
01:35.8	Circularize at 200 n mi Orbit at First Apogee Stabilize, Check Out Orbiter Systems, Update Ephemeris, Open Orbiter Cargo Bay Doors, Verify Readiness to Proceed with Experiment Operations
02:00	Orbiter Coarse-attitude Acquisition
02:30	Turn on Electrical Subsystem
02:35	Turn on Control and Display Panel, Image Control Subsystem Servos, and Camera Control
02:45	Adjust Band Selection Grating
03:00	Release Telescope Launch Locks
03:02	Rotate Telescope to 90-deg Position and Lock
03:17	Pitch Telescope into Initial Operations Position
03:34	Uncover Spectroheliograph Optics
04:04	Perform Initial Calibration, Quiet Sun, Plages
04:19	Perform Initial Calibration, Quiet Sun, (Inner) Corona
04:34	Perform Initial Calibration, Standard Lamps (Internal)
05:04	Initiate Repeatable On-orbit Operations Sequence
...Typical Repeatable On-orbit Operations Sequence Requiring 1468 min (24 hr 28 min) is Performed 6 Complete Times, Plus one Partial Cycle, Achieving 156 hr 16 min of Observation (See Table III-7) Ending at...	
164:08	Cover Spectroheliograph Optics
164:44	Pitch Telescope into Stowed Position
165:44	Secure Telescope Launch Locks
165:48	Turn off Control and Display Panel, Image Control Subsystem Servos, and Camera Control
165:52	Turn off Electrical System
165:54	Check Out Orbiter, Prepare for Return to Earth
166:54	Initiate Deorbit

Table III-7 Typical Repeatable On-orbit Operations Sequence, XUV Spectroheliograph

FUNCTION	TIME, min
A. Observe Corona, 1 Exposure/min	20
B. Observe Plage, 1 Exposure/10 to 30 s	24
C. Observe Plage, 1 Exposure/hr	240
D. Observe Corona, 1 Exposure/min	20
E. Observe Plage, 1 Exposure/10 to 30 s	24
F. Observe Plage, 1 Exposure/hr	240
G. Observe Corona, 1 Exposure/min	20
H. Observe Plage, 1 Exposure/10 to 30 s	24
I. Observe Plage, 1 Exposure/hr	240
J. Observe Corona, 1 Exposure/min	20
K. Observe Plage, 1 Exposure/10 to 30 s	24
L. Observe Plage, 1 Exposure/hr	240
M. Observe Corona, 1 Exposure/min	20
N. Observe Plage, 1 Exposure/10 to 30 s	24
O. Observe Plage, 1 Exposure/hr	240
P. Observe Corona, 1 Exposure/min	20
Q. Calibrate, Quiet Sun Plages Photos	5
R. Calibrate, Quiet Sun (Inner) Corona	5
S. Calibrate, Standard Lamps (Internal)	18
Total	1468 (24 hr 28 min)

Table III-8 Mission Timeline - Coronagraphs

ELAPSED TIME,	EVENT
00:00	Liftoff
00:06.5	Insert into 50 x 100 n mi Orbit
00:50.1	Transfer to 100 x 200 n mi Orbit at First Apogee
01:35.8	Circularize at 200 n mi Orbit at First Apogee Stabilize, Check out Orbiter Systems, Update Ephemeris, Open Orbiter Cargo Bay Doors, Verify Readiness to Proceed with Experiment Operations
02:00	Orbiter Coarse-attitude Acquisition
02:30	Turn on Electrical and Thermal Control Subsystems
02:35	Turn on Control and Display Panel, Occulting Disc Control Subsystems, Camera and Filter Control, and Thermal Control Electronics
02:45	Turn on and Stabilize Telescope Thermal Control Systems
03:15	Release Telescope Launch Locks
03:17	Rotate Telescope to 90-deg Position and Lock
03:32	Pitch Telescope into Initial Operations Position
03:49	Open Covers and Lens Caps on both 1 to 6 Solar radii and 5 to 30 Solar radii Coronagraphs
04:00	Acquire Sun in Telescope FOV
04:06	Achieve Thermal Equilibrium
14:18	Adjust Positions of External Occulting Discs to Obtain Maximum Suppression of Diffraction Effects for 1 to 6 Solar radii
04:33	Adjust Positions of External Occulting Discs to Obtain Maximum Suppression of Diffraction Effects for 5 to 30 Solar radii Coronagraph
04:48	Adjust Intensity Calibration Wedges for 1 to 6 Solar radii Coronagraph
05:00	Adjust Intensity Calibration Wedges for 5 to 30 Solar radii Coronagraph
05:10	Initiate Automatic Observation Program
...Continue Automatic Observation Program with no Interruption until a Limb Flare occurs. During a Limb Flare, Astronaut Astronomer Adjusts Data Acquisition Rate for Duration of Flare, then returns to Normal Automatic Observation Program, Ending at...	
164:16	Close Covers and Lens Caps on both 1 to 6 Solar radii and 5 to 30 Solar radii Coronagraphs
164:42	Pitch Telescope into Stowed Position
165:42	Secure Telescope Launch Locks
165:46	Turn off Control and Display Panel, Occulting Disc Control Subsystem, Camera and Filter Control, and Thermal Control Electronics
165:52	Turn off Electrical and Thermal Control Subsystem
165:54	Check out Orbiter, Prepare for return to Earth
166:54	Initiate Deorbit

Table III-9 Mission Timeline - Stratoscope III

ELAPSED TIME,	EVENT
00:00	Liftoff
00:06.5	Insert into 50 x 100 n mi Orbit
00:50.1	Transfer to 100 x 250 n mi Orbit at First Apogee
01:35.8	Circularize at 250 n mi Orbit at First Apogee Stabilize, Check out Orbiter Systems, Update Ephemeris, Open Orbiter Cargo Bay Doors, Verify Readiness to Proceed with Experiment Operations
02:00	Orbiter Coarse-attitude Acquisition
02:30	Turn on Electrical System, Activate Caution and Warning System, Control and Display Panels, and Thermal Control System
03:00	Release Telescope Launch Locks
03:02	Rotate Telescope to 90-deg Position and Lock
03:17	Pitch Telescope into Initial Operations Position
13:34	Release Launch Locks to Protect Primary and Secondary Mirror Assemblies
03:36	Open Covers on Optics, Extend Shield
03:48	Perform Functional Check of Console Systems
04:00	Activate and Check out Drives
04:06	Turn on Main Power to Instrument Detectors
04:08	Monitor Temperature Control System until Stabilization
04:32	Initiate Repeatable On-orbit Operations Sequence

...Typical Repeatable On-orbit Operations consist of Observing Targest for 70 min per Repeatable Cycle with the Remainder of the Cycle being Utilized to Point the Telescope (30 min), Calibrate the Instrument (7 min), and to Select Filter, Grating, and Instruments (2 min). The Repeatable Cycle Requires 109 min and is Performed 87 times, plus one Partial Cycle, Achieving 101 hr 30 min of Observation, Ending at...

162:56	Retract Shield, Close Covers on Optics
163:20	Secure Launch Locks to Protect Primary and Secondary Mirror Assemblies
163:36	Pitch Telescope into Stowed Position
165:06	Secure Telescope Launch Locks
165:10	Switch to Standby Control and Display Panels, Caution and Warning System, Thermal Control System, and Electrical System
165:30	Check out Orbiter, Prepare for Return to Earth
166:30	Initiate Deorbit

Table III-10 Mission Timeline, 1-Meter Infrared Telescope

ELAPSED TIME,	EVENT
00:00	Liftoff
00:06.5	Insert into 50 x 100 n mi Orbit
00:50.1	Transfer to 100 x 250 n mi Orbit at First Apogee
01:35.8	Circularize at 250 n mi Orbit at First Apogee Stabilize, Check out Orbiter Systems, Update Ephemeris, Open Orbiter Cargo Bay Doors, Verify Readiness to Proceed with Experiment Operations
02:00	Orbiter Coarse-attitude Acquisition
02:30	Release Telescope Launch Locks
02:32	Rotate Telescope to 90-deg Position and Lock
02:54	Pitch Telescope into Initial Operations Position
03:18	Open Cover
03:20	Set up Telescope/Instrument, allow Temperature Stabilization
07:54	Perform Alignment and Calibration
08:54	Initiate Repeatable On-orbit Operations Sequence
...Typical repeatable on-orbit operations consist of periodic checkout (12 min), periodic calibration (6 min), guide star acquisition (3 min), object location (3 min), object observation (10.4 min), guide star acquisition (3 min), object location (3 min), object observation (32.6 min), guide star acquisition (3 min), object location (3 min), object observation (12.6), and rotate other detector to focal point (3 min). The repeatable cycle requires one orbit (94.6 min) and is performed 98 times achieving 55.6 min observation per orbit, ending at...	
163:25	Close Cover
163:37	Pitch Telescope into Stowed Position
164:54	Secure Telescope Launch Locks
165:00	Switch Subsystems to Standby
165:30	Check out Orbiter, Prepare for Return to Earth
166:30	Initiate Deorbit

Table III-11 Specific Assumptions and Parameters

Solar Telescopes
1. Orbital altitude - 370 km (200 n mi)
2. Orbital inclination - 66.5 to 90.0 deg
3. Altitude and inclination provide continuous sun for 7-day mission
Stratoscope III
1. Orbital altitude - 463 km (250 n mi)
2. Orbital inclination - 28.5 deg
3. Constrained from viewing within 45 deg of sun and 15 deg of earth and moon
4. Sunside operation is possible
IR Telescope
1. Orbital altitude - 463 km (250 n mi)
2. Orbital inclination - 28.5 deg
3. Constrained from viewing within 90 deg of sun and 45 deg of earth and moon
4. Sunside operation is possible
5. Cryogenic cooling systems must be operating at launch to maintain precooling of detectors and mirrors. Therefore, control and display panels, the caution and warning system, and electrical systems must be operating during the mode
6. On-orbit time for setup and temperature stabilization of 4 hr 34 min assumes prelaunch conditioning and an active cryogenic cooling system at launch

D. MISSION ANALYSIS

Preliminary mission analyses were performed to define the preferred orbital parameters for the baseline telescopes and arrays. One of the first realizations was that the orbital parameters for a seven-day sortie mission are quite different from those required for long-duration satellite missions. A seven-day mission has more flexibility in terms of selecting a particular launch date, orbital altitude, and inclination to satisfy the experiment objectives since the long-term effects of the sun, earth, and moon positions and the regression of the orbit plane are not as important.

In addition to defining the preferred orbital parameters for the baseline experiments, the requirement for the Shuttle to have the air-breathing engine system (ABES) for the astronomy sortie missions was investigated. This was an important issue for the astronomy sortie missions since the addition of the ABES system to the Shuttle would reduce the payload capability by approximately 7,260 kg (16,000 lb) and make the higher inclination orbits marginal.

1. Air-Breathing Engine System (ABES)

In the Space Shuttle reference documentation, two values were given for payload capabilities, one with ABES and one without. The ABES was required for all passenger flights or for missions that required crossrange capabilities greater than 2040 km (1100 n mi) during landing. Since the astronomy sortie missions are not passenger flights, the crossrange requirements were investigated to determine if ABES would be required. The results of this investigation are presented in the following paragraphs and indicate the ABES would not be required for the astronomy sortie missions.

In this analysis it was assumed that KSC was the Shuttle launch and landing site and that a landing opportunity must exist within the 2040 km (1100 n mi) crossrange capability of the Shuttle prior to a ground elapsed time (GET) of 168 hr. Four orbital altitudes were investigated for each of four inclinations to determine the landing opportunities.

Figure III-6 shows the landing opportunities that exist on the seventh day of the mission for a 500-km (270-n-mi) altitude and a 28.5-deg inclination. From the figure it can be seen that five landing opportunities exist prior to the GET of 168 hr. Only landing opportunities that are within the 2040-km crossrange are shown on the figure. For those revolutions that do not appear, the crossrange exceeds the 2040-km capability of the Shuttle.

Figure III-7 shows parametric data for various altitudes and inclinations that are candidates for astronomy missions. From the figure it can be seen that a landing opportunity exists for each of the orbits considered within 1½ hr of the GET of 168 hr. The landing opportunity shown was the last opportunity before the 168-hr GET. In all cases there was a minimum of two additional landing opportunities on the revolutions prior to the one identified.

From the above analyses, it was determined that the astronomy sortie missions would have an adequate number of landing opportunities within the 2040-km (1100-n-mi) crossrange capability of the Space Shuttle without an ABES system. Therefore it was recommended that the ABES be deleted for the astronomy missions.

2. Solar Telescopes Orbit Selection

The solar telescopes prefer orbits that provide continuous sun observations without viewing through the earth's atmosphere and orbits that provide a beta angle near 90 deg to minimize the doppler effects of the spacecraft.

Figure III-8 shows the orbit plane and sun line relationships and their shifts that affect the desired conditions. The three-dimensional view at the bottom shows the general relationships at some point in time. Note that beta angle, defined as the minimum angle between the sun line and orbit plane is a function of the inertail regression rate and the apparent motion of the sun.

The top view illustrates the change in sun angle due to inertial orbit regression. This regression rate is a function of orbit altitude and inclination and varies from 0 deg/day at an inclination of 90 deg to a maximum of about 6 deg/day at the lower inclinations.

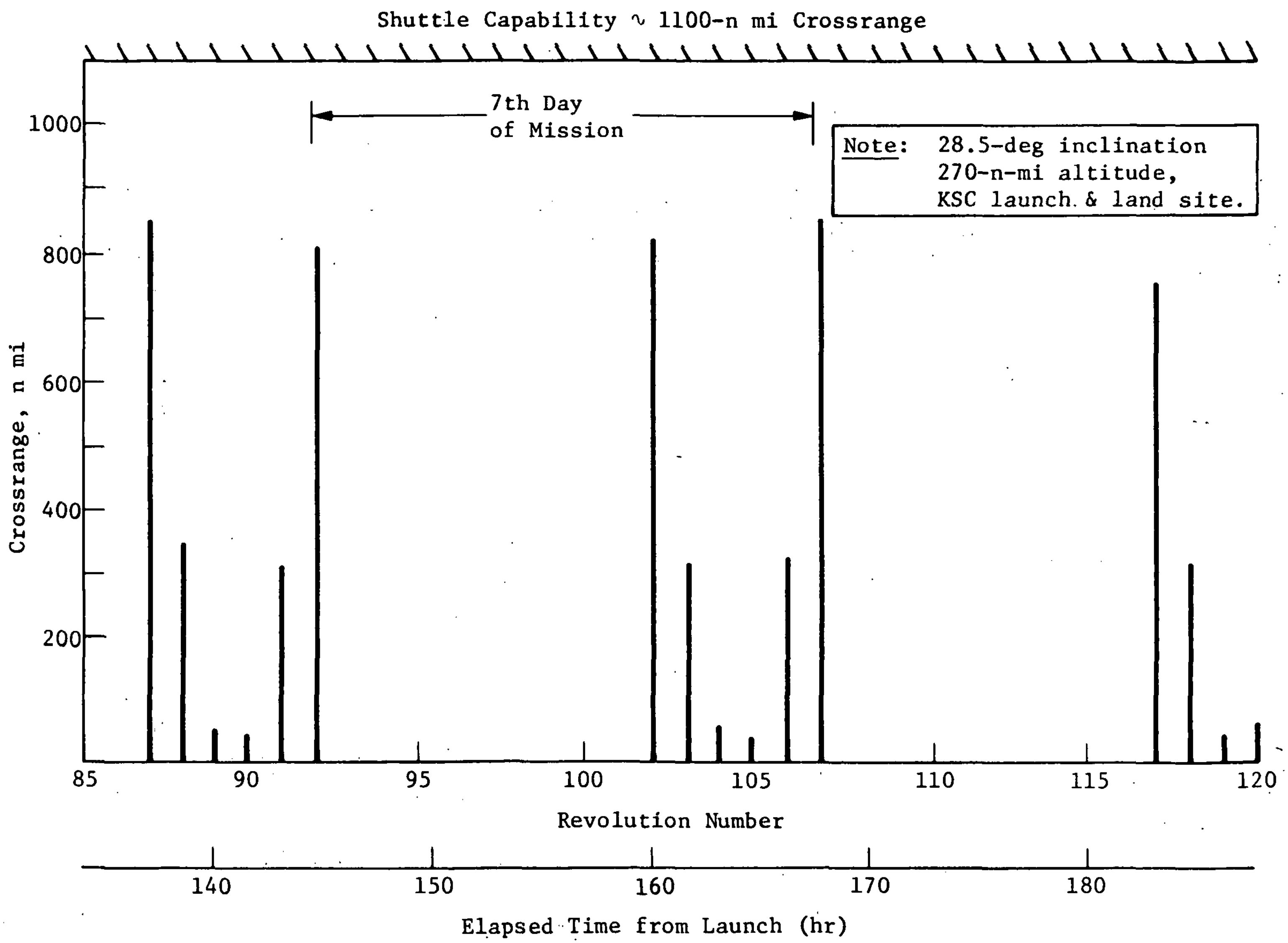


Fig. III-6 Shuttle Landing Opportunities, 28.5-Deg and 270-N-Mi Orbit

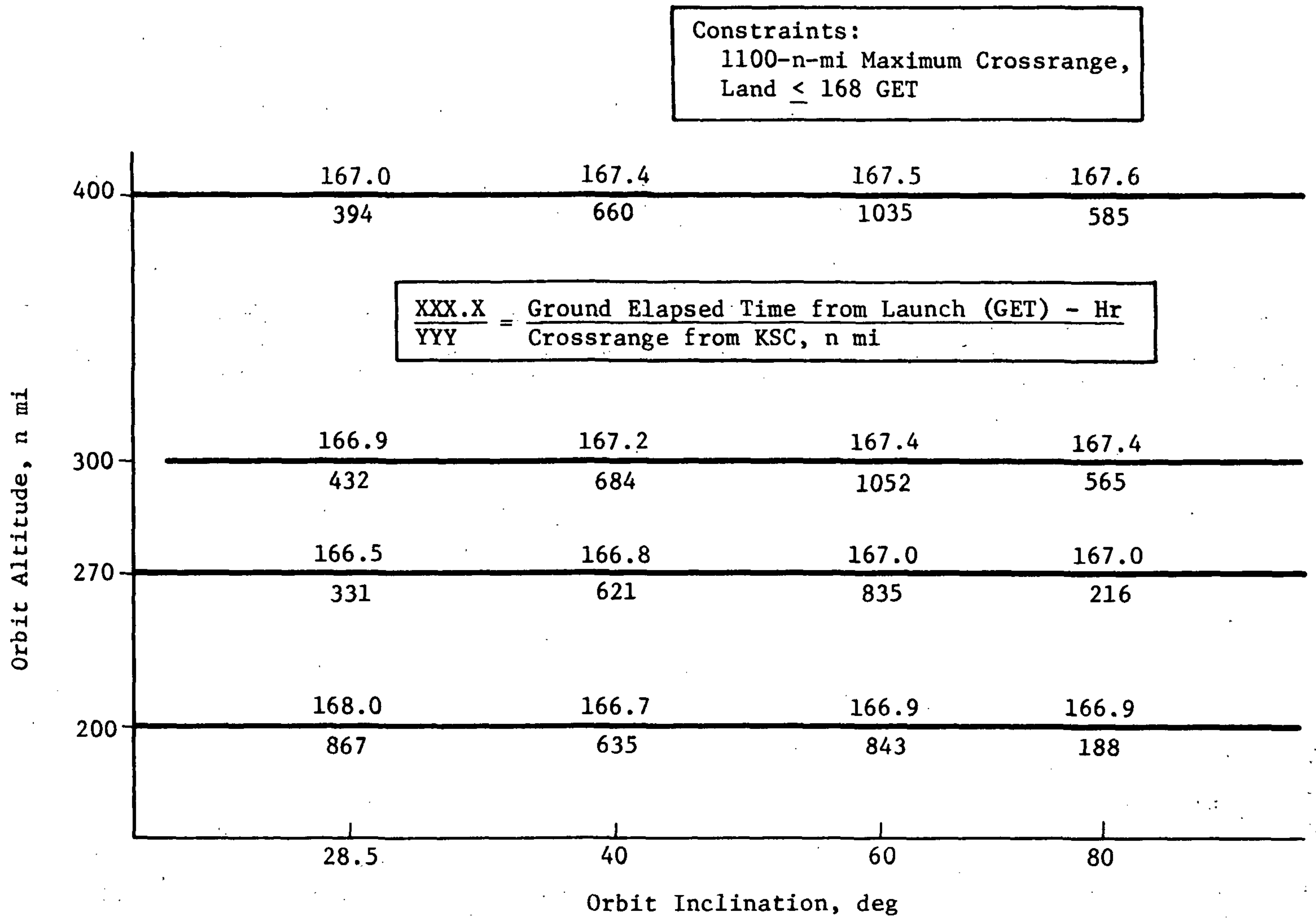
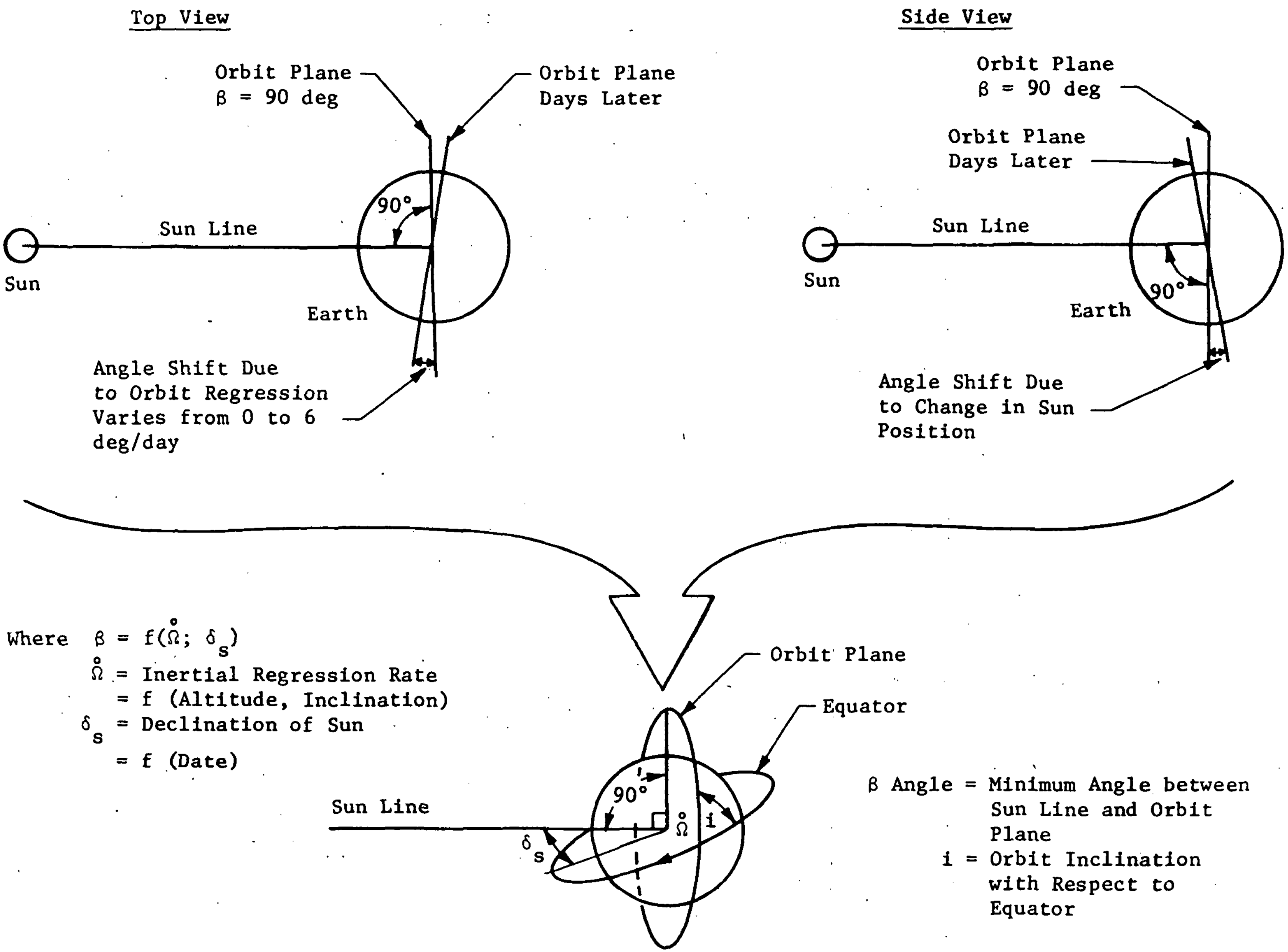


Fig. III-7 Shuttle Landing Opportunities for Different Orbits



Where $\beta = f(\mathring{\Omega};\ \delta_s)$

$\mathring{\Omega}$ = Inertial Regression Rate

= f (Altitude, Inclination)

δ_s = Declination of Sun

= f (Date)

β Angle = Minimum Angle between Sun Line and Orbit Plane

i = Orbit Inclination with Respect to Equator

Fig. III-8 Sun Line/Orbit Plane/Beta Angle (β) Relations

The side view shows the change in sun angle due to the apparent motion of the sun. This change is a function of the time of year since the sun's position will vary from 0 to ± 23.5 deg in declination and 0 to 360 deg in right ascension. Figure III-9 shows the inclination that would be required to provide a beta angle of 90 deg for various dates throughout a year. The minimum altitude shown is the altitude that would be required to provide continuous sun without viewing through the atmosphere. The atmosphere that was assumed for this analysis was 185 km (100 n mi). Subsequent work identified the need for an atmosphere of 400 km (216 n mi) and is reported in Volume III, Book 1) of this report.

Based on the above data, the preliminary mission analysis indicated that the solar payloads could be flown any time during the year and that the orbital inclination would vary from 66.5 to 90 deg (assuming the capability exists to launch any time during a 24-hr day) with a maximum altitude of 370 km (200 n mi).

3. IR Telescope Orbit Selection

The IR telescope prefers an orbit that maximizes the dark time, maximizes the celestial sphere availability, and minimizes the sun, earth, and moon interference with celestial viewing.

Since it was desirable to maximize the dark time because this would also maximize the telescope efficiency, an elliptical orbit was analyzed to determine if it would provide a significant increase in dark time compared to a more conventional circular orbit. Figure III-10 summarizes the results of this analysis and shows the minutes of dark time that would be available for circular orbit altitudes between 370 and 740 km (200 to 400 n mi) at beta angles of 0 to 60 deg. The figure also shows the minutes of dark time that would be available for elliptical orbits that would require the same energy as the corresponding circular orbit.

As shown, the dark time with elliptical orbits increases only at very low beta angles and then the increase is small (less than 3 min maximum). Note that substantial decreases occur (even for circular orbits) at the higher beta angles and altitudes. Since the elliptical orbits did not offer a significant advantage over the circular orbits in the amount of dark time and because they have some operational disadvantages such as ground station coverage, it was recommended that only circular orbits be considered for the IR sortie missions.

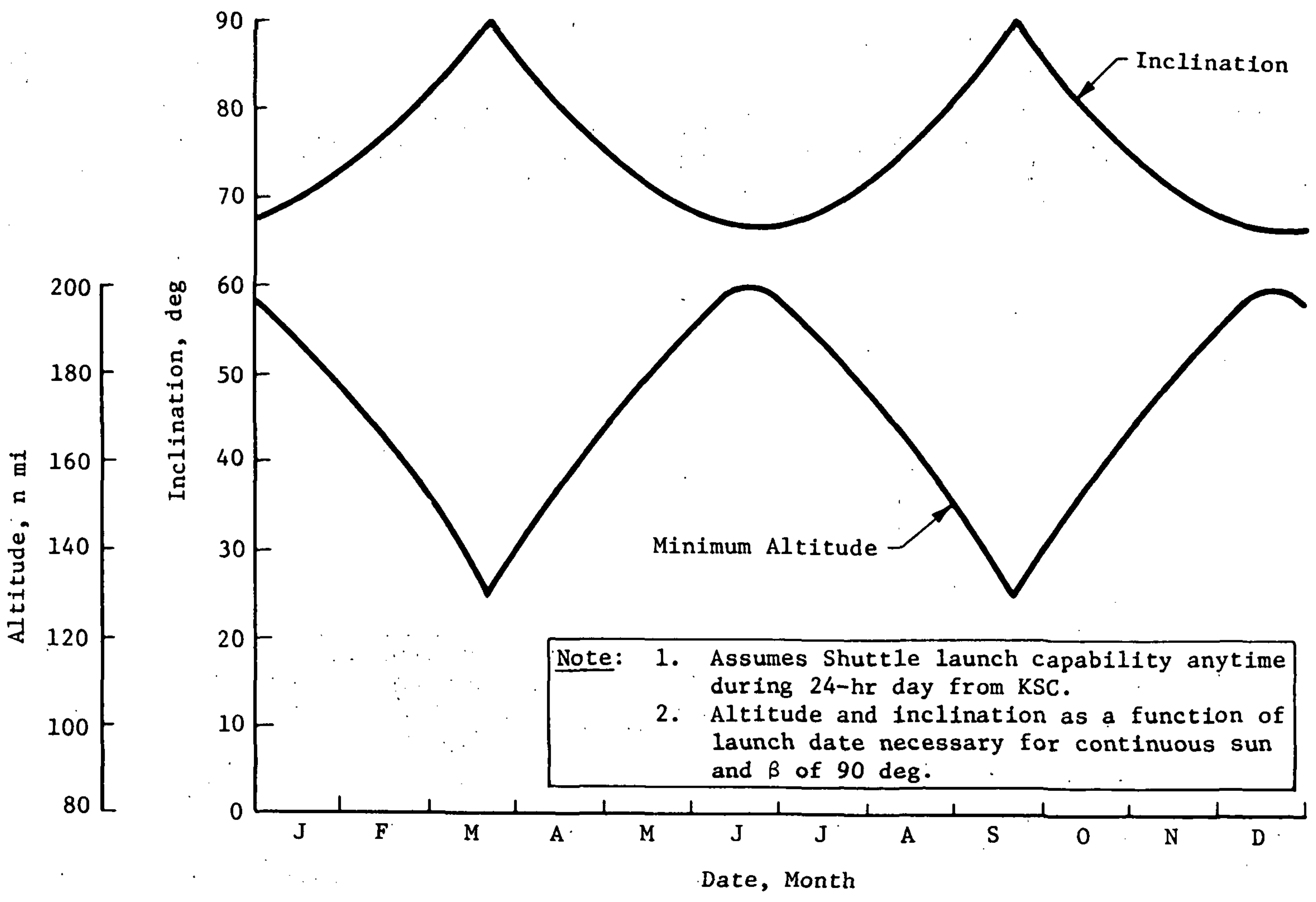


Fig. III-9 Solar Payloads, Altitude and Inclination Selection

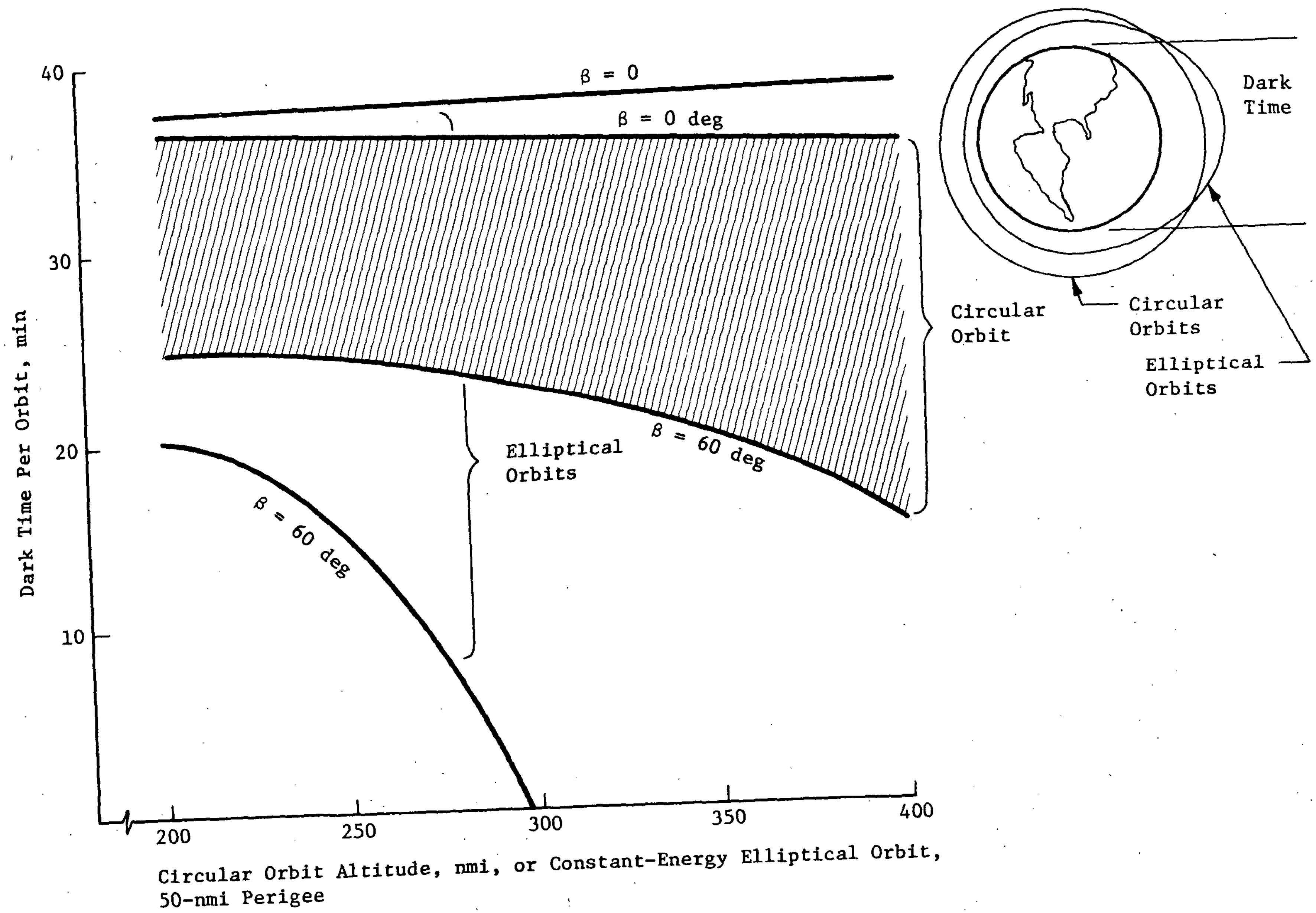


Fig. III-10 IR Elliptical Orbit Analysis

The availability of the celestial sphere for viewing is a direct result of the operational constraints placed on the IR telescope. The baseline constraint placed on the telescope operation was that the telescope axis could not view within 90 deg of the sun and 45 deg of the moon or limb of the earth. With these constraints, the relative positions of the sun, earth, and moon have a major effect on the celestial sphere area available for observations. Figures III-11 and III-12 show the amount of the celestial sphere that would be available for viewing during one orbit for two launch dates separated by 14 days.

Figure III-11 shows the area that would be available (clear area) during a full moon with the above operational constraints. Figure III-12 shows the area available during a new moon. As can be summarized from these figures, it would be very advantageous to fly the IR missions during the new moon phase. During times of a new moon (± approximately 4 days), viewing capability for the IR telescope is maximum because the moon-proximity constraint is included within the restriction imposed by the sun. The minimum and maximum celestial sphere viewing capabilities for the IR telescope indicate that the variation is a function of the lunar period. Figure III-13 shows the change in the percentage of the celestial sphere available for viewing during the lunar months of 1977. The maximum percentage regions are approximately 8 days in duration. Thus, the 7-day sortie mission capability for IR viewing could be maximized by launching at the start of a maximum percentage region.

Because of the preference for dark time (which decreases at hich inclinations), an inclination of 28.5 deg was selected for the IR telescope. The altitude of 463 km (250 n mi) was selected because there is no requirement to go higher for sortie missions, and the basic Shuttle OMS is adequate at the 463-km altitude without adding tanks and propellant.

4. Stratoscope III (SII) Orbit Selection

The SIII is constrained to viewing no closer than 45 deg to the sun and 15 deg to the moon and earth's horizon. Orbit inclination may be varied to optimize target location in the celestial sphere and to reduce the effect of the restrictions imposed by the viewing proximity constraints. An inclination of 28.5 deg was selected as the baseline although it is recognized that higher inclinations could be desirable for certain targets should they be specifically identified later.

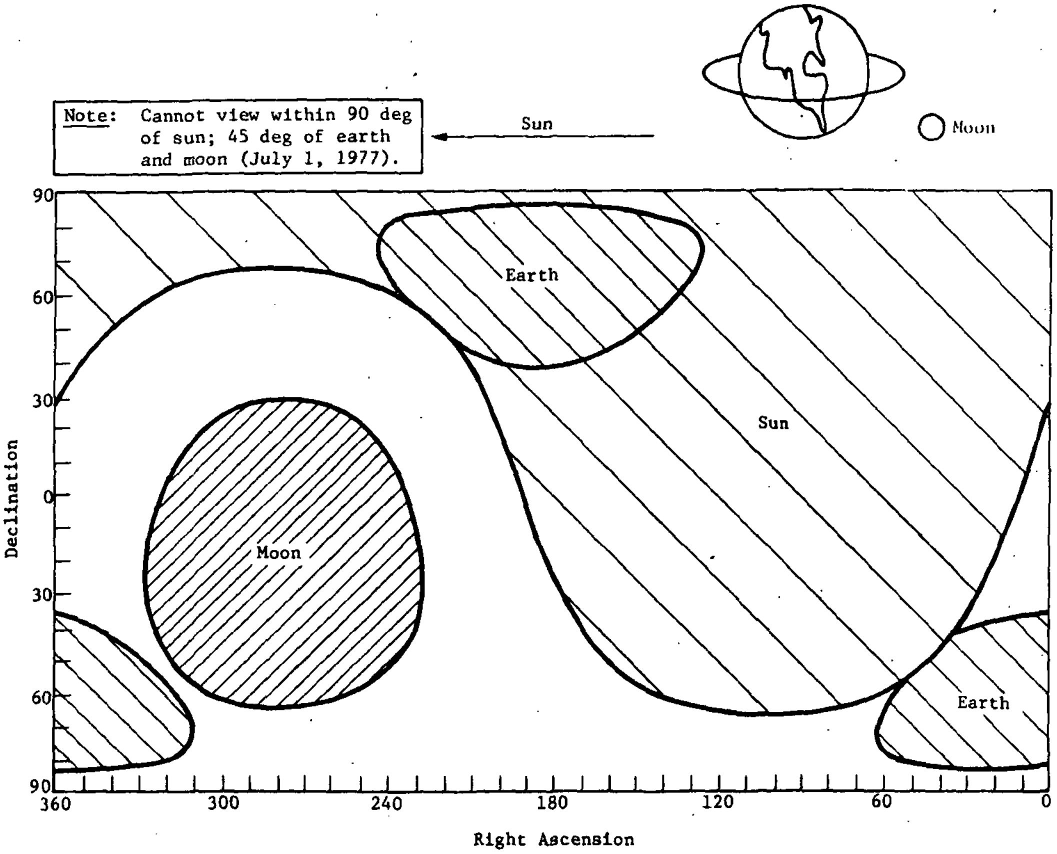


Fig. III-11 IR Celestial Sphere Viewing, 0 deg Beta Angle (Minimum)

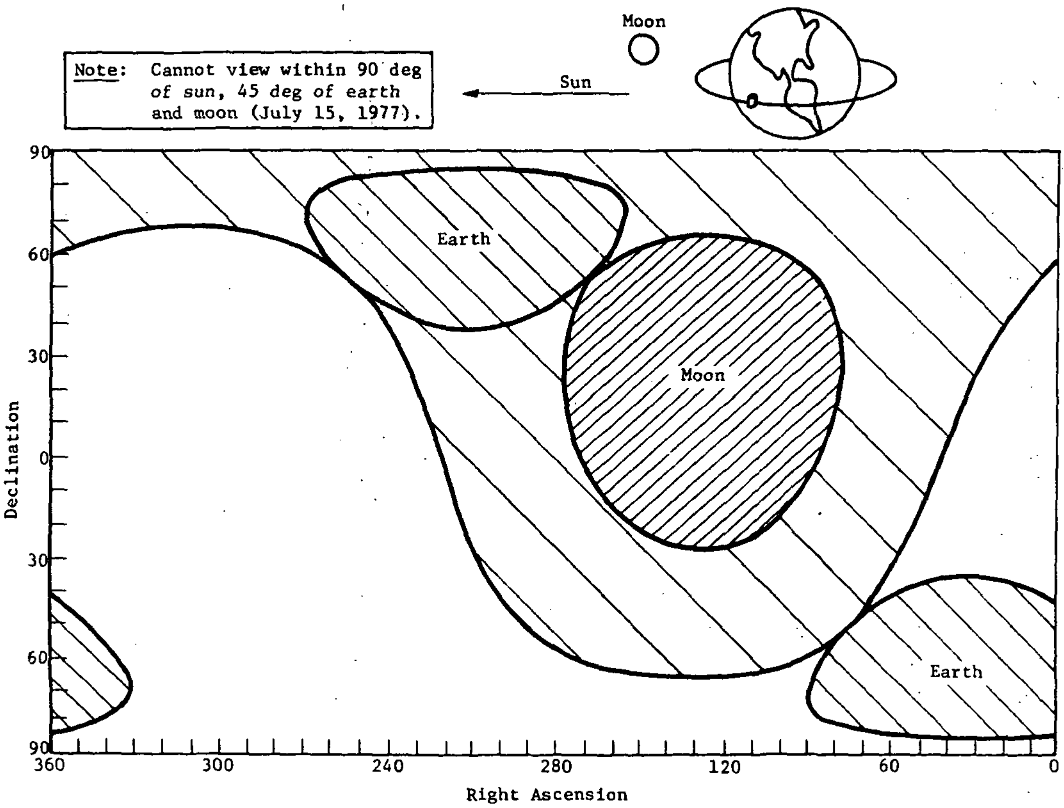


Fig. III-12 IR Celestial Sphere Viewing, 0 deg Beta Angle (Maximum)

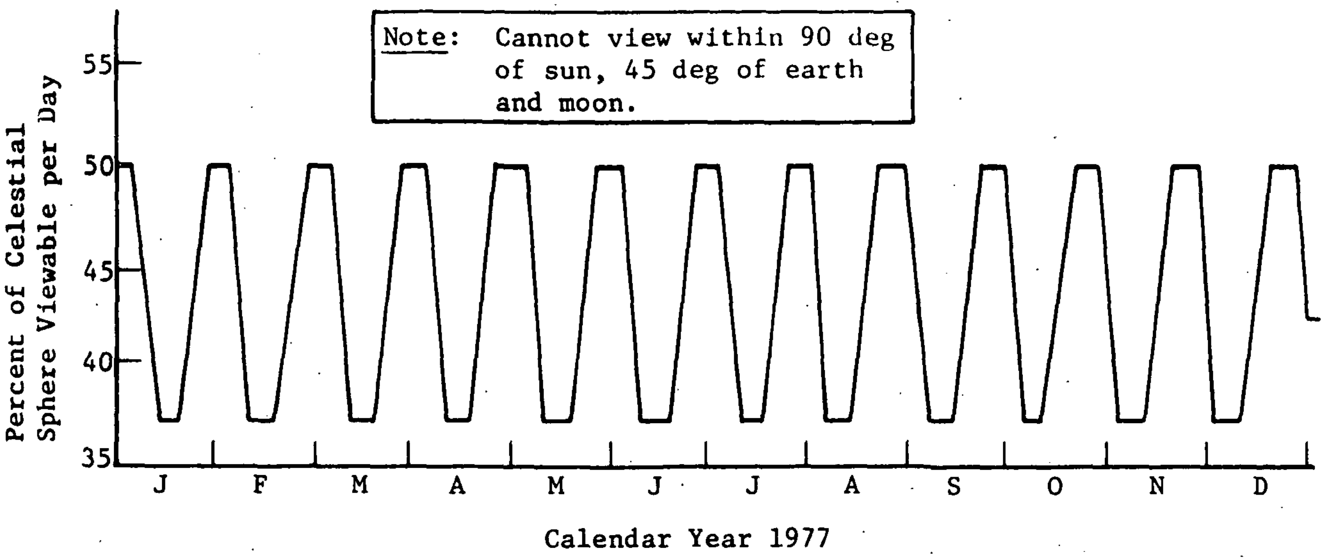


Fig. III-13 IR Viewing Variation with Sun and Moon Position

5. Orbit Selection for Arrays

The X-ray and gamma-ray arrays for the sortie payloads operate throughout the missions except during passage through the South Atlantic Anomaly. Thus the orbit altitude and inclination preference for the arrays is to minimize time spent in the anomaly area.

Figure III-14 shows the percent of time spent in the South Atlantic Anomaly for circular orbits from 370- to 740-km (200 to 400 n mi) altitudes and inclinations from 28.5 to 90 deg. Although losses due to passage through the anomaly are lowest for low-altitude high-inclination orbits, none of the losses exceed about 4.5%. Thus the orbit preferences of the telescopes as primary payloads may take precedence without seriously affecting the results obtained with the arrays.

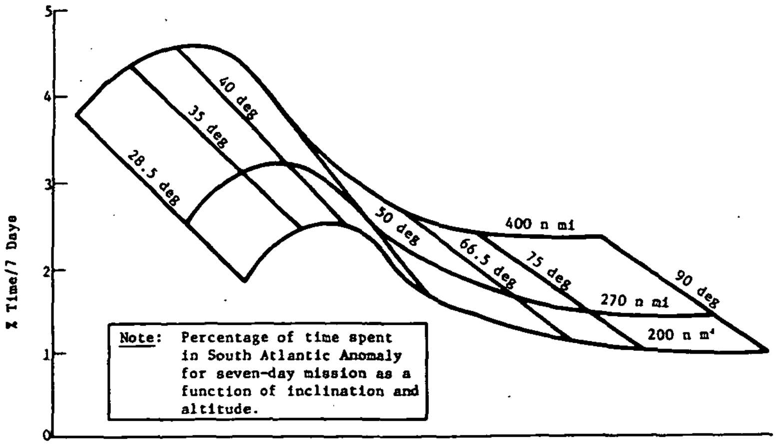


Fig. III-14 Array Time in South Atlantic Anomaly

E. MISSION EFFECTIVENESS

In general, the scientific performance of the baseline experiments would be enhanced by the sortie mode of operation. Foremost would be the benefit resulting from the scientific crewmen because they can monitor performance, provide flexibility of schedule, and offer fast reaction to targets of opportunity. Of those scientific objectives identified for the baseline experiments, only the IR telescope would suffer from the sortie mode of operation. One of the scientific objectives listed in the Blue Book for the IR telescope was an all-sky survey of faint infrared objects. This was to be accomplished by letting the spacecraft orbital motion sweep the detector array through the sky. While this leisurely survey ties up the IR telescope full time for a year, it also allows a narrow electrical bandwidth and therefore excellent NEFD (noise-equivalent flux density) at the aperture. With a sortie mission of only one week, it is clearly impractical to undertake an all-sky survey this way. Two options are open--the astronomers can select a few areas for complete surveying and thus gather statistics on infrared celestial objects, and alternatively, the survey can be speeded up by sweeping the detector array (aligned along the flight path) at right angles to the orbital plane. The sweep could be accomplished by nodding the whole telescope, or by moving the image or detector internally. However, the sweep rate would have to be increased so much that the electrical bandwidth would be about 200 times wider and the NEFD would be worse by a factor of at least 14.

Mission effectiveness would also be enhanced by the sortie method of operation because each mission could be tailored to its observational program. The launch time and orbit would be selected to give maximum observing time of a particular object or area, or to minimize the interference of sun, earth, or moon. The scientific crew would be chosen for the applicability of this scientific background to each observational program.

Sortie missions would also offer the opportunity to improve the astronomical program with time. As experience is gained, it would be possible to update operational techniques and to redesign hardware for maximum mission effectiveness. To accomplish this, some time should be allotted at the end of each of the earlier flights for nonastronomical experimentation. For instance a waste dump could be commanded, and the increased sky brightness measured as a function of time. The telescopes could be pointed a little closer to the sun, earth, or moon than is normally allowed to see how rapidly performance degrades with angle and time. These and other experiments would show what restrictions may be relaxed or tightened to maximize mission effectiveness.

The baseline time-lines presented in Section C were analyzed to determine the effectiveness of the sortie missions in providing on-orbit observation time. The missions were defined to use the scientific crewmen for performing most alignment, calibration, focusing, checkout, and preparation functions and to monitor data acquisition during observation sequences.

1. Solar Telescopes Effectiveness

The solar telescopes would be flown at variable altitudes and inclinations to provide continuous daylight and beta angles near 90 deg. For the preliminary missions, an inclination of 70 deg and an altitude of 370 km (200 n mi) was selected.

a. Photoheliograph Mission - The on-orbit operations time-line for the photoheliograph defines observation requirements in all three sun modes--quiet, active, and flare. Each observation requires target selection, target acquisition, alignment, and fucusing. These preparation functions were assumed to be performed by the crew, and times were estimated for accomplishing each. The repeatable cycle resulted in the mission providing 86 hr 24 min observation time for a minimum mission efficiency of 52%. The photoheliograph time-use summary is tabulated.

Function	Time, hr:min
Boost to insertion, activate and deploy	2:00
Initial alignment, claibration, focusing, and checkout	2:02
Repetitive preparation for observation	73:58
Observation Sequences	86:24
Retract, stow, check out orbiter, initiate deorbit	86:24
Total	166:54

It is readily observed that most (some 92%) of the time unavailable for observation is required for the repetitive preparation necessary for each cycle. For the maximum mission efficiency preparation times were reduced by performing target selection while observation of the previous cycle was still in progress. Times required for target acquisition, alignment, and focusing were also reduced using the rationale that some functions could be automated and crew skills would improve after a few operational cycles. On this basis, observing time could be increased to 123 hr 36 min for a maximum mission efficiency of 74%.

It may be noted that with an orbit in the continuous sun region, observation time for the photoheliograph sortie mission is limited only by the time lost to set up, calibrate, acquire targets, align, and focus, and for boost and deorbit phases. It is expected that the maximum mission efficiency shown may be improved as further analysis of the operations continues.

b. X-ray Focusing Telescope Mission - This mission is quite similar to the photoheliograph, requiring observation in all three sun modes--quiet, active, and flare. Each observation requires target selection, target acquisition, and indexing. These preparation functions were assumed to be performed by the crew, and times were estimated for accomplishing each. The repeatable cycle resulted in the mission providing 105 hr 52 min observation time for a minimum mission efficiency of 63%. The x-ray focusing telescope time-use summary is tabulated.

Function	Time hr:min
Boost to insertion, activate and deploy	2:00
Initial alignment, calibration, focusing, and checkout	2:10
Repetitive preparation for observation	54:22
Observation sequences	105:52
Retract, stow, check out orbiter, initiate deorbit	2:30
Total	166:54

To develop the maximum efficiency cycle, preparation times for target acquisition and indexing were reduced to reflect automation and skill improvement. Also the target to be observed next was selected during the previous observation period. This would result in a total of 123 hr and 36 min observation time for a maximum efficiency of 72%.

c. XUV Spectroheliograph Mission - The on-orbit operations sequence for the XUV spectroheliograph provides near-continuous and repetitive observation of corona and plages for 24-hr periods, with a daily 28-min calibration sequence. After initial alignment, calibration, focusing, and preparation for observation, these functions need not be repeated for a 7-day sortie mission. The XUV spectroheliograph time-use summary is tabulated.

Function	Time hr:min
Boost to insertion, activate and deploy	2:00
Initial alignment, calibration, focusing, and checkout	3:04
Repetitive preparation for observation	2:48
Observation sequences	156:16
Retract, stow, check out orbiter, initiate deorbit	2:46
Total	166:54

It may be noted that the mission efficiency would be 94%, which is considered a maximum and is quite high compared to those for the photoheliograph and x-ray focusing telescopes.

d. Coronagraphs Mission - The coronagraphs are operated continuously and automatically with no interruption until a limb flare occurs after initial alignment calibration, focusing, and checkout. During a limb flare, the crew adjusts the data acquisition rate for the duration of the flare, then returns the experiments to the normal automatic observation program. As with the XUV spectroheliograph, the coronagraphs are very efficient, the on-orbit operations seqeunce providing 159 hr 06 min observation time for a mission efficiency of 95%. The time-use summary is tabulated.

Function	Time hr:min
Boost to insertion, activate and deploy	2:00
Initial alignment, calibration, focusing, and checkout	3:10
Observation sequence	159:06
Retract, stow, check out orbiter, initiate deorbit	2:38
Total	166:54

2. Stratoscope III (SIII) Effectiveness

For the preliminary SIII mission, an altitude of 463 km (250 n mi) and an inclination of 28.5 deg gave a launch-to-deorbit duration of 166 hr 30 min. With allowances for the once-per-mission functions of boost, setup, temperature stabilization, and retract and stow functions, 158 hr 24 min are available for repetitive checkout and observation.

Using 70 min as the observation duration during a repeatable cycle, the minimum mission efficiency would be 61%. The time-use summary is tabulated.

Function	Time hr:min
Boost to insertion, activate and deploy	3:20
Telescope setup and temperature stabilization	1:12
Pointing sequence to acquire target (87 times)	56:54
Observation sequence (87 times)	101:30
Retract, stow, check out orbiter, initiate deorbit	3:34
Total	166:30

For the maximum mission efficiency, the pointing sequence was reduced to 15 hr 24 min, increasing the observation time to 143 hr and a maximum efficiency of 86%. This mode of operation would be used to observe targets continuously for long periods of time. Although operations in this mode for the entire mission are unlikely, this is the limit in efficiency that could be obtained for SIII.

3. IR Telescope Effectiveness

The preliminary IR telescope mission assumed an altitude of 463 km (250 n mi) and an inclination of 28.5 deg resulting in a launch-to-deorbit duration of 166 hr 30 min. With allowances for the once-per-mission functions of boost, setup, temperature stabilization, alignment, and the retract and stow function, 154 hr 31 min are available for repetitive checkout and observation.

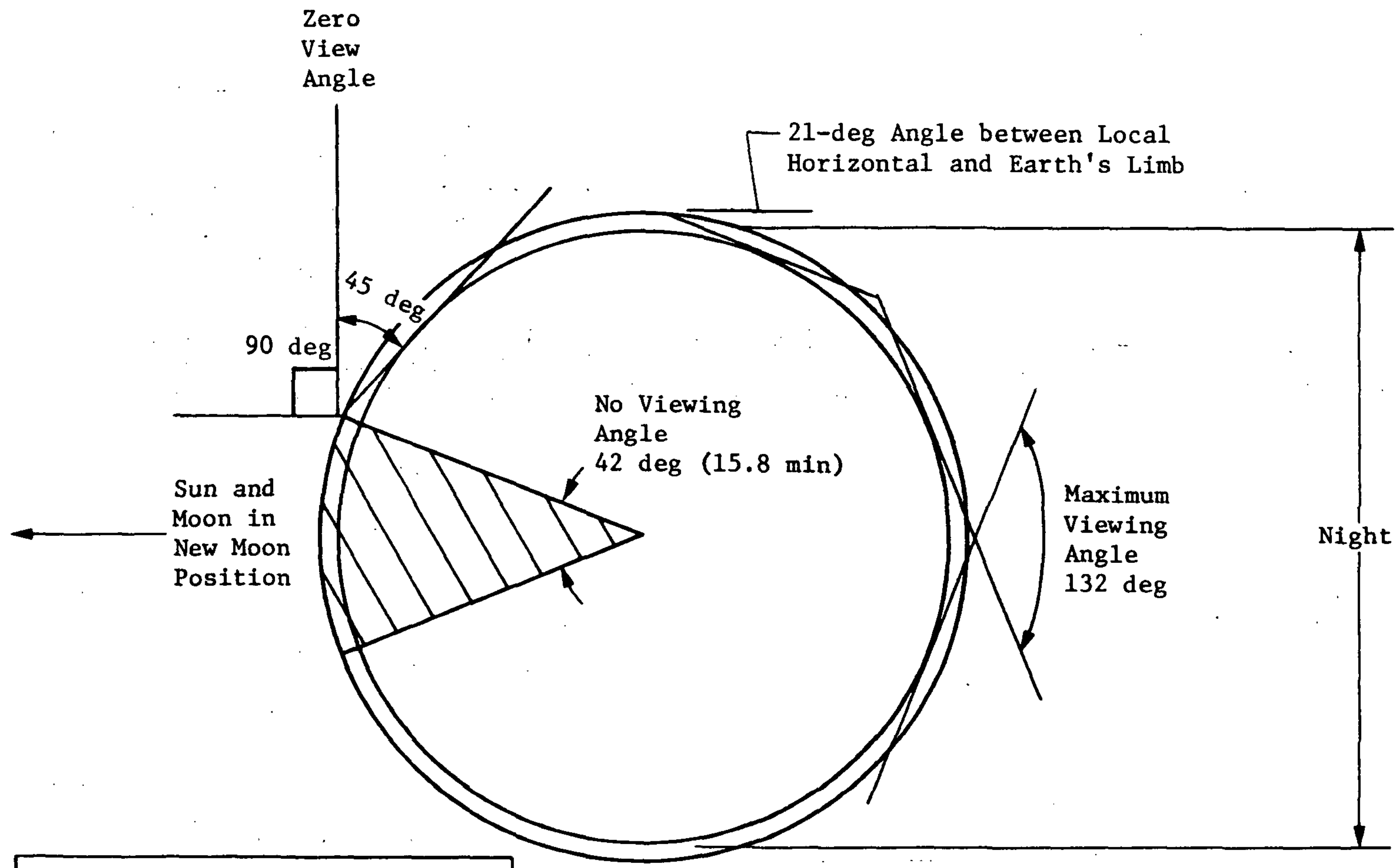
Observation is limited to viewing no closer than 90 deg to the sun and no closer than 45 deg to the earth and moon. Analysis of the orbit trajectory for a 0-deg beta angle, (*Fig. III-15*), shows that this constraint makes 15.8 min of each orbit unavailable for viewing. Accordingly, the preparation requirements of periodic checkout, calibration, guide star acquisition, and object locations were planned for this time of viewing constraint when possible. These repetitive preparation times for the preliminary operations cycle total 39 min/orbit so all cannot be performed while in the restricted viewing zone. The total observation time for the repetitive cycle is 55.6 min/orbit. This is the basis for the minimum mission efficiency of 55%. The time-use summary is tabulated.

Function	Time hr:min
Boost to insertion, activate and deploy	3:20
Telescope setup and temperature stabilization	4:24
Initial alignment and calibration	1:00
Periodic checkout, calibration, pointing, and instrument selection (98 times)	63:42
Periodic observation (98 times)	90:49
Retract, stow, check out orbiter, initiate deorbit	3:05
Total	166:30

The maximum mission efficiency for this payload was derived by considering only the viewing constraint time of 15.8 min/orbit. To implement this cycle, repetitive preparation times must be reduced and scheduled to coincide with the restricted viewing zone. This would result in a maximum mission efficiency of 77%. It should be noted that the no viewing area would disappear at higher inclinations and increase the maximum mission efficiency.

4. Array Effectiveness

The analyses that were performed to select orbits for the X-ray and gamma-ray arrays were summarized in Section D. In addition to the time-loss through the South Atlantic Anomaly, the overall mission efficiency that can be expected for the arrays will be reduced by the boost, deploy, retract, stow, and deorbit times that vary for telescopes of each payload. These losses are tabulated.



Note: 250-n mi altitude.
Cannot view within 90 deg of sun, 45 deg of earth and moon.

Fig. III-15 IR Viewing Constraints

Telescope	%Time Loss
Solar	4
Stratoscope III	4.9
Infrared	7.2

Adding the above losses to the time spent in the South Atlantic Anomaly, the total losses for the arrays may be as low as 5%, and should not exceed 12%. Thus, overall mission efficiencies for the arrays is expected to be at least 88%, ranging up to 95% maximum.

F. OPERATIONS AND PHENOMENA THAT INFLUENCE DESIGN

The objective of this task was to identify the operations or phenomena that would influence the experiment, support hardware, or interface design so more detailde analyses could be performed during the remainder of the study.

1. Space Shuttle Capabilities and Constraints

Of primary importance to the experiment and support hardware design is the Space Shuttle environmental and operational constraints and capabilities. The following specific items were identified for more detailed analyses and the results of these analyses are included in Volume III of this report:

1) Cargo bay thermal environment;

2) Cargo bay acoustical environment;

3) Shuttle contamination environment;

4) Shuttle inertial attitude constraints;

5) Shuttle stabilization system capabilities;

6) Shuttle communications capabilities;

7) Shuttle payload capabilities;

8) Shuttle cg constraints.

2. In addition to the above items, the operations concept defined in Section B, the baseline flight schedule, the Space Shuttle turnaround schedule, and the time-lines of Section C will determine the number of RAMs, pallets, and crews that would be required to support the astronomy sortie program over the life of the program.

The baseline flight schedule for the astronomy sortie missions definition study was provided by the NASA-MSFC COR and is shown in Table III-12. As shown on the schedule, the three primary experiments are the SIII, 100-cm photoheliograph, and the IR telescope. Although the 25-cm XUV spectroheliograph, 32-cm X-ray telescope, and the coronagraphs are not shown on the schedule, it is intended that they become a part of the 100-cm photoheliograph payloads. The X-ray and gamma-ray arrays are shown on the schedule as secondary experiments; i.e., they fly with one of the primary experiments.

The number of RAM pallets and RAM pallet crews necessary to support the astronomy sortie program is based on this baseline flight schedule. To provide two flights a year, a total turnaround time of 26 weeks is available. For eight flights per year, this turnaround time is reduced to 6½ weeks if only one RAM pallet is available.

Figure III-16 shows the impact of the number of RAM pallets used in the program on the weeks available for refurbishment during the program years when eight flights per year are planned. Even launch-to-launch centers of 6½ weeks were selected to represent the frequency of eight flights per year as shown on the baseline schedule.

It may be noted that for one RAM pallet, the unshaded portion of 4½ weeks is available for payload turnaround, which requires 472 to 483 work hr as shown in the time-lines of Section C. For two RAM pallets, launches still occur every 6½ weeks but the turnaround period increases to 11 weeks. Finally, for three RAM pallets, the period is 17½ weeks.

Figure III-17 shows the crews per RAM pallet that must be provided to accomplish the work hr (472 to 483) necessary to turn around each payload. It was assumed that each crew works a 40-hr week, since this schedule for the crew over the 12-year program duration appears the most desirable.

Table III-12 Baseline Flight Schedule

Experiments \ Calendar Year	79	80	81	82	83	84	85	86	87	88	89	90
Astronomy												
Stratoscope III				1	2	3	3	3	3	3	3	3
100-cm Photoheliograph	1	2	3	3	3	2	2	2	2	2	2	2
IR Telescope	1	1	2	3	3	3	3	3	3	3	3	3
X-ray Arrays	1	1	3	4	4	4	4	4	4	4	4	4
Gamma-ray Arrays	1	2	2	3	4	4	4	4	4	4	4	4
Total	2	3	5	7	8	8	8	8	8	8	8	8

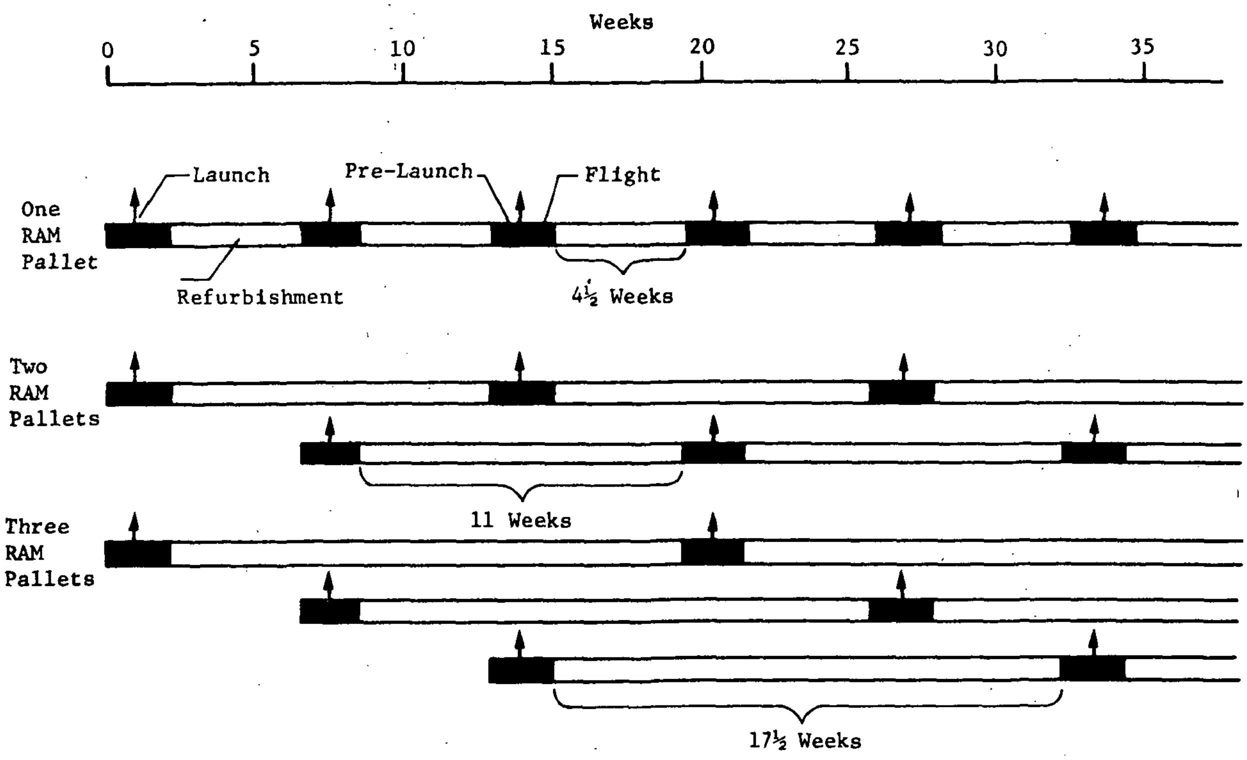


Fig. III-16 RAM Pallet use and Turnaround Effect

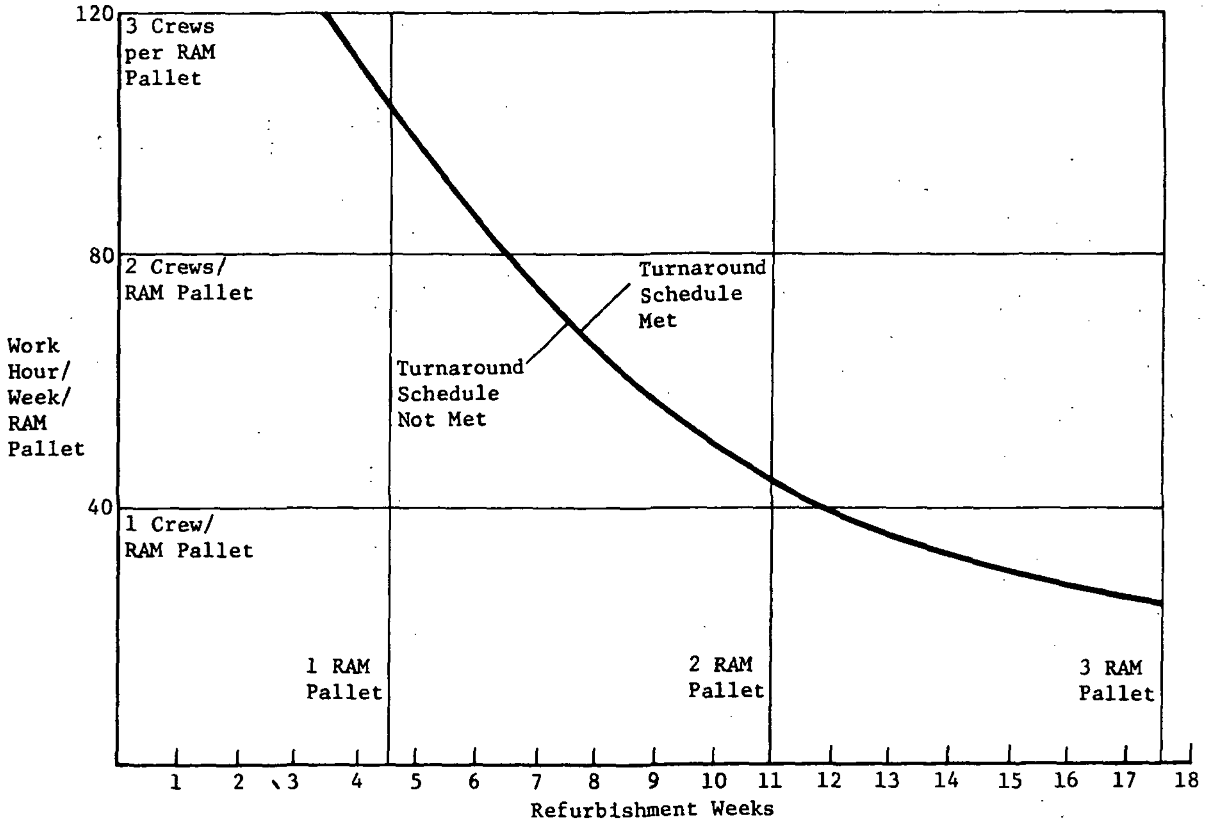


Fig. III-17 Effect of Turnaround Schedule on Program

For one RAM pallet being turned around in 4½ weeks, two crews are not adequate but three crews will more than meet schedule requirements. For the two RAM pallet cases, one crew per RAM pallet lacks about 10% of meeting the 11-week schedule. Finally, for three RAM pallets, one crew per RAM pallet is sufficient.

For the baseline flight schedule, one RAM pallet and one crew will be adequate during the first two years of the program (two flights in 1979 and three flights in 1980). From 1981 to 1990 the astronomy sortie program will require two RAM pallets with one crew per RAM pallet.

To select a baseline program, a cost comparision of hardware and crew usage that satisfy schedule constraints was made. The results are summarized in Table III-13.

The RAM pallet price of $10 million was taken from estimates made by General Dynamics in their study of RAM pallets for astronomy payloads in sortie missions (Ref III-9). Crew size was derived from data generated by Martin Marietta in the study for *Implementation of Research and Applications Payloads at the Shuttle Launch Site* (Ref III-5).

A preliminary selection of two RAM pallets with one crew for each RAM pallet was made assuming the use of 10% overtime to satisfy the schedule shown previously. Note that this selection is least costly, and that if only one RAM pallet is selected, there is no backup with which to continue the program should that unit become disabled.

Table III-13 RAM Pallet and Crew Requirements Costs

No. of Crews/ RAM Pallet	No. of RAM Pallets 1	2	3
1	Won't Satisfy Program	Selected two RAM Pallets with one Crew/per RAM Pallet. $54.6M (Note 3)	$76.8M
2	Won't Satisfy Program	$82.4M	Not Required for Program
3	$56.8M	$113.6M	Not Required for Program

Note:
1. RAM Pallets priced at $10M each.
2. 36-man crews priced at $36,000 per man per year ($15.6M per crew for the 12-year program).
3. Includes 10% overtime to satisfy program turnaround schedule.

G. UTILIZATION OF MAN

Of great interest to the sortie concept is the role man should play in telescope operation. There are several questions to be considered. What roles can he fill that improve performance? What roles do not affect performance but improve reliability or lower cost? What roles can he fill that add flexibility of schedule?

Effective utilization of man requires his application to (1) tasks requiring the unique capabilities of human judgment and manual skills, (2) nonrepetitive functions, and (3) repeatable functions that are best performed by the crew. The astronomy sortie program relies on man in two key areas--on-orbit and ground mission support.

1. On-Orbit Support

The two scientific-observer crewmen initiate, monitor, assess, verify, and terminate the tasks of checkout, setup, deployment, alignment, calibration, indexing, slewing, retracting, and stowing of the telescopes and arrays. The flight crewmen are essential to the decision processes for target selection, and initiate and control the slewing to acquire guide stars for stellar observations or features of interest on the sun. It is expected that the larger telescopes will be fitted with automatic alignment and focus controls (the smaller ones will require no adjustments). The crew will periodically calibrate these controls by overriding the servos in discrete steps and observing the resulting quality of the image. The crew can also improve mission reliability by adjusting alignment and focus should the automatic devices fail.

The inflight crew activities relative to data assure that the correct targets are observed and that data quality is acceptable. The crewmen decide (with voice consultation with ground-based scientists) when it is necessary to retake data and when additional data are required. The crew will monitor the progress of each observation and terminate it should any unusual perturbation occur. If, for instance, an out-of-specification vibration momentarily comes from the Shuttle, the crew could start the observation anew. The appearance of an unexpected bright contamination cloud would also terminate an observation. The crew will also judge when a new instrument calibration may be needed, and perform the calibration in some cases.

Of great importance will be the crew's ability to react to targets of opportunity, such as solar activity or a nova. His reaction time will probably be faster than that of the LST or LSO, since no time is lost in writing and encoding commands. In general the crew will carry out the observation schedule so that the time and money normally allocated for computerized control will not be required.

The crew will coordinate with the shuttle pilot to ensure that momentum dumps and waste ventings do not interfere with the scientific program. The crew will also coordinate with the PI on earth or with ground observatories to make changes in the observing schedule or interpret unexpected data. This can greatly enhance the scientific output of the flight.

In the early phases of the project, time at the end of each flight should be allotted for experimenting with the payloads. These operations should be controlled by the crew and may include (1) determining the effect of contaminants on brightness and the dissapation with time, (2) determining the effect of telescope tube temperature variations, and (3) defining the effect on the data of viewing closer to the sun, earth, or moon than the specified limits.

The philosophy that has been observed is that "if a crewman can do it effectively, don't automate the function." This crew-utilization philosophy imposes requirements for effective crew training and for onboard control and display equipment that provide the necessary data from which to make decisions and initiate action. It provides a mode of operation closely paralleling existing observatories in which the scientist is present at the data source to assure maximum results.

2. Ground Support

The scientific crewman's role in space is partly determined by activities on earth before and during the flight. There are three individuals, or groups of individuals, whose roles on the ground are of interest

The astronomer, or PI, for each flight will set the scientific objectives, select the targest and guide stars, and specify the choice of instruments and operating conditions. He will brief the scientific crewman and train him to react to the observations and conditions expected. He will coordinate with the crew during the flight, and will be responsible for data reduction after the flight.

The degree to which the astronomer is able to brief the crew will determine how well the crew can monitor the observations as they progress and make adjustments to maximize the scientific output.

The engineering and ground support that precedes each flight also affects the role of the crew in orbit. A perfectly programmed and preconditioned telescope should make few technical demands on the crew. However, a tradeoff exists between the time and money spent for automatic quiipment to assure scientific mission success vs reliance on the crew's ability to make the changes necessary because of equipment degradation.

Finally, there is the scientific crewman himself and his ability to assimilate the scientific briefings, or his background experience with image analysis and telescope adjustment. The scientific crewman should have thorough scientific and technical training, and it would be preferable to have the scientific crewman be an associate or colleague of the astronomer who is based on the ground.

H. REFERENCES

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III-2. *Optical Telescope Technology Report*. NASA SP-233. Prepared by Office of Space Science and Applications on workshop held at MSFC April 29 - May 1, 1969 and including:

"The OAO Series of Space Telescopes" by Joseph Purcell, NASA GSFC;

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"Apollo Telescope Mount Operations and Data Handling" by James M. Rives, NASA GSFC.

III-3. *Skylab Operations Handbooks, Apollo Telescope Mount*. MSC 04728. Prepared under direction of Crew Procedures Division, Systems Procedures Branch.

III-4. *Preliminary Reference Skylab Flight Plan, SL-1/SL-2, SL-3, and SL-4.* Prepared by Flight Planning Branch, Crew Procedures Division, MSC, September 27, 1971.

III-5. *Implementation of Research and Application Payloads at the Shuttle Launch Site Study.* (Contract NAS10-7685), Martin Marietta Corporation, Denver, Colorado.

III-6. *KSC Space Shuttle Processing Study.* KSC Planning and Future Programs Offices, 29 November 1971.

III-7. *SOAR Study Documentation.* McDonnell Douglas Corporation, (Contract NAS8-26790).

III-8. Shuttle booster and orbiter performance characteristics for this study were derived from several references including the following:

1) Space Shuttle PRD, Level 1, Shuttle/Payload Interface,

2) NASA Safety Program Directive No. 1, Rev A, My-1700.120, December 12, 1969;

3) Space Shuttle Directive Program Directive No. 1, August 31, 1970;

4) Space Shuttle Technical Directive No. TD-3003, September 16, 1971.

III-9. *Research and Applications Modules (RAM), Phase B Study.* General Dynamics, Convair Aerospace Division, (Contract NAS8-27539).

IV. IDENTIFICATION OF ALTERNATIVE SORTIE PROGRAMS

The tasks described in this chapter were undertaken to identify promising alternative Astronomy Sortie program concepts and to highlight the potential commonalities of subsystem requirements and operating techniques. To accomplish these objectives, experiments were grouped into credible mission payload combinations, based on study ground rules. These payload combinations formed the basis for the payload grouping analysis and identification of baseline payloads in subsequent tasks. In addition, four alternative payload accommodation concepts, representing major impacts on the Astronomy Sortie missions were identified. These concepts were defined and evaluated in subsequent tasks.

A. CANDIDATE PAYLOAD COMBINATIONS

Candidate payload combinations were developed to identify credible combinations of experiments for consideration as mission payloads. These combinations were developed within the following constraints:

1) Each mission payload will consist of at least one optical telescope and one complete high-energy array.

2) Solar and stellar telescopes will not be combined on the same payload.

3) For classification purposes three telescopes, the 100-cm photoheliograph, 100-cm infrared telescope, and 120-cm Stratoscope III, are identified as primary experiments. The balance of the telescopes and all of the arrays are considered secondary experiments.

Examination of the experiment characteristics and requirements revealed no gross incompatibilities between experiments. However, combined requirements for crew participation and the usefulness of the wide coverage x-ray detector array in supporting the activities of other arrays, led to the condidate payload combinations listed in Table IV-1.

Table IV-1 Candidate Payload Combinations

Secondary Experiment \ Primary Experiment	100-cm Photo-heliograph	100-cm IR Telescope	120-cm Strato-scope III
<u>Solar Telescopes</u>			
32-cm X-Ray Telescope	OK	(Note 1)	(Note 1)
25-cm XUV Spectroheliograph	OK	(Note 1)	(Note 1)
2.45- & 4.0-cm Coronagraphs	OK	(Note 1)	(Note 1)
<u>Stellar X-Ray Arrays</u>			
Wide Coverage X-Ray	OK	OK	OK
Large Area X-Ray	OK (Note 2)	OK (Note 2)	OK (Note 2)
Narrow Band Spectrometer/Polarimeter	OK (Note 2)	OK (Note 2)	OK (Note 2)
Collimated Plane Crystal Spectrometer	No-Crew Req	OK (Note 2)	OK (Note 2)
Large Modulation Collimator	No-Crew Req	OK	OK
<u>Stellar Gamma-Ray Arrays</u>			
Low Background Gamma-Ray Detector	OK	OK	OK
Gamma-Ray Spectrometer	No-Crew Req	OK	OK

Note: 1. Did not consider solar and stellar telescopes on same payload.
2. Desirable that the wide coverage X-ray array fly with these payloads.

These candidate payload combinations are based on flying one of the three primary telescopes with one or more of the secondary experiments. In reviewing the compatibility of the primary and secondary experiments, it was determined that two of the X-ray arrays (collimated plane crystal spectrometer and large modulation collimator) and one of the gamma-ray arrays (gamma-ray spectrometer) should not be considered as secondary experiments for the 100-cm photoheliograph. This determination was based on the crew participation requirement for the photoheliograph of approximately 13.3 hr/day and the crew requirements of the three arrays, which range from 7.2 to 12 hr/day.

An additional consideration for the grouping of payloads was that it was highly desirable to fly the wide coverage X-ray detector with the large area X-ray detector, the narrow band spectrometer/polarimeter, and the collimated plane crystal spectrometer. This desirability was based on using the wide coverage X-ray detector as a low resolution device to locate targets that would then be examined in detail with the higher resolution detectors.

B. ALTERNATIVE CONFIGURATIONS

The approach taken to physically and operationally accommodate the mission payloads is an important factor in configuring the Astronomy Sortie missions. The selected configuration must represent the best composite of a number of feasible alternative configuration features. Four alternatives were identified for subsequent definition, analysis, and evaluation leading to the selection of the recommended configurations. These alternatives are listed in Table IV-2. These alternatives were selected because they represent major variations in the areas of payload and subsystem support, physical and operational interfaces with the Shuttle, payload operations, and environmental protection of the payload.

In the definition of these alternatives it was necessary to consider the use of wide angle gimbals vs Shuttle pointing and the use of deployed payloads vs nondeployed payloads as one trade study. Wide angle gimbals on nondeployed payloads proved impractical because of the limited gimbaling possible within the confines of the pallet and Shuttle payload bay. In addition, Shuttle pointing eliminates the need for wide angle gimbals.

Table IV-2 Sortie Payload Configuration Alternatives

Use of RAM to Provide Pressurized Volume for Observers and Support Equipment	vs	Use of Shuttle to Provide Pressurized Volume for Observers and Support Equipment
Use of Wide Angle Gimbal for Sky Coverage	vs	Use of Shuttle Maneuvering Capability for Sky Coverage
Use of Deployed Payload	vs	Use of Nondeployable Payload
Use of Common Environmental Shroud for Payload Protection	vs	Use of Individual Payload Environmental Protection Devices

The use of RAM vs Shuttle pressurized volume for experiment operation, and the use of a common environmental shroud vs individual payload protection were analyzed independently and the interrelationships between them were not considered significant.

V. DEFINITION OF ALTERNATIVE SORTIE PROGRAMS

Definition of the alternative Sortie programs identified in Chapter IV was carried to a level sufficient to evaluate these programs, and select the recommended program. Payload grouping analyses were conducted, based on the candidate payload combinations developed in Chapter IV. From the results of these analyses, baseline mission payloads were established for use in the remainder of the study. The alternative configuration analyses evaluated the effects of the alternative programs on the baseline payloads.

The definitions of the Shuttle and RAM used in this study are contained in Ref V-1 and V-2.

A. PAYLOAD GROUPING ANALYSIS

Grouping analyses were conducted individually on the telescopes and on the arrays, using the candidate payload combinations developed in Section B of Chapter IV. Telescope groupings were developed first because of the large physical sizes of most of these candidate groups. The desire for commonality of hardware led to the use of telescope support devices to accommodate the deployment and pointing of the arrays. Physical constraints on the azimuth table, deployment yoke, and fine pointing system were determined from layouts that used the Shuttle and RAM baseline definitions.

Layout studies of the accommodation of candidate payloads indicated the need to deploy the experiments out of the pallet so that wide angle gimbals could be used. The sizing of the fine pointing system was based on a deployment scheme that does not require nesting of this system into the azimuth yoke. This allows the maximum space available for the experiment.

1. Telescope Grouping

Results of the telescope grouping analysis are summarized in Fig. V-1.

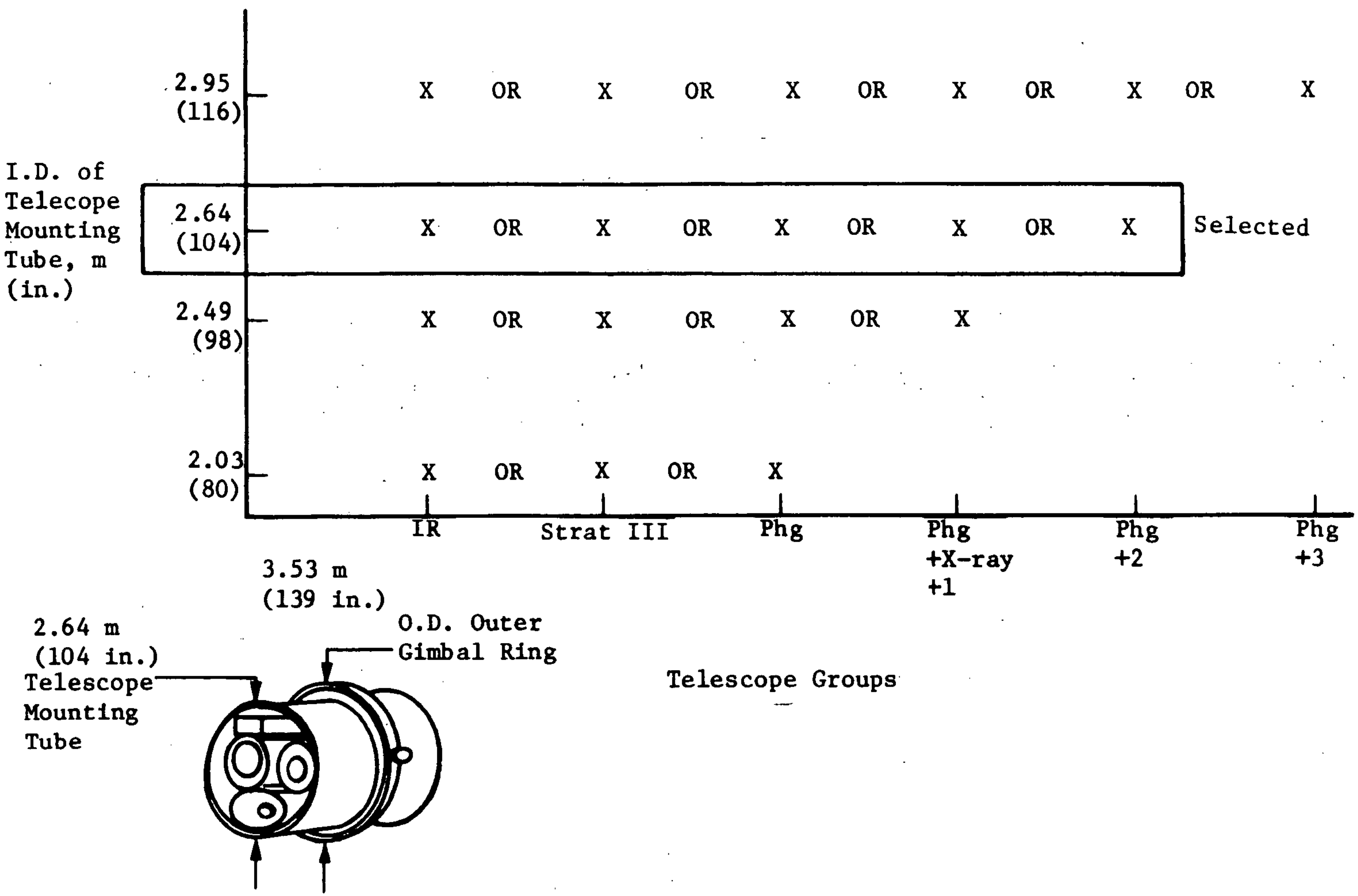


Fig. V-1 Telescope Accommodation Matrix

The size of the telescope gimbal and yoke is a major factor in determining the makeup of the payloads to be carried for each mission. The largest telescope, based on the largest cross-section dimension, is the Stratoscope III. A gimbal sized for it will accommodate any one of the other telescopes. However, because of the desirability of flying the photoheliograph plus one or more of the other solar telescopes on every solar-oriented flight, a larger gimbal is required. The entire solar telescope complement cannot be packaged together because the required gimbal and azimuth yoke are too large to fit in the Shuttle. An intermediate size, capable of carrying the photoheliograph plus any two of the other solar telescopes, was selected.

Because packages of two or more telescopes must include a common mounting structure, the sizes referred to relate to the inside diameter of the telescope mounting tube.

Sizing and Selection Sequence - The sequence for sizing and selection was as follows:

1) Developed 2.03 m (80 in.) design to accommodate Stratoscope III;

2) Developed 2.95 m (116 in.) design to accommodate entire solar telescope group. Ruled out as too large;

3) Developed 2.49 m (98 in.) design to accommodate photoheliograph plus the X-ray telescope plus either the XUV spectroheliograph or the coronagraphs;

4) Developed 2.64 m (104 in.) design to accommodate photoheliograph plus two of the three secondary solar telescopes. This is also the maximum that the Shuttle can house;

5) Selected 2.64 m (104 in.) design based on - 2.03 m (80 in.) design has no growth capability, 2.64 m (104 in.) design has more versatility than 2.49 m (98 in.) design, although only 0.15 m (6 in.) larger, 2.64 m (104 in.) design results in the maximum on-orbit time for the highest prioity solar telescopes based on a given number of flights.

Figures V-2 and V-3 are layouts of the installation of the various telescope combinations in the four telescope mounting tube diameters discussed above. The mounting tube shown will not necessarily be used for single telescopes. The use of adapters to support individual telescopes within the fine pointing assembly will be considered later in the study.

Figure V-4 depicts a concept for the telescope wide angle gimbal, fine pointing system, and telescope deployment structure, mounted on a modified RAM pallet within the Shuttle payload bay. This concept is based on the 2.64 m (104 in.) inside diameter telescope mounting tube selected above.

2. Array Grouping

The arrays considered in this study fall into two areas of scientific interest, X-ray and gamma-ray source detection and analysis.

In developing the rationale for grouping of the arrays, several constraints were identified. These were:

1) The wide coverage X-ray detector should fly as a supporting experiment for the other X-ray arrays, and must be held stationary with respect to the Shuttle;

2) The large modulation collimator has a requirement for oscillatory motion;

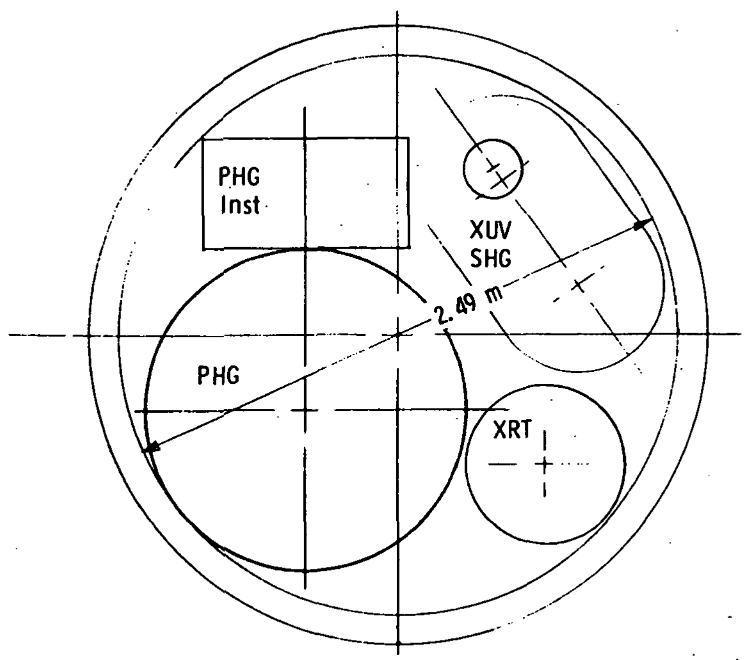
3) Both of the gamma-ray arrays are adversely affected by passage through the South Atlantic Anomaly and must be powered down at that time. In addition, the gamma-ray spectrometer must be totally shielded to avoid damage;

4) It is desirable to fly X-ray experiments together and the gamma-ray experiments together;

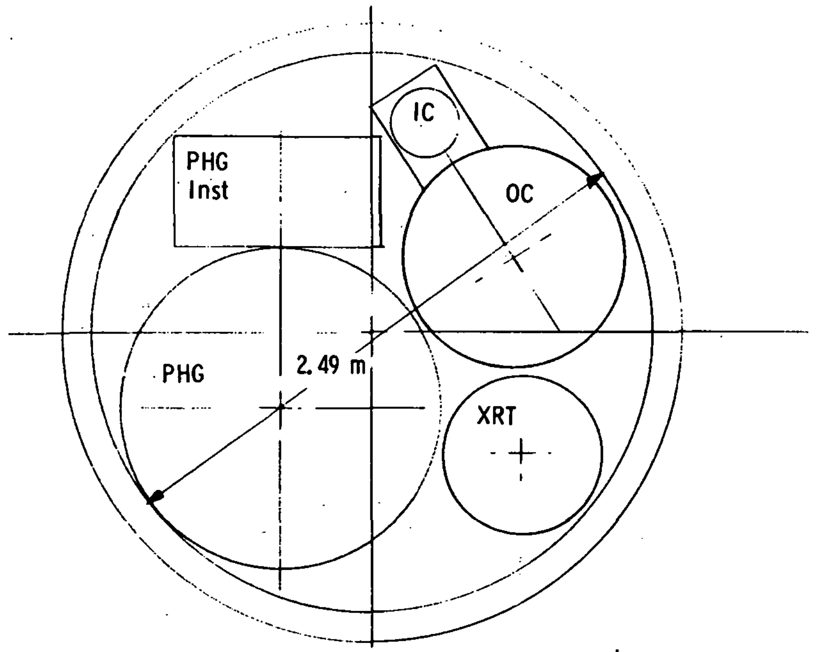
5) The arrays do not require the fine pointing accuracy and stability that the telescopes require. Therefore, the telescope azimuth and elevation drives could be used for the arrays, thereby achieving the desired commonality. This results in mounting the arrays to a platform that has the same outside diameter of 3.53 m (139.0 in.) as the outer ring of the fine pointing system.

SOLAR PACKAGE

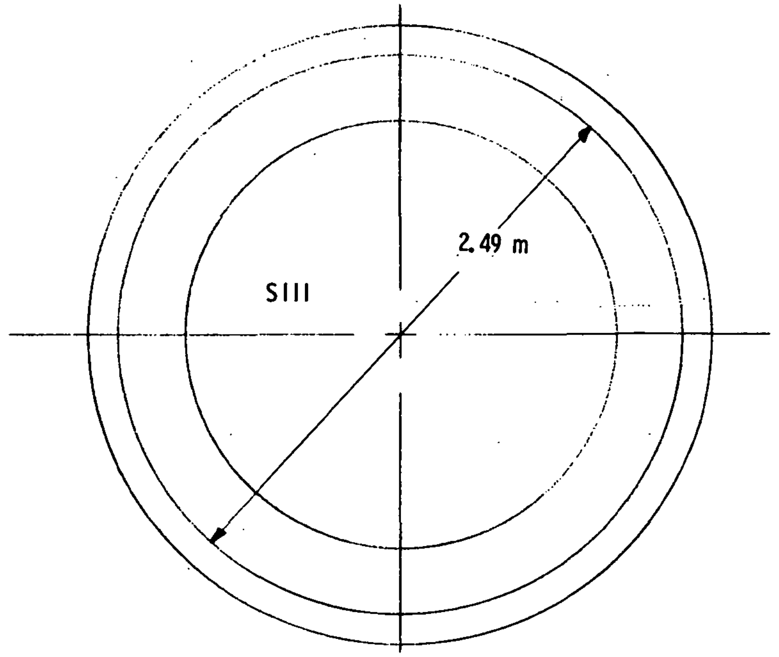
STELLAR PACKAGE



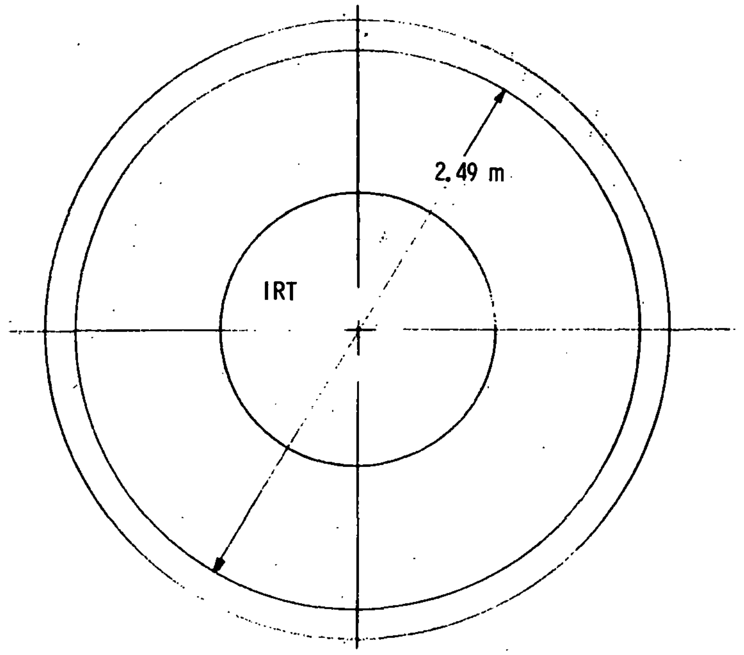
2.49 m (98 in.) Tube with 1.0 m Photoheliograph, X-Ray Telescope and XUV Spectroheliograph



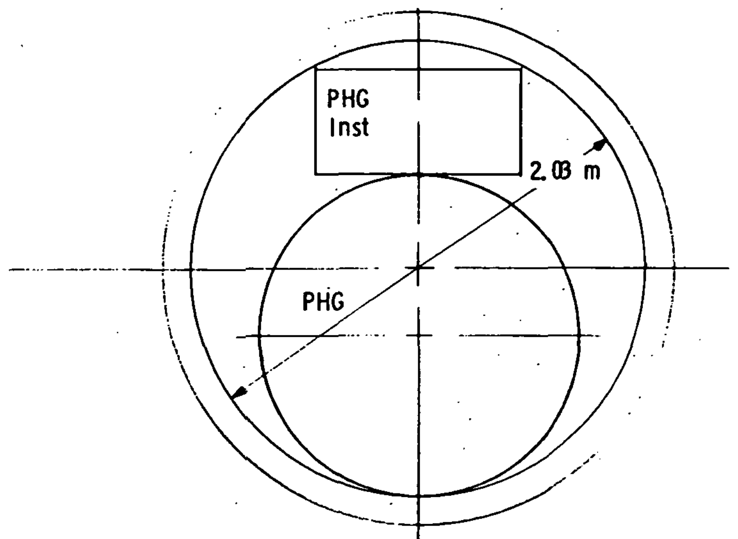
2.49 m (98 in.) Tube with 1.0 m Photoheliograph, Inside-Outside Coronagraph and X-Ray Telescope



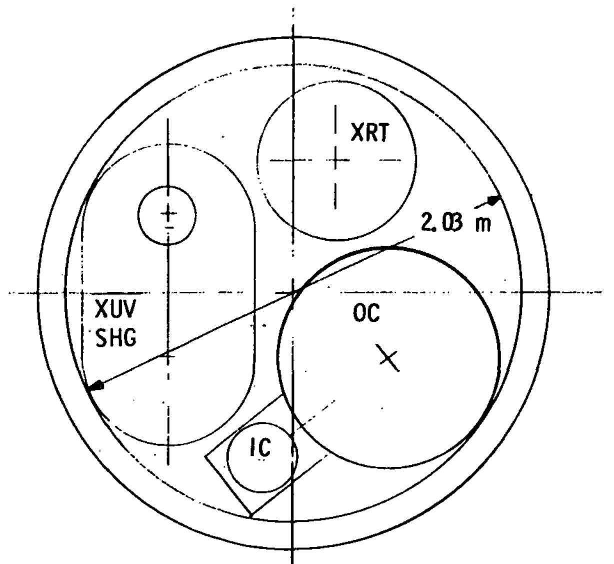
2.49 m (98 in.) Tube with Stratoscope III Stellar Telescope



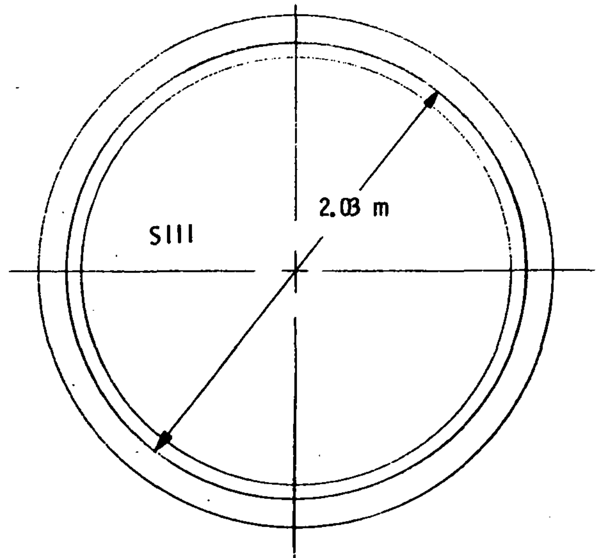
2.49 m (98 in.) Tube with Infrared Telescope



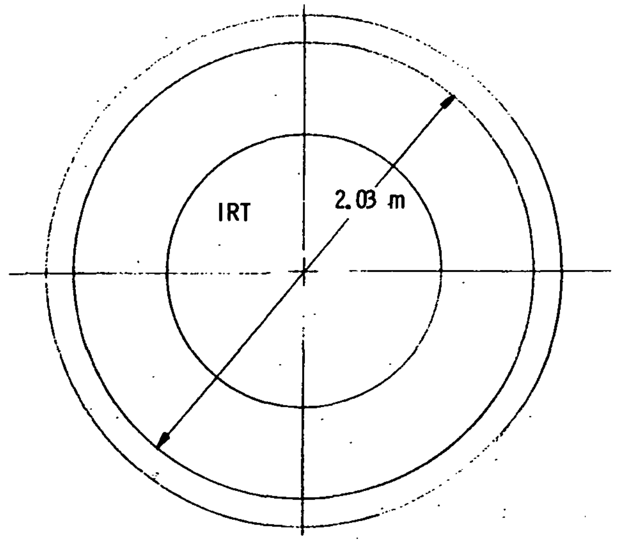
2.03 (80 in.) Tube with 1.0 m Photoheliograph



2.03 m (80 in.) Tube with Inside-Outside Coronagraph, X-Ray Telescope and XUV Spectroheliograph



2.03 m (80 in.) Tube with Stratoscope III Stellar Telescope



2.03 m (80 in.) Tube with Infrared Telescope

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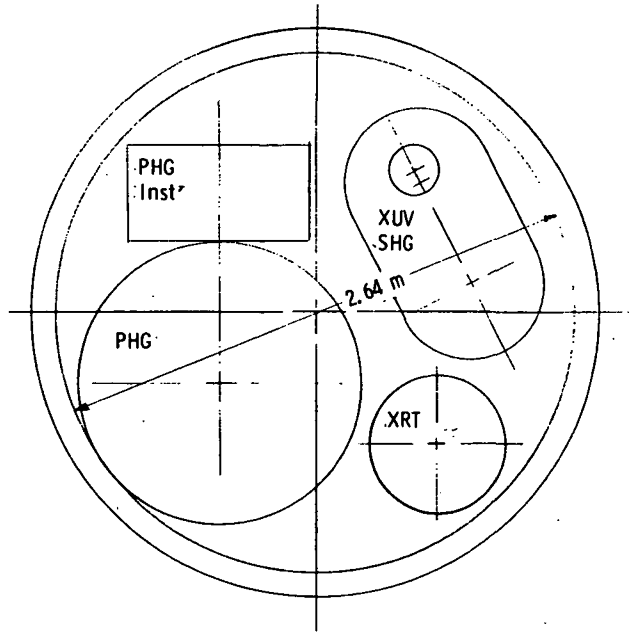
Telescope Mounting Tube Sizing Study, 2.03 m (80 in.) and 2.43 m (98 in.)

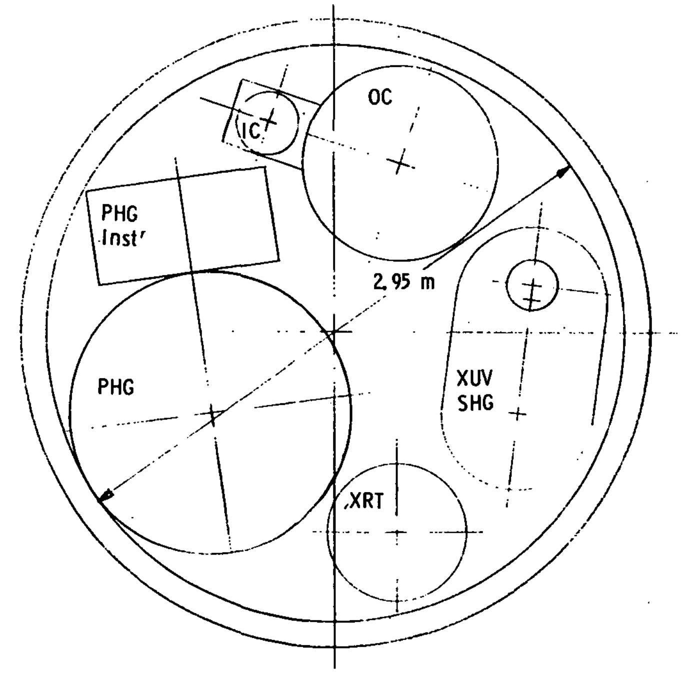
Figure V-2

SOLAR PACKAGES

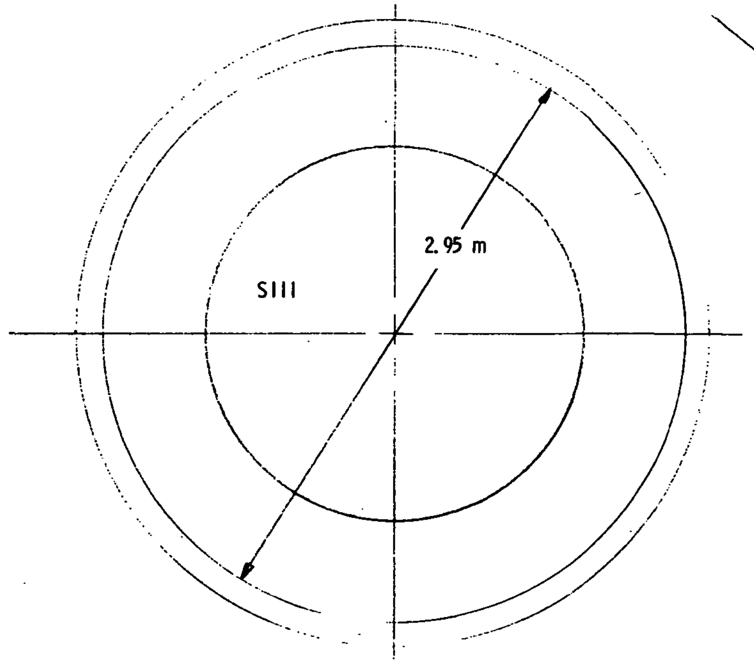
STELLAR PACKAGES



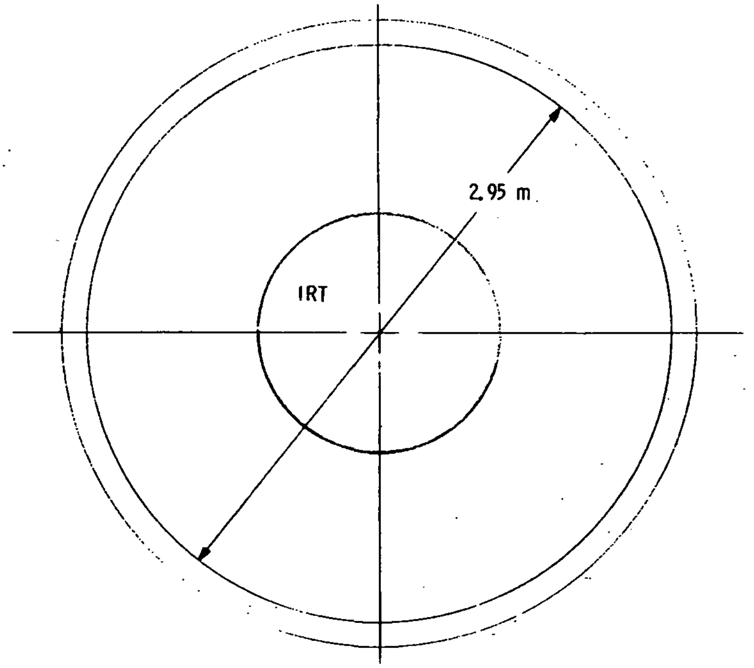
2.64 m (104 in.) Tube with 1.0 m Photoheliograph, XUV Spectrograph, and X-Ray Telescope



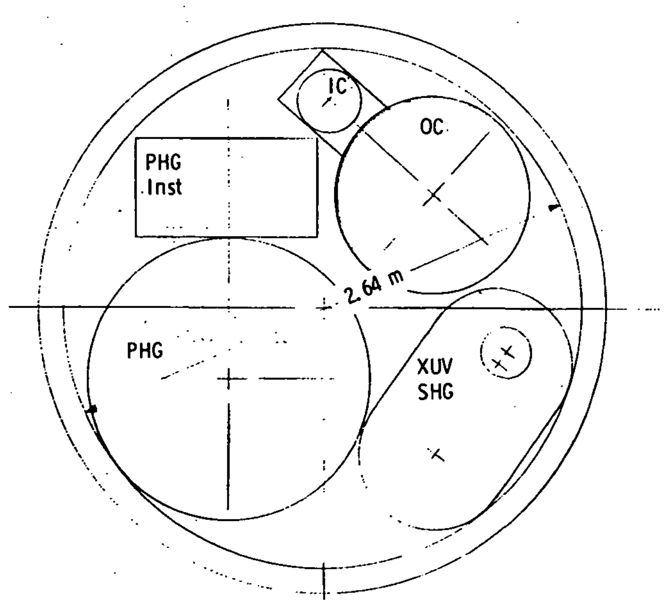
2.95 m (116 in.) Tube with 1.0 m Photoheliograph, Inside-Outside Coronograph, XUV Spectroheliograph, and X-Ray Telescope



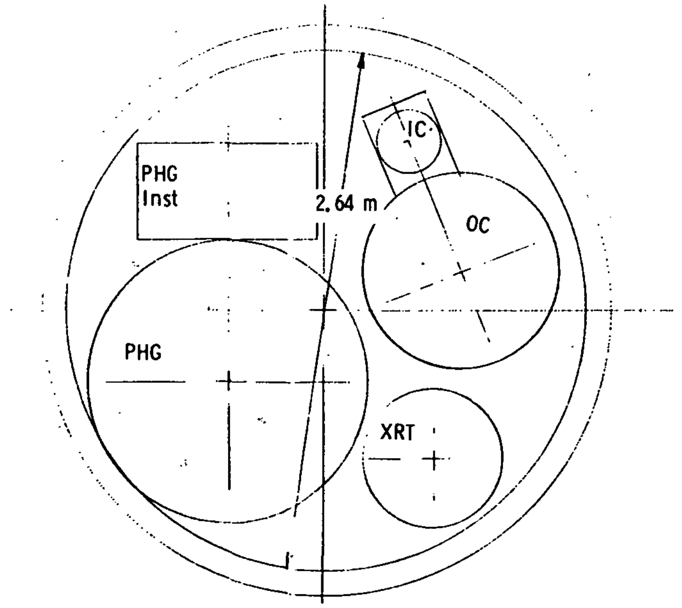
2.95 m (116 in.) Tube with Stratoscope III Stellar Telescope



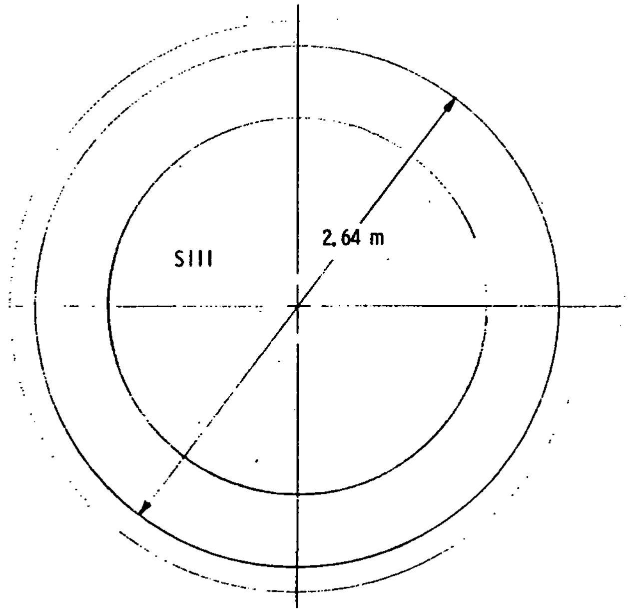
2.95 m (116 in.) Tube with Infrared Telescope



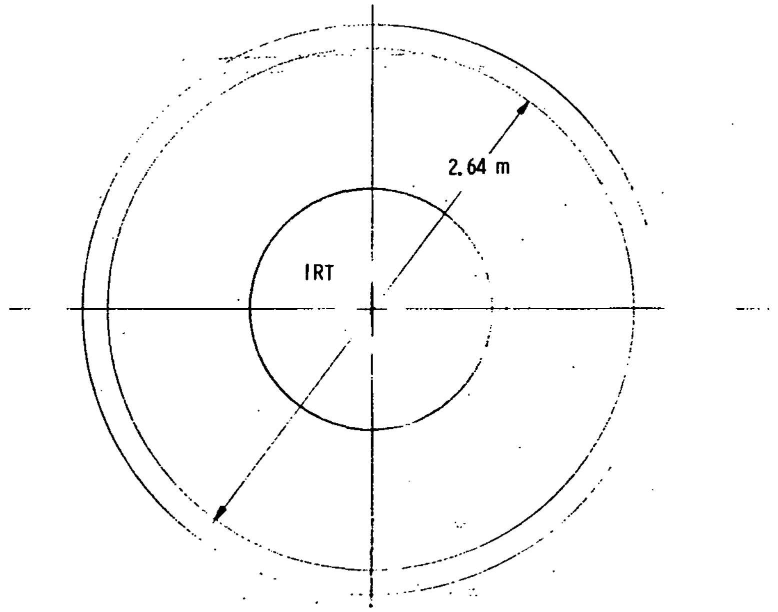
2.64 m (104 in.) Tube with 1.0 m Photoheliograph, Inside-Outside Coronagraph, and XUV Spectroheliograph



2.64 m (104 in.) Tube with 1.0 m Photoheliograph, Inside-Outside Coronagraph, and X-Ray Telescope



2.64 m (104 in.) Tube with Stratoscope III Stellar Telescope



2.64 m (104 in.) Tube with Infrared Telescope

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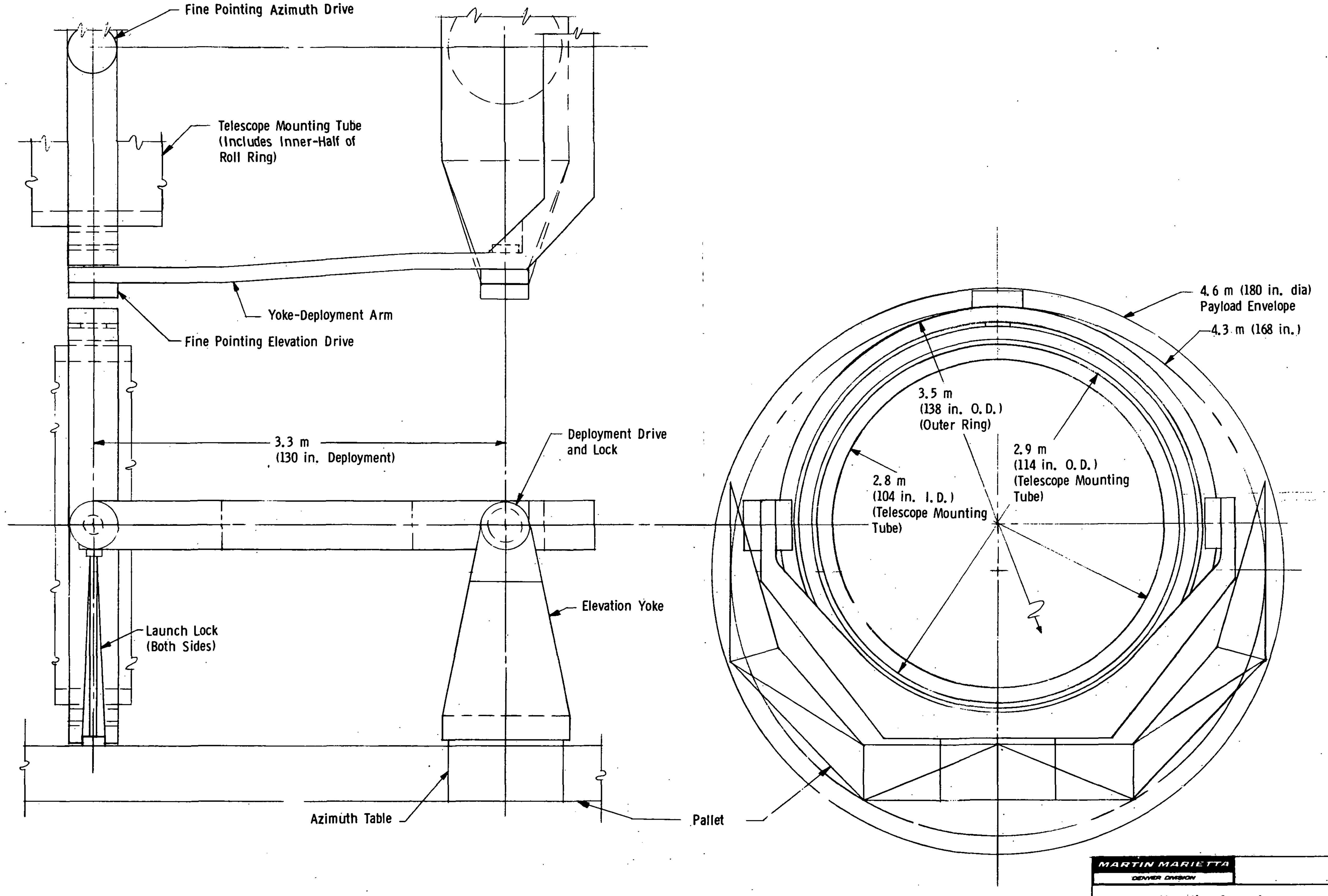
Telescope Mounting Tube Sizing Study, 2.64 m (116 in.) and 2.95 m (116 in.)

Figure V-3



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Telescope Mounting Concept, 2.6 m (104 in.) Mounting Tube

Figure V-4

The constraints led to the grouping of arrays shown in Fig. V-5.

Due to the requirement for oscillation, the large modulation collimator is carried alone on the platform.

The wide coverage X-ray detector is supported and oriented by its own mechanism, independent of the platform used for the other arrays. Mounting on the platform with other arrays was not feasible because of the large size, viewing requirements, and conflict with the oscillation requirement for the large modulation collimator.

The gamma-ray arrays are small enough to conveniently mount together on the platform, as desired.

The physical size of the narrow band spectrometer/polarimeter requires the entire platform for mounting of this one array.

The collimated plane crystal spectrometer and large area X-ray detector are the only X-ray arrays that can be carried simultaneously on the platform.

B. BASELINE PAYLOADS

The payload combinations to be used as a baseline for the study are shown in Table V-1, and are the result of the payload grouping analysis described in Section A of this chapter.

For the photoheliograph payloads it was determined that the maximum solar package that could be accommodated consisted of the photoheliograph plus any two of the three secondary solar telescopes. Therefore, three basic solar payloads are identified. This solar payload grouping will require that the photoheliograph payloads be compatible with the removal and installation of different secondary solar telescopes during the refurbishment cycle at the Payload Integration Center (MSFC). Only one array group has been identified for the photoheliograph payloads. This particular array group does not have excessive crew demands and is compatible with the solar payload groupings.

The IR telescope and the Stratoscope III payloads are compatible with all of the potential array combinations. Three basic payload combinations have been identified for the IR telescope and Stratoscope III.

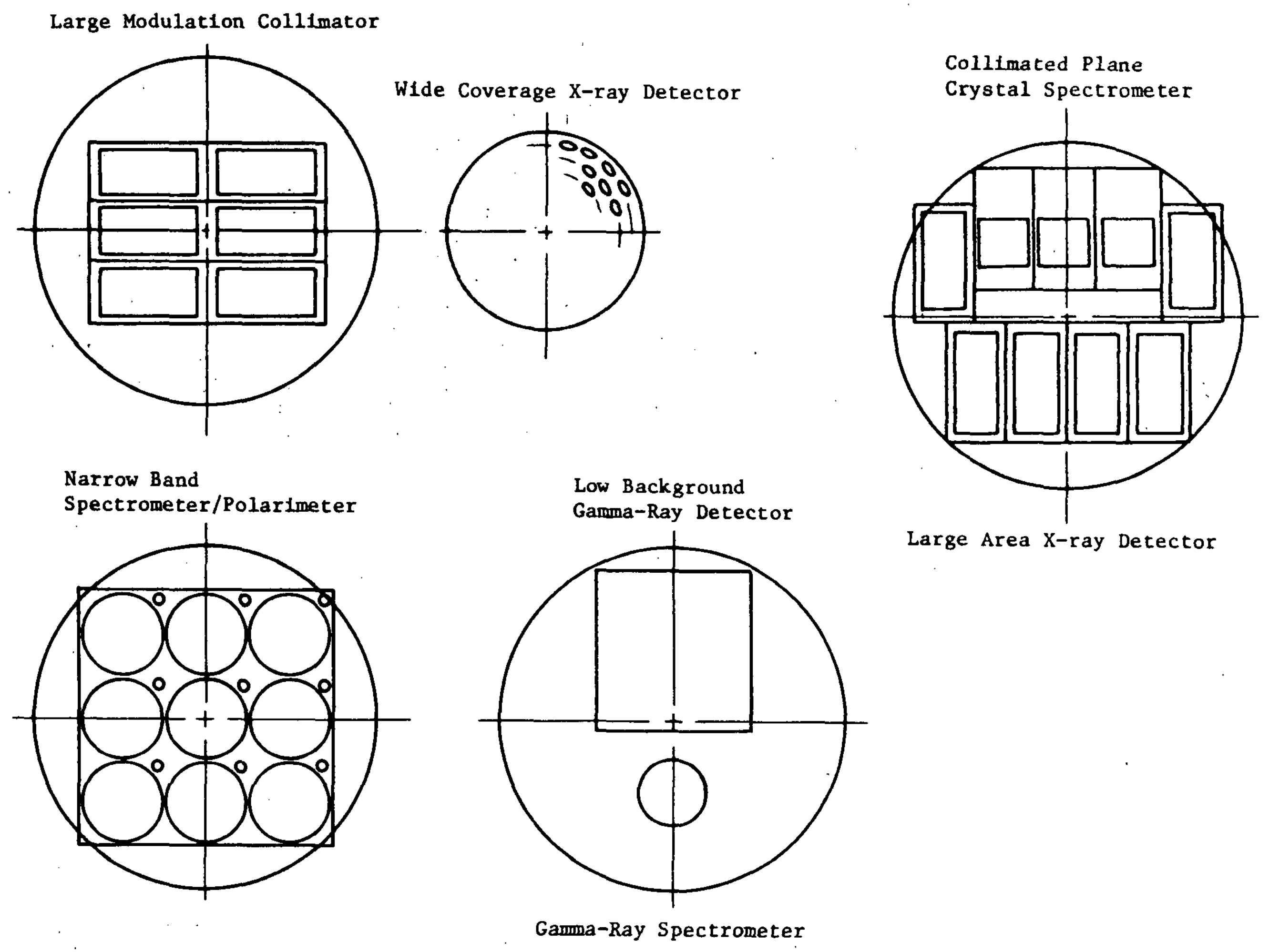


Fig. V-5 Selected Grouping of Arrays

Table V-1 Baseline Payload Combinations

Payloads / Experiment Groups	Photoheliograph Payloads			Stratoscope III Payloads			IR Payloads		
	1AB	2AB	3AB	4AC	4AD	4AE	5AC	5AD	5AE
<u>Telescope Groups</u>									
1. PHG + XUV SHG + X-Ray	X								
2. PHG + X-Ray + Coronagraphs		X							
3. PHG + XUV SHG + Coronagraphs			X						
4. Stratoscope III				X	X	X			
5. IR Telescope							X	X	X
<u>Array Groups</u>									
A. Wide Coverage X-Ray	X	X	X	X	X	X	X	X	X
B. Narrow Band Spectrometer/Polarimeter	X	X	X						
C. X-Ray Spectrometer + Low Background X-Ray Detector				X			X		
D. Large Modulation Collimator					X			X	
E. Large Area X-Ray Det. & Collimated Plane Crystal Spectrometer						X			X

PHG = 100-cm Photoheliograph

XUV SHG = 25-cm XUV Spectroheliograph

X-Ray = 32-cm X-Ray Telescope

C. ALTERNATIVE CONFIGURATION ANALYSIS

Three trade studies were conducted to define and analyze configuration alternatives having major impacts on the Astronomy Sortie missions. These were:

1) Shuttle pointing with nondeployed payloads
   vs
   wide angle gimbaling of deployed payloads;

2) Use of RAM for pressurized volume
   vs
   use of Shuttle pressurized volume;

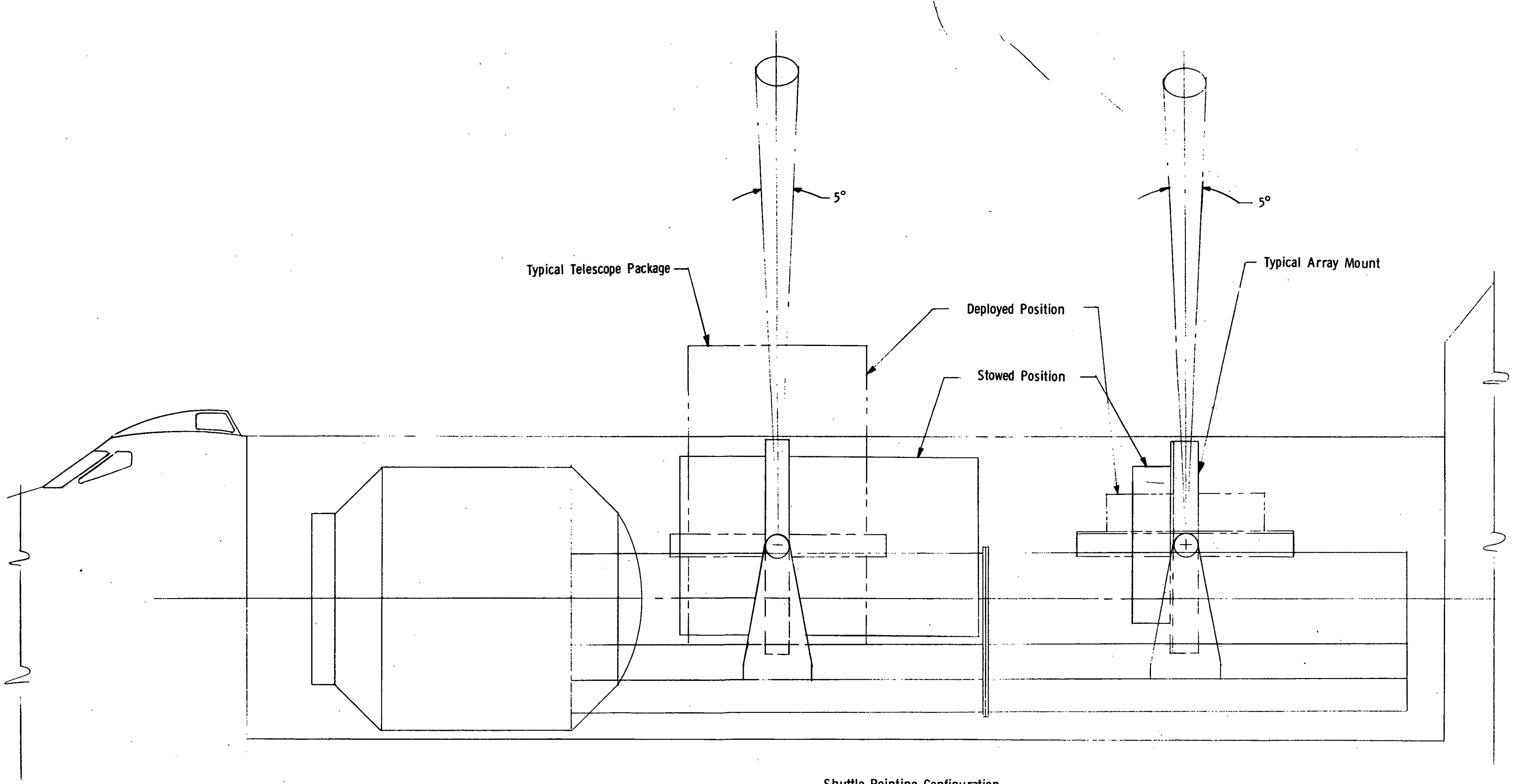
3) Use of environmental shroud over entire payload
   vs
   environmental protection applied directly to payload.

Of these studies, the first tradeoff resulted in a decision on the best of the two choices. The definitions of the four remaining configuration alternatives produced in other studies were used during the evaluation of alternative Sortie programs described in Chapter VI.

1. Shuttle Pointing with Nondeployed Payloads vs Wide Angle Gimbaling of Deployed Payloads

When assessing the impacts of the alternatives on the payloads and on Shuttle operations, this is the most important trade study of the three conducted. The configurations developed to illustrate the concepts assumed the use of the Sortie RAM since this is the "worst case" from the standpoint of restricted payload volume.

a. Concepts - Figure V-6 shows the concept using the Shuttle for coarse pointing the experiments, with the experiments mounted on a fine pointing gimbal. In this concept, the Shuttle must maneuver to provide any significant viewing capability. The fine viewing cone that is illustrated is typical of what can be achieved with a fine pointing gimbal similar to the Apollo Telescope Mount (ATM).



Shuttle Pointing Configuration
(Gimbal Allows ±2-1/2° Fine Pointing
in Any Direction after Coarse Pointing
by Shuttle)

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Shuttle Pointing
with Nondeployed Payload

Figure V-6

Another concept that must be considered in determining the preferred method of pointing the astronomy experiments is the use of a limited travel gimbal shown in Fig. V-7. An elevation drive is needed for each of the experiments to allow gimbaling of the payload without deploying it from the pallet.

The maximum travel that could be achieved with a limited gimbal is approximately 110 deg (total angle). The major restrictions on viewing are the RAM and the vertical fin on the Shuttle.

This concept does offer some significant advantages for experiment pointing when compared to a stationary experiment that is pointed by the Shuttle; therefore, it was included in the alternatives being considered.

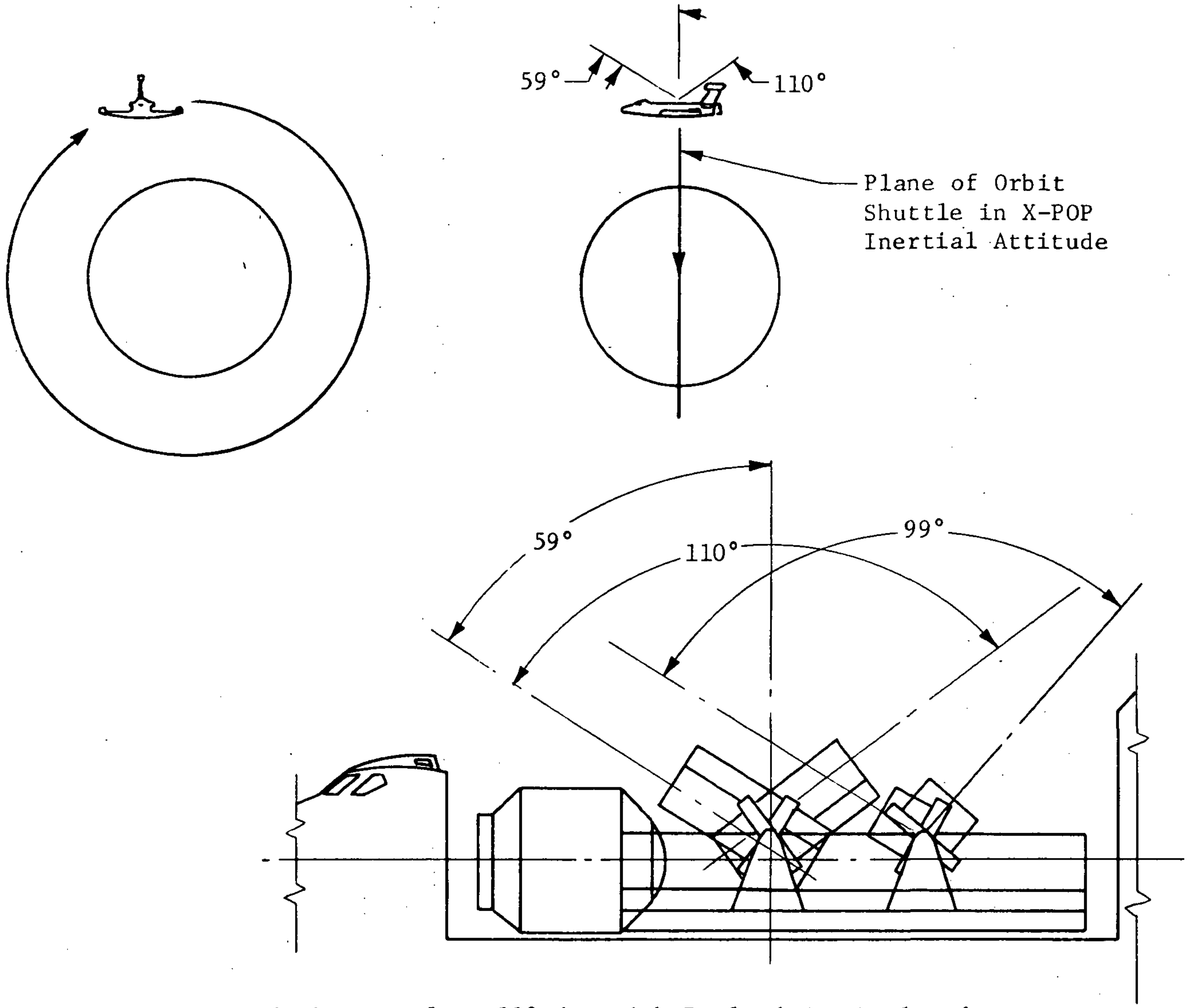
The wide angle gimbaling of deployed experiments is illustrated in Fig. V-8. An azimuth table is used that allows 360 deg rotation, plus an elevation mechanism with a range of ± 90 deg. With this approach, hemispherical coverage is achieved. The experiments must be deployed out of the pallet to effectively take advantage of the capabilities of the wide angle gimbaling approach.

b. Shuttle Inertial Attitudes - An important parameter in the selection of the pointing technique is the inertial orientation of the Shuttle. Two methods of achieving inertial attitudes are where the Shuttle X-axis is in-orbit-plane, (X-IOP) and where the Shuttle X-axis is perpendicular-to-orbit-plane (X-POP). Figure V-9 summarizes the characteristics of these two Shuttle attitudes.

To determine which of these methods is most desirable for Astronomy Sortie missions, it is necessary to define the sky coverage that is available as well as the delta system weights that would be required to maintain the attitude.

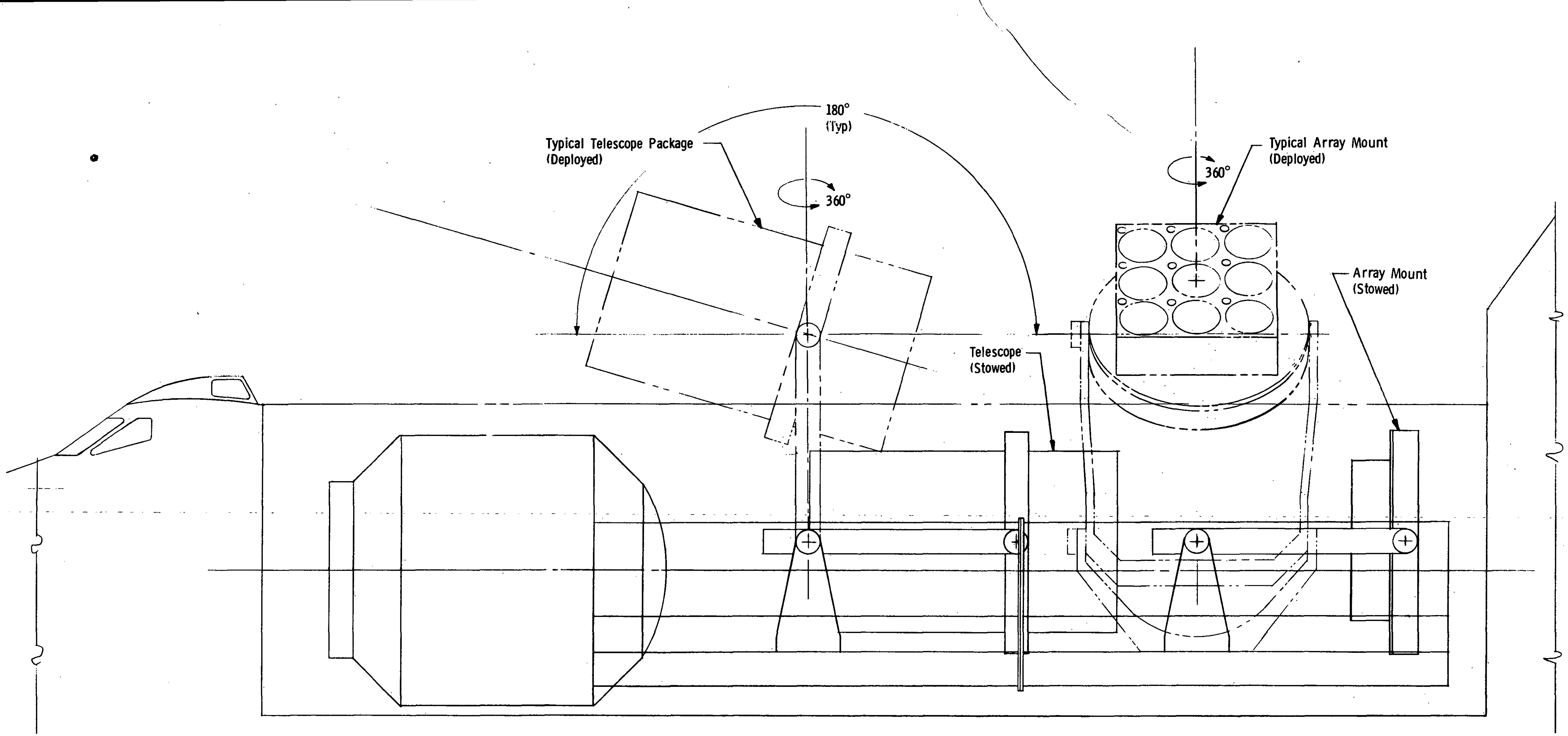
For sky coverage the X-IOP mode will allow any position in the celestial sphere to be viewed while maintaining the X-axis in the orbit plane. For the X-POP mode it would only be possible to view along the orbit plane if gimbals are not provided for the experiments.

To determine the delta systems weight to maintain the inertial attitudes, the gravity gradient torques were defined for each method. Based on these torques, a propulsion system and a CMG



Maximum Angle ≈ 110 deg with Payload Not Deployed

Fig. V-7 Shuttle Pointing with Nondeployed Payload and Limited Gimbal Angles



Wide Angle Gimbal Pointing
(Full Hemispherical Coverage
after Deployment)

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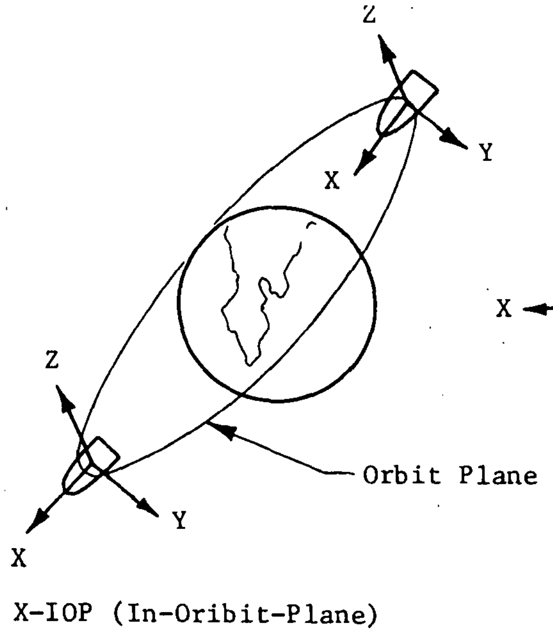
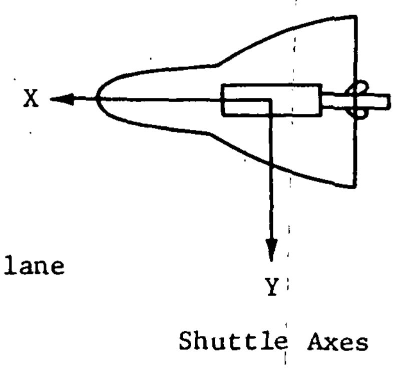
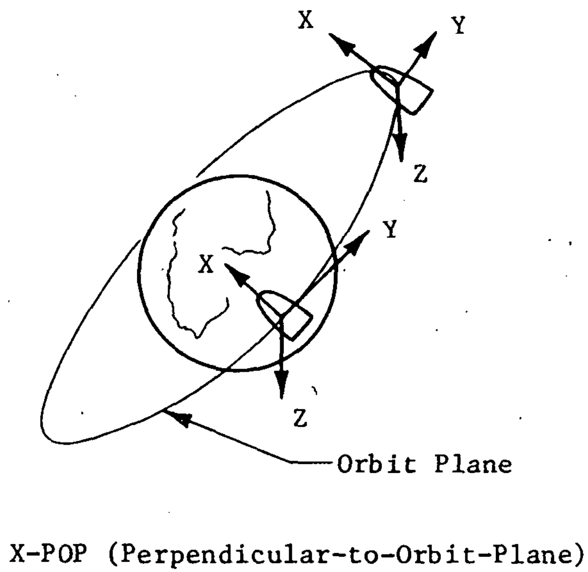
Wide Angle Gimballing of
Deployed Payloads

Figure V-8







Characteristic	X-IOP	X-POP
Sky Coverage	Total Sphere	Orbit Plane Only
Propulsion System Weight to Maintain Inertial Attitude	954 kg (2100 lb) includes 642 kg (1414 lb) of propellant for 7 days	262 kg (577 lb) includes 135 kg (297 lb) of propellant for 7 days
or		
CMG System Weight to Maintain Inertial Attitude	1226 kg (2700 lb) for momentum envelope of 1814.8 kg-m-sec (13,122 lb-ft-sec)/½ orbit	408 kg (900 lb) for momentum envelope of 621 kg-m-sec (4490 lb-ft-sec)/½ orbit

Fig. V-9 Shuttle Inertial Attitudes

system were defined that would counter these torques. The propulsion systems weights shown are based on the addition of a 2.72 kg (6 lb) hydrazine thruster system with associated tankage and propellant required to maintain the inertial attitude for seven days.

The CMG system weights are based on using six ATM CMGs at 318.1 kg-m-s-(230 lb-ft-sec) for the X-IOP mode and two ATM CMGs for the X-POP mode. The choice between CMGs and propulsive systems is included in Volume III of this report. Both methods are shown for information only.

c. Payload Pointing Techniques - The three concepts developed above were combined with the two Shuttle inertial attitudes that were analyzed, to identify six possible methods for pointing the astronomy experiments. Each of these pointing techniques was then evaluated for its applicability to the two general types of payloads being considered. These are: solar telescopes with stellar arrays, and stellar telescopes with stellar arrays. Table V-2 presents the results of the evaluation.

For the Shuttle pointing-only method, it would not be possible to operate both the solar telescopes and stellar arrays simultaneously because both experiments would be restricted to viewing the same place. This method was eliminated for this reason.

For the limited-travel-gimbal method it is not possible to view the sun while in the X-POP inertial attitude because it would be necessary to gimbal the solar telescopes 90 deg. This 90-deg gimbal is required because the preferred orbit inclination for solar viewing is one that provides a beta angle near 90 deg.

Wide angle gimbals provide hemispherical coverage for both X-IOP and X-POP Shuttle attitude. However, for X-IOP the gravity gradient torques are greater, and therefore, the delta system weights are also greater. For this reason, plus the fact that it offers no advantages, the wide angle gimbal with X-IOP inertial attitude was eliminated.

The two pointing methods that remain for further evaluation are a limited travel gimbal with the Shuttle in X-IOP inertial attitude and a wide angle gimbal with the Shuttle in X-POP inertial attitude. These methods are compared in Table V-3.

Table V-2 Evaluation of Pointing Techniques

Pointing Technique \ Payload	Solar Telescopes and Stellar Arrays Payloads	Stellar Telescope and Stellar Arrays Payloads	Note
<u>Shuttle Pointing Only</u>			
X-IOP	Not possible, must gimbal one or other	Limited, both point at same place	1
X-POP	Not possible, need 90-deg gimbal for solar	Very limited, both point near orbit plane	1
<u>Limited Travel Gimbal</u>			
X-IOP	Good, dual coverage limited by gimbal angle	Good, dual coverage limited by gimbal angle	
X-POP	Not possible, need 90-deg gimbal for solar	Fair, coverage limited by gimbal angle	1
<u>Wide Angle Gimbals</u>			
X-IOP	Excellent	Excellent	2
X-POP	Excellent	Excellent	

Note: 1. Pointing technique must satisfy both classes of payloads.

2. X-IOP and wide angle gimbal does not offer any advantages and has a weight penalty of = 816 kg (1800 lb).

Table V-3 Comparison of Best Pointing Techniques

Consideration / Pointing Technique	X-IOP, Limited Travel Gimbal, Nondeployed	X-POP Wide Angle Gimbal, Deployed
Solar Telescopes and Stellar Array Viewing	Good, view sun and up to 110 deg away for stellar at same time	Excellent, can view opposite hemispheres
Stellar Telescope and Stellar Array Viewing	Good, can view 110 deg apart at same time	Excellent, can view opposite hemispheres
Operational Constraints	Will require maneuvering the Shuttle to obtain hemispherical coverage	Wide angle gimbals provide hemispherical coverage
Hardware Required	Elevation gimbal (2) Support yoke (2)	Elevation gimbal (2) Azimuth table (2) Deployment mechanism (2)
Weight	1680 kg (3700 lb)	1360 kg (3000 lb)

As can be seen, the limited travel gimbal with the X-IOP Shuttle inertial attitude does provide good viewing capability for both solar and stellar experiments. However, to obtain hemispherical coverage it will be necessary to maneuver the Shuttle. This concept requires a minimum of 1678.3 kg (3700 lb) of hardware and propulsion system to provide this pointing.

The deployed wide angle gimbal with the X-POP Shuttle inertial attitude provides hemispherical coverage without maneuvering the Shuttle. This concept requires additional hardware to provide this capability, but the total system weight is less due to the lower gravity gradient torques on the Shuttle.

d. Pointing Technique Selection - The pointing technique selected for the Astronomy Sortie missions uses the deployed wide angle gimbal with an X-POP Shuttle inertial attitude. This technique was selected for the following reasons:

1) It minimizes Shuttle maneuvering for target acquisition, thereby conserving Shuttle crew time, experiment crew time, and Shuttle propellant;

2) Flexibility of technique minimizes impact of Shuttle orientation constraints that may be imposed. Hemispherical viewing is always possible;

3) Best Shuttle inertial attitude from standpoint of gravity gradient torques.

2. Use of RAM for Pressurized Volume vs Use of Shuttle Pressurized Volume

Major factors entering into this comparison included: the available volumes, payload weight penalties, length of payload bay available for experiments and subsystem equipment, efficiency of experiment control and monitoring operations, complexity of payload/Shuttle interfaces, and relative costs. Two configuration sketches (Fig. V-10 and V-11) were used as aids in making the comparison.

The Sortie RAM affords nearly 100 times as much volume as the Shuttle contains for experiment control and monitoring. Total pressurized volume of the Sortie RAM is approximately 37.67 m^3 (1330 ft^3) while the Shuttle presently provides 0.37 to 0.42 m^3 (13 to 15 ft^3) for payload control and display (C&D) and storage. This appears to be inadequate for accommodating the C&D panel, tape recorders, and tape stowage facilities.

Use of the Sortie RAM involves a weight penalty of 1814 kg (4000 lb). Total weight of the subsystem-equipped RAM and pallet is 5810 kg (12,800 lb) while the weight of a longer subsystem-equipped pallet plus necessary equipment, mounting and interface provisions in the Shuttle totals 3989 kg (8795 lb).

Assuming a full-length pallet with the unpressurized payload support subsystems installed at one end, a total length of 15.8 m (52 ft) is available for experiments in the payload bay. Use of the Sortie RAM reduces the available length to 12.2 m (40 ft).

The Sortie RAM allows maximum separation of experiment crew operations from Shuttle crew activities. This is an important factor when considering the efficiency of the crews, and possible conflicts during sleep cycles if the experiment crew must share space in the Shuttle.

Shuttle/payload interfaces are considerably more complex without the Sortie RAM. Because the RAM contains supporting subsystems such as C&D, data, and electrical power that would otherwise be located in the Shuttle, interfaces are between it and the pallet rather than between the pallet and Shuttle. The RAM allows the payload to be totally decoupled from the Shuttle until the payload is installed in the Shuttle cargo bay.

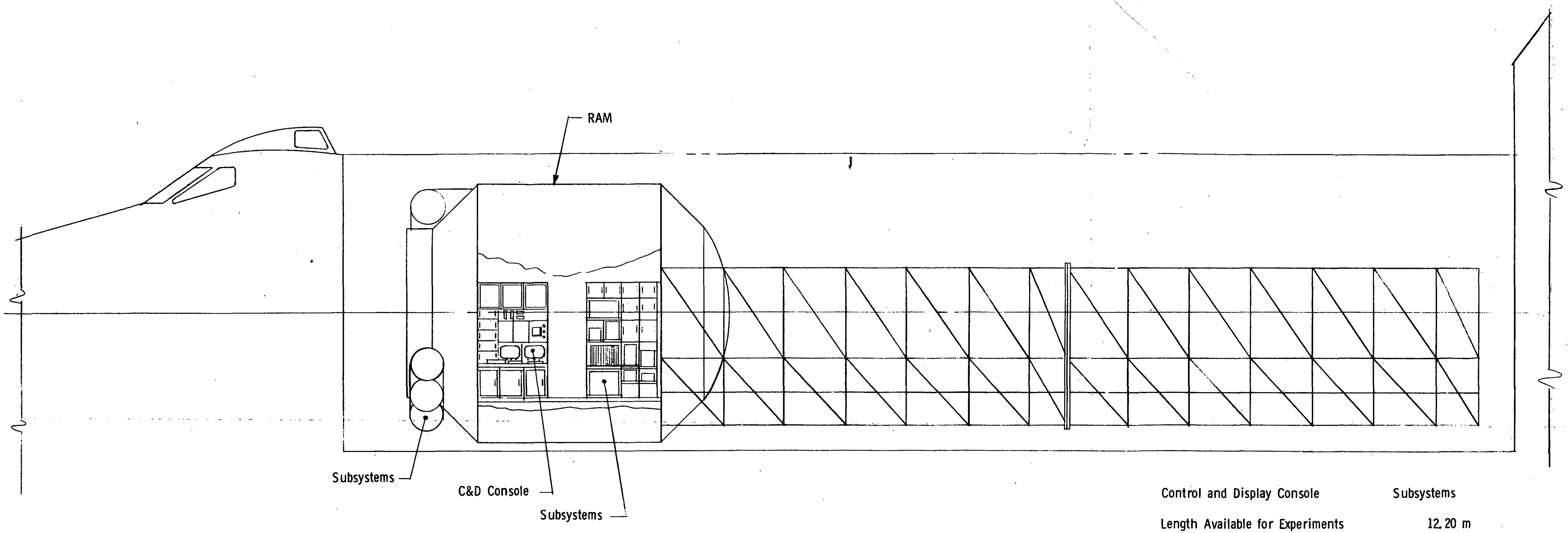
Cost differences arise when comparing the added cost of the Sortie RAM with the costs of extending the pallet, installing experiment support systems on the pallet, and interfacing these systems with the Shuttle. While the cost of the Sortie RAM and its subsystems is higher than the alternative, commonality of usage of the RAM with programs other than the Astronomy Sortie missions will reduce this margin.

3. <u>Use of Environmental Shroud Over Entire Payload Vs. Environmental Protection Applied Directly to Payload</u>

The majority of the Astronomy Sortie experiments require environmental protection during the Sortie missions. Protection against thermal, meteroroid, and contamination effects is required for the exposed payloads while on orbit. During launch, and perhaps during reentry, the acoustic environment in the payload bay exceeds the anticipated capabilities of the payload. Two payload protection approaches were studied.

Figure V-12 shows an approach using a shroud to cover the entire payload aft of the Sortie RAM. The lower portion of the shroud is also a strongback used to support the payload. Nonstructural doors open to allow experiment deployment.

The alternative to this approach is to have each telescope and array provide its own environmental protection. This protection would be incorporated into the basic telescope and array design.



(Experiments not Shown)

Control and Display Console	Subsystems
Length Available for Experiments	12.20 m (40 ft)
RAM and Pallet Mass	5810 kg (12800 lb)
Pressurized Volume Available	37.6 m^3 (1330 ft^3)

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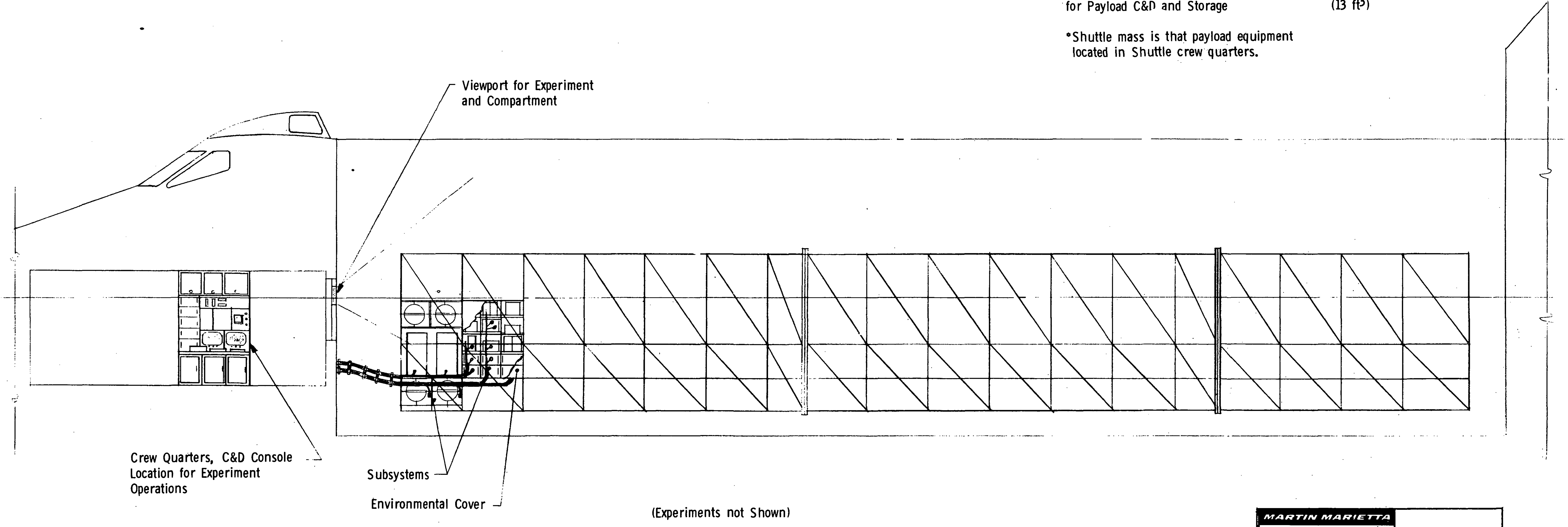
RAM Pressurized Volume

Figure V-10

Length Available for Experiments	15.85 m (52 ft)
Pallet and Shuttle Mass*	3995 kg (8795 lb)
Pressurized Volume Available for Payload C&D and Storage	0.37 m^3 (13 ft^3)

*Shuttle mass is that payload equipment located in Shuttle crew quarters.



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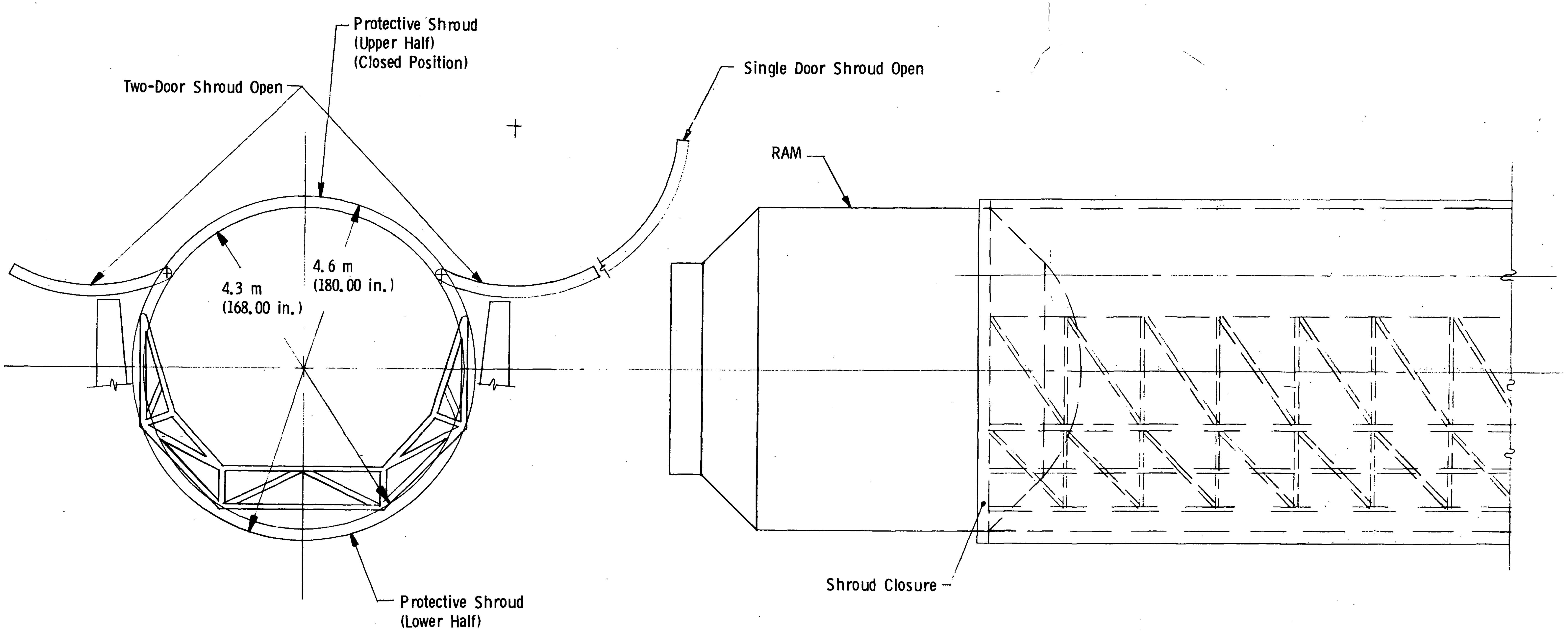
Shuttle Pressurized Volume

Figure V-11



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Overall Environment
Shroud Concept

Figure V-12

One of the important factors in the comparison of the two approaches is the difference in payload weight penalties. The weight of sound attenuation material is a significant part of the weight of the individual payload shrouds. This weight was calculated assuming that the overall sound pressure level which the payload can tolerate is 140 dB.

Figure V-13 shows sound transmission loss as a function of frequency for a shroud with a surface density of 9.76 kg/m^2 (2.0 lb/ft^2). This curve was extrapolated from Martin Marietta test data for the measured attenuation, at liftoff across a Titan III payload shroud having a surface density of 7.81 kg/m^2 (1.6 lb/ft^2). Figure V-14 presents the Shuttle payload bay sound levels at liftoff, and the expected levels on experiments and subsystems protected by shrouds with a surface density of 9.76 kg/m^2 (2.0 lb/ft^2).

The weight to provide this protection to the mission payload with the largest surface area is 724 kg (1590 lb). This weight is very conservative since it does not consider the sound attenuation provided by the thermal, meteoroid, and contamination protection which is also required but is considered as a part of the experiment weight. Weight of the overall shroud-strongback minus the portion of the structure required to support the payload is 1532 kg (3368 lb). This weight was derived from data developed during the SOAR study (Ref V-3). The net weight penalty for using the overall shroud is 810 kg (1778 lb).

Other factors were also considered in comparing the various approaches:

1) For contamination control during prelaunch and launch phases, it is easier to apply a dry gas purge to the overall shroud than to several individual shrouds.

2) The overall shroud requires opening large doors for experiment deployment. Unfavorable features include possible shading of Shuttle radiators, additional obstructions to experiment viewing, and the possibility of failure of the door mechanisms.

3) The overall shroud reduces the allowable envelope of the payload.

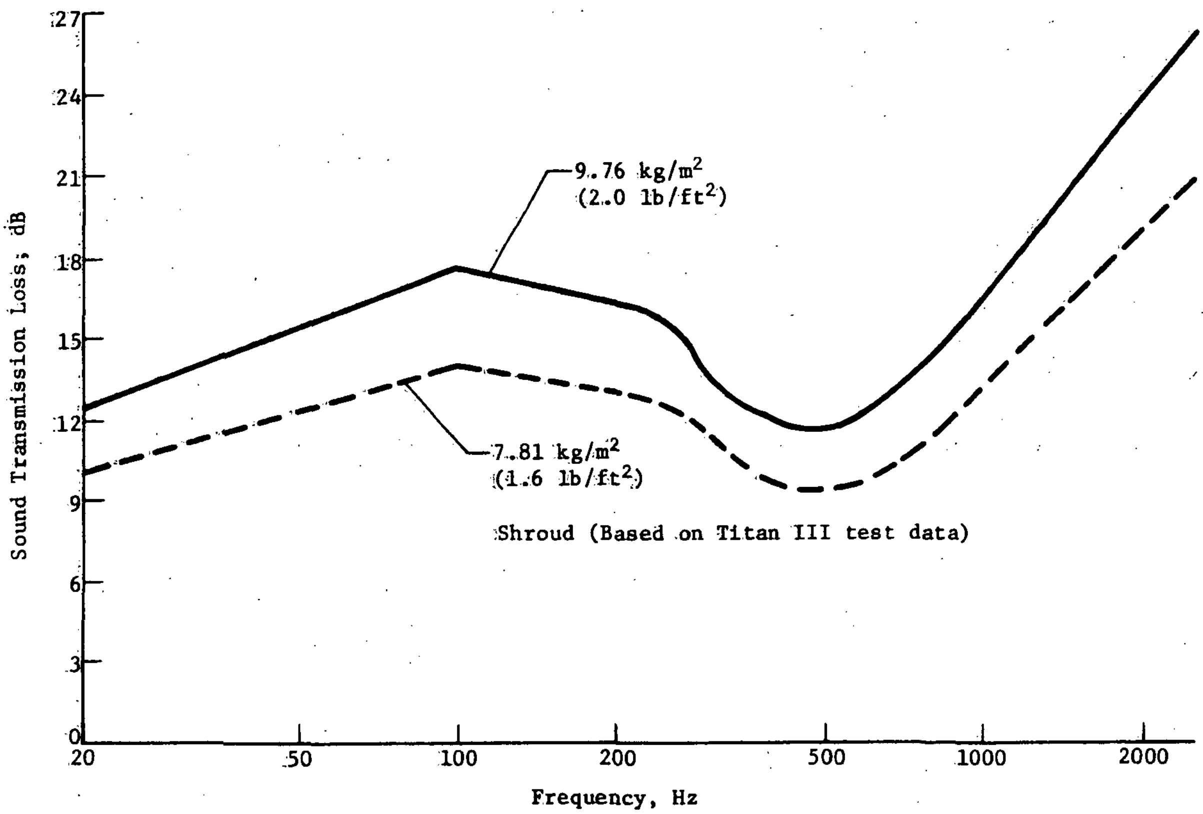


Fig. V-13 Sound Transmission Losses at Liftoff

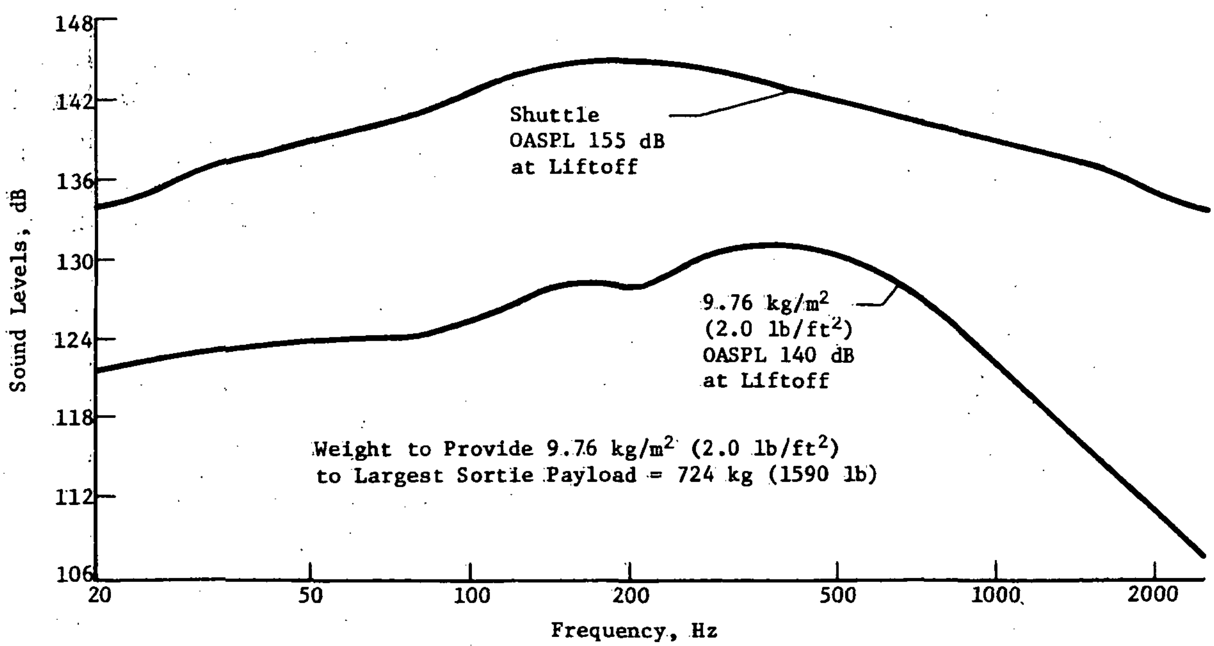


Fig. V-14 Addition of Acoustic Protection to Payload

4) Thermal, meteoroid, and contamination protection, and for several instruments, radiation protection is needed by most of the experiments. This requires only the addition of acoustic protection, if necessary, to ensure survival while in the Shuttle payload bay.

D. REFERENCES

V-1. Baseline RAM Definition (BRD) for Sortie Payloads, Martin Marietta, 1972.

V-2. Baseline Shuttle Definition (BSD) for Sortie Payloads, Martin Marietta, 1972.

V-3. SOAR Study, Contract NAS8-26790, MDAC, 1971.

VI. EVALUATION OF ALTERNATIVE SORTIE PROGRAMS

The primary objective of the evaluation of the alternative Sortie programs was to assure the selection of one program that combines the best features to support the Astronomy Sortie missions. An evaluation rationale was developed and applied to the rating of the four alternatives. The data developed in Chapter V, Section C were used as the basis for determining the ratings. The evaluation resulted in the recommendation of one configuration that is the baseline for the remainder of the study.

A. EVALUATION RATIONALE

The evaluation rationale used to select the recommended Astronomy Sortie mission program is summarized in this section and is included in its entirety in Ref. VI-1. This rationale was coordinated with, and approved by the COR, NASA-MSFC.

The approach used to establish the comparative ratings of the alternative Astronomy Sortie mission programs is based on the decision analysis technique of Kepner-Tregoe (Ref. VI-2) and consists of:

1) Passing each of the alternatives through a coarse screen that considers only go/no go (must) criteria;

2) Establishing a relative numerical rating of each alternative that passes the coarse screen, against a set of weighted desirable objectives, and selecting the two alternatives that receive the highest numerical ratings;

3) Examining the sensitivity of the two alternatives to changes in the relative weights of the desirable objectives;

4) The final selection of the recommended Astronomy Sortie mission program.

B. CONFIGURATION SELECTION

The four most promising configurations selected for comparative evaluation were:

1) RAM with pallet and overall shroud (Configuration 1);

2) RAM with pallet and individual protection (Configuration 2);

3) Shuttle with pallet and overall shroud (Configuration 3);

4) Shuttle with pallet and individual protection (Configuration 4).

All configurations use wide angle gimbaling of deployed payloads.

The selection process is described in this section.

1. Coarse Screening of Alternatives

Characteristics of the four configuration alternatives were compared with the "must" criteria to determine if any should be dropped from further consideration. The "must" criteria were: (1) maximum weight of 23,600 kg (52,000 lb); (2) maximum size of 4.27m dia by 17.7m long (14 ft dia by 58 ft long); (3) maximum Shuttle integration time $\leq$ 12 hr; (4) minimum operating efficiency $\geq$ 50%; and (5) accommodate all payloads. All five criteria were met by all four configurations. All payloads fit within the payload envelope. Each of the alternatives can be integrated into the Shuttle in less than the maximum of 12 hr if the payload is essentially launch-ready at time of integration. Operating efficiencies range from 49% to 86% and are primarily affected by the particular payload. Only minor influences are exerted by the accommodation configuration. Each configuration can accommodate any of the experiments. However, some regrouping of the experiments in the baseline payloads may be necessary for the configurations with overall shrouds, due to the reduced envelope for experiments within the shroud.

None of the alternative configurations was eliminated as a result of the coarse screening.

2. Numerical Rating of Alternatives

The comparative ratings of the four alternative configurations are shown in Table VI-1. The only ground rule adopted for rating, was that the best configuration(s) from the standpoint of each desirable objective must receive a score of 10. These ratings were determined as follows:

1) Averaging the task leader's ratings, which were arrived at on an individual basis, without discussion;

2) Producing a "consensus" rating at a group discussion meeting of all task leaders;

3) Averaging the results of Items 1) and 2). These averages were used as the final ratings.

The two highest rated configurations are 1 and 2. The scores of these two configurations, which use the pressurized RAM Sortie Module were significantly higher in the following categories:

Maximum Responsiveness - Included responsiveness to payload objectives and the baseline flight schedule, and viewing and operating responsiveness;

System Requirements - Considered safety, reliability, maintainability, and refurbishment;

Utilization of Man - All elements of on-orbit crew involvement;

Flexibility - Considered modifications to major payload elements to support all payloads, and the sensitivity of the configuration to changes in major program elements;

Interface Simplicity - Simplicity of interfaces between major program elements.

3. Sensitivity Analysis

A sensitivity analysis was conducted to uncover possible inadvertent biasing of the ratings due to the assigned weighting factors. The analysis changed the scale of weighting factors to 1 through 4. New weighted scores were calculated with no effect on the relative ranking of the configurations, although changes in differences between total weighted scores were noted.

Table VI-1 Alternative Configuration Ratings

Desirable Objectives	Weight	Configuration Alternative							
		Config. 1, RAM and Pallet and Shroud		Config. 2, RAM and Pallet		Config. 3, Shuttle and Pallet and Shroud		Config. 4, Shuttle and Pallet	
		Actual Score	Weighted Score	Actual Score	Weighted Score	Actual Score	Weighted Score	Actual Score	Weighted Score
Maximum Responsiveness	10	8.8	88	9.8	98	7.1	71	8.3	83
Maximum Cost	10	9.1	91	9.8	98	9.1	91	9.8	98
System Requirements	10	9.3	93	9.8	98	8.0	80	8.8	88
Utilization of Man	7	10.0	70	10.0	70	7.4	52	7.4	52
Compatibility	7	8.1	57	9.8	69	7.3	51	9.0	63
Flexibility	7	8.3	58	10.0	70	6.6	46	8.4	59
Interface Simplicity	5	8.8	44	10.0	50	6.6	33	7.6	38
Growth Capability	4	7.5	30	9.0	36	8.0	32	9.5	38
Maximum Commonality	3	9.7	29	9.7	29	8.0	24	7.7	23
Minimum Support Requirements	2	8.0	16	8.5	17	9.0	18	9.5	19
Total Weighted Score			576		635		498		561

4. <u>Selection of Recommended Astronomy Sortie Mission Program</u>

Although Configuration 2 received a higher rating than 1, both were evaluated to determine if adverse characteristics and risk factors would affect this rating. The result of this evaluation showed that Configuration 1, which uses an overall shroud, had higher cost, schedule, and mission success risks.

Configuration 2, which includes the Sortie RAM with pallet and individual environmental protection devices is the recommended configuration for the Astronomy Sortie missions.

C. REFERENCES

VI-1. Sortie Program Evaluation Rationale. Martin Marietta, 1-21-72

VI-2. C. H. Kepner and B. B. Tregoe: *The Rationale Manager*. McGraw-Hill Book Company, 1965.

VII. RECOMMENDED ASTRONOMY SORTIE PROGRAM

The Astronomy Sortie program recommended to the NASA/MSFC, COR at the completion of the first three months of the study is summarized in this chapter. This recommendation was presented to NASA/MSFC at the first performance review. As a result of the review, a number of ground rules and guidelines were modified, which had a direct impact on the recommended program. Chapter VIII summarizes the Astronomy Sortie mission program that was approved by the NASA/MSFC, COR for the remainder of the study.

The recommended Astronomy Sortie program represents a composite of the results of studies accomplished during the first portion of the study. The program is summarized in Table VII-1.

The program includes nine payload combinations consisting of three IR payloads, three Stratoscope III payloads and three photoheliograph payloads. As mentioned previously, the primary constraint in establishing the payload combinations was the physical size of the telescopes and arrays.

The orbits selected for the program consist of a 28.5-deg inclination and 463 km (250 n mi) altitude for the IR and Stratoscope III payloads, and a 66.5 to 90-deg inclination and 370 km (200 n mi) altitude for the photoheliograph payloads. These orbits were selected based on the mission analyses performed, and provide the best orbits for satisfying the telescope objectives.

The mission analyses indicated that to achieve maximum effectiveness for the IR telescope it should be flown during a new moon to take advantage of the sun-moon positions. The photoheliograph orbit selection depends on the relative position of the sun with respect to the earth's equator, and the launch date and inclination should be selected so that a beta angle of 90 deg is available sometime during the mission. The altitude should be 370 km (200 n mi) to provide a continuous view of the sun during the seven-day mission.

The support hardware recommended for the Astronomy Sortie mission consists of the RAM pallet and supporting subsystems as defined by the RAM study; deployment mechanisms to extend the telescope and array out of the pallet to enable the wide angle gimbals to view a hemisphere; a fine pointing system for the telescopes to

Table VII-1 Recommended Astronomy Sortie Program

Payload Complements
IR telescope with any one of three array combinations
Stratoscope III telescope with any one of three array combinations
Photoheliograph with any two of three solar telescopes plus one array combination
Orbit Selections
IR payloads: 28.5-deg inclination; 463 km (250 n mi) altitude
Stratoscope payloads: 28.5-deg inclinations; 463 km (250 n mi) altitude
Photoheliograph payloads: 66.5- to 90-deg inclination; 370 km (200 n mi) altitude
Launch Dates
IR payloads: Depends on time of year; new moon is desirable
Stratoscope payloads: Anytime
Photoheliograph payloads: Depends on time of year; want β = 90-deg
Support Hardware
RAM with supporting subsystems
Pallet
Deployment mechanism
Wide angle gimbal
Fine pointing system
Control and display console
Operational Concept
Payload integration center (MSFC)
Space astronomy control facility
Shuttle Interface Requirements
Shuttle maintains X-POP inertial attitude
Shuttle launch possible anytime during 24-hr period
ABES not installed for Astronomy Sortie missions

provide the additional pointing and stability required by the telescopes; and a control and display console for operation of the experiments.

The operational concept recommended for the Astronomy Sortie program uses the Payload Integration Center (MSFC) for all sustaining engineering required for the astronomy payloads over the 12-year baseline flight schedule. The operational concept also uses a Space Astronomy Control Facility to provide a central location for mission planning, mission control, postflight data analysis, data processing, and data storage.

The Shuttle interfaces necessary for the recommended Astronomy Sortie program are shown. The X-POP inertial attitude is recommended because it minimizes the gravity gradient torques. The orbit inclination recommended for the Astronomy Sortie program requires the capability for launch anytime during a 24-h day. The performance of the Shuttle was based on not using the ABES for the Astronomy Sortie mission.

A. CONFIGURATION

The recommended Astronomy Sortie mission configuration is shown in Fig. VII-1. Major features include use of the Sortie RAM module, a modified RAM pallet, and deployment of the instruments out of the pallet and Shuttle payload bay.

When deployed, the telescope and array payloads essentially have a hemispherical field of view. The Shuttle vertical fin and a small part of the cockpit area are the only fixed obstructions. While the deployed instrument payloads will somewhat obstruct each others view, they can be retracted to remove the obstruction, if desired. The vertical distance of deployment was determined by the open payload bay doors. This distance will probably be reduced as the Shuttle configuration becomes firm, thereby reducing the length of the deployment yoke.

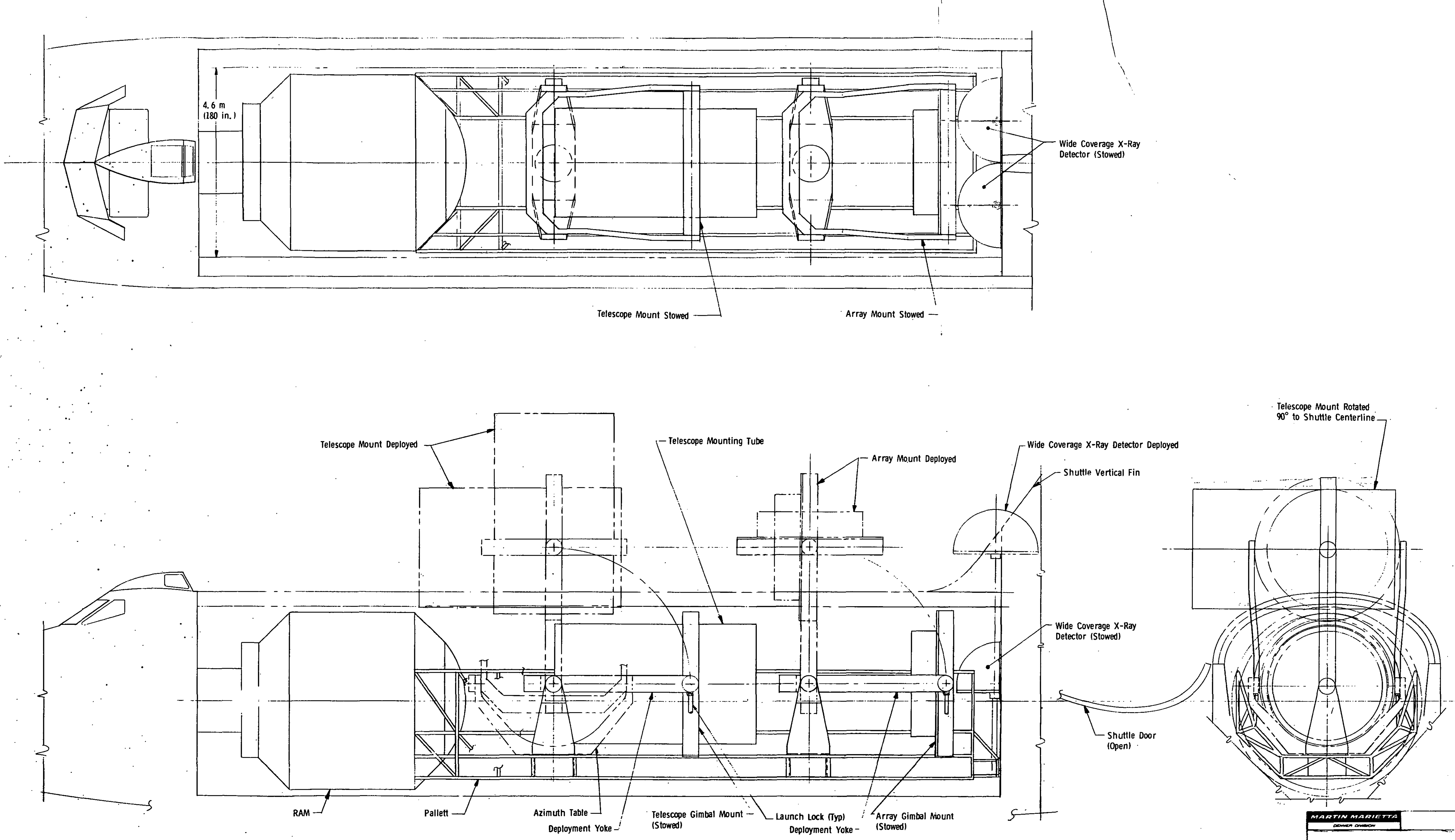
Use of the Sortie RAM with its subsystems should prove cost effective when considering potential commonalities with missions involving other payload disciplines. In addition, the Sortie RAM provides the experimenters with a spacious work station which is removed from the Shuttle crew quarters. Growth in C&D and other supporting subsystems can be accommodated with essentially no impact on the Shuttle.

Telescope and array payloads are stowed in an attitude which is most suitable for withstanding launch accelerations. Launch locks secure the payloads while in the stowed position, by attaching to the deployment yoke. The yoke rotates 90 deg to move the payloads to their deployed positions. The payloads are kept from rotating with respect to the Shuttle during deployment to avoid interferences. Elevation drives are employed to move the payloads with respect to their deployment yoke.

Pointing of the telescope payloads requires the use of a three-axis fine pointing system. The requirements of the arrays that are pointed, are not so stringent, and roll orientation is not necessary. This allows mounting of the pointed arrays on a platform that interfaces with the deployment yoke in the same manner that the telescope fine pointing system employs. In summary, deployment and pointing of the array and telescope payloads is accomplished with identical azimuth tables, deployment yokes, and elevation drives. The three-axis fine pointing system is added for the telescope packages.

The wide coverage X-ray detector array is carried on all flights. This device is used for survey work to identify sources for the high resolution and sensitivity arrays. Due to its size and the desirability of holding it fixed with respect to the Shuttle, the array is mounted, deployed, and oriented by its own mechanisms. Viewing requirements and the available space for stowing the array led to the configuration that separates it into two half hemispheres.

The recommended program hardware is shown in simplified form in Figure VII-2. The concept shown satisfies a requirement for simplicity and commonality of elements.



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DENVER DIVISION

Recommended Astronomy Sortie Mission Configuration

Figure VII-1

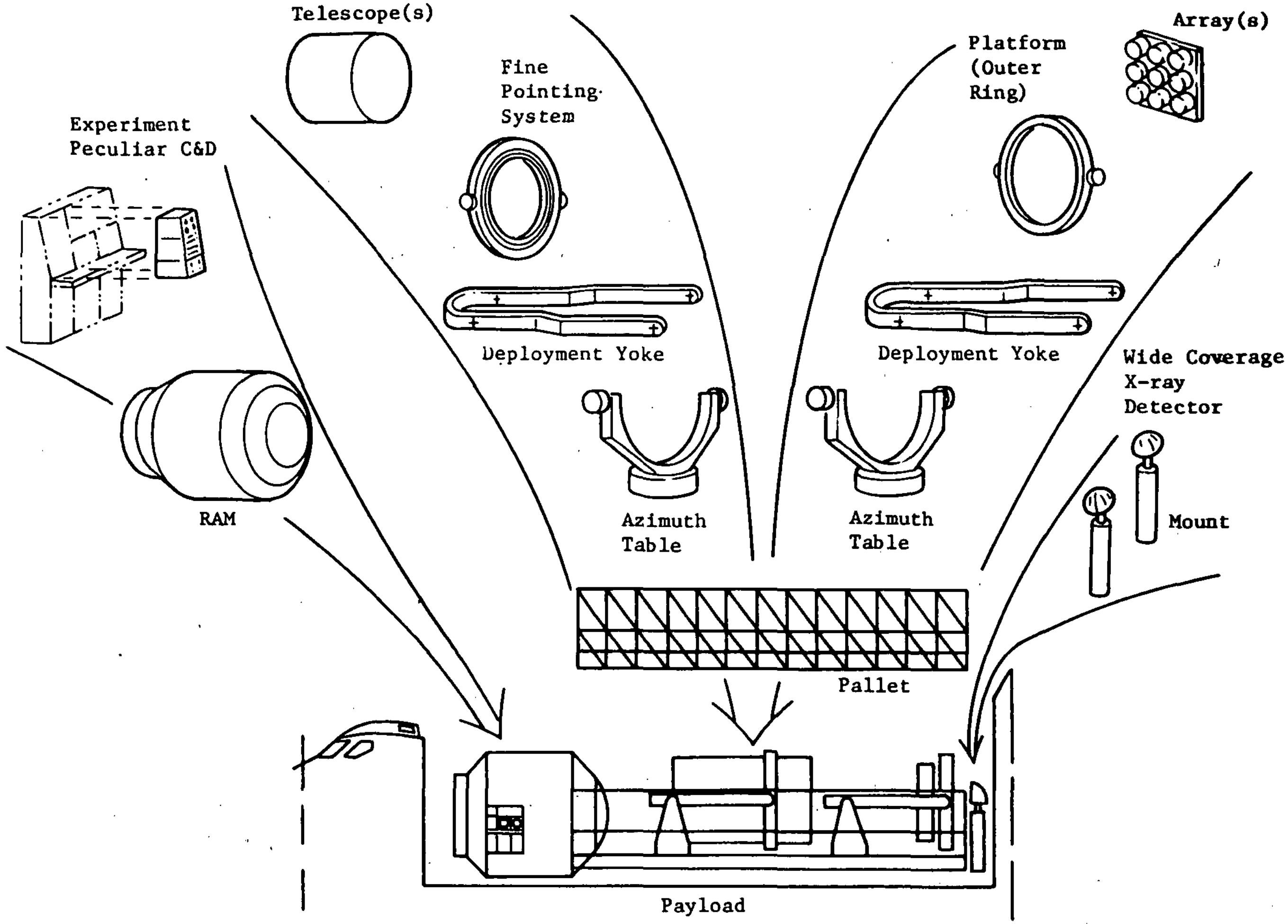

Fig. VII-2 Recommended Program Hardware

A Sortie RAM and pallet allows room for experiment-peculiar C&D installations in the hybrid console, with ample growth potential for both C&D and subsystems. Extending the basic RAM pallet by 6.7 m (22 ft) is necessary to accommodate a dual-mount configuration. The front and rear mounts are identical to the point where a fine pointing system is used for the telescope payload and a simple platform is used for the array.

Two individual but identical mounts are used to stow, deploy, and orient the two half-hemispheres of the wide coverage X-ray detector array.

Experiment-peculiar mounting kits allow mounting of the telescope and array payloads on their respective orientation devices.

B. CHARACTERISTICS

1. Payload Support Requirements

Major support requirements for the photoheliograph, Stratoscope III, and IR payloads are listed in Tables VII-2, VII-3, and VII-4, respectively. These are presented in the form of minimum and maximum requirements for selected parameters of the payloads, including the experiments, and controls and displays equipment. The minimum or maximum requirements identified cannot be associated with a specific photoheliograph payload combination since they represent totals of minimum and maximum values for individual experiments. Rather, the intent is to show the range of requirements that these payloads impose on the supporting subsystems. Requirements provided by the experiments themselves, are not included.

2. Payload Weights vs Shuttle Capability

Figure VII-3 shows the Shuttle payload capabilities for the various altitudes and inclinations considered for the Astronomy Sortie missions. The solid curves represent 80% of the Shuttle capability to the particular orbit and are based on an Orbit Maneuvering System (OMS) specific impulse (Isp) of 310 sec without an ABES.

Table VII-2 Support Requirements, Photoheliograph Payloads

	Parameter	Minimum Requirement	Maximum Requirement
Experiments	● Weight	2185 kg (4829 lb)	2223 kg (4921 lb)
	● Power		
	●Average	361 W	507 W
	●Peak	529 W	737 W
	● Energy	58 kWh	81 kWh
	● Data		
	●Rate	7.5 kbps	17.4 kbps
	●Total	4.32×10^9 bits	10^{10} bits
	● Crew	23 hr/day	34.4 hr/day
	● Pointing Accuracy		
	●Telescope	9.6×10^{-6} rad (2.0 arc-s)	9.6×10^{-6} rad (2.0 arc-s)
	●Array	1.5×10^{-3} rad (5 arc-min)	1.5×10^{-3} rad (5 arc-min)
	● Pointing Stability		
	●Telescope	0.49×10^{-6} rad (0.1 arc-s)	0.49×10^{-6} rad (0.1 arc-s)
	●Array	0.29×10^{-3} rad (1.0 arc-min)	0.29×10^{-3} rad (1.0 arc-min)
Controls & Displays	● Panel Area	0.775 m^2 (1202 in^2)	0.885 m^2 (1370 in^2)
	● Panel Weight	196.1 kg (436 lb)	240.3 kg (534 lb)
	● Power	299 W	333 W
	● Energy	47.8 kWh	53.3 kWh

Table VII-3 Support Requirements, Stratoscope III Payloads

	Parameter	Minimum Requirement	Maximum Requirement
Experiments	• Weight	2425 kg (5376 lb)	3115 kg (6891 lb)
	• Power		
	•Average	255 W	385 W
	•Peak	391 W	562 W
	• Energy	40.8 kWh	61.6 kWh
	• Data		
	•Rate	4.4 kbps	29.5 kbps
	•Total	2.53×10^{9} bits	1.7×10^{10} bits
	• Crew	7.8 hr/day	16.2 hr/day
	• Pointing Accuracy		
	•Telescope	9.7×10^{-6} rad (2.0 arc-s)	9.7×10^{-6} rad (2.0 arc-s)
	•Array	1.74×10^{-2} rad (60 arc-min)	0.29×10^{-3} rad (1.0 arc-min)
	• Pointing Stability		
	•Telescope	0.49×10^{-6} (0.1 arc-s)	0.49×10^{-6} rad (0.1 arc-s)
	•Array	0.3×10^{-2} rad (10.2 arc-min)	0.29×10^{-3} rad (1.0 arc-min)
Controls & Displays	• Panel Area	0.439 m^2 (680 in.^{2})	0.614 m^2 (952 in.^{2})
	• Panel Weight	122.8 kg (273 lb)	166 kg (369 lb)
	• Power	173 W	229 W
	• Energy	26.7 kWh	36.6 kWh

Table VII-4 Support Requirements, IR Payloads

	Parameter	Minimum Requirement	Maximum Requirement
Experiments	• Weight	1225 kg (2701 lb)	1915 kg (4216 lb)
	• Power		
	•Average	445 W	575 W
	•Peak	626 W	797 W
	• Energy	71.2 kWh	92 kWh
	• Data		
	•Rate	3.5 kbps	28.6 kbps
	•Total	2.02×10^{9} bits	1.65×10^{10} bits
	• Crew	12.6 hr/day	21.0 hr/day
	• Pointing Accuracy		
	•Telescope	19.4×10^{-6} rad (4.0 arc-s)	19.4×10^{-6} rad (4.0 arc-s)
	•Array	1.74×10^{-2} rad (60 arc-min)	0.29×10^{-3} rad (1.0 arc-min)
	• Pointing Stability •Telescope	2.34×10^{-6} rad (0.5 arc-s)	2.34×10^{-6} rad (0.5 arc-s)
	•Array	0.3×10^{-2} rad (10.2 arc-min)	0.29×10^{-3} rad (1.0 arc-min)
Controls & Displays	• Panel Area	0.350 m^2 (542 in.^{2})	0.525 m^2 (814 in.^{2})
	• Panel Weight	98.1 kg (218 lb)	141.3 kg (314 lb)
	• Power	96 W	152 W
	• Energy	15.4 kWh	24.3 kWh

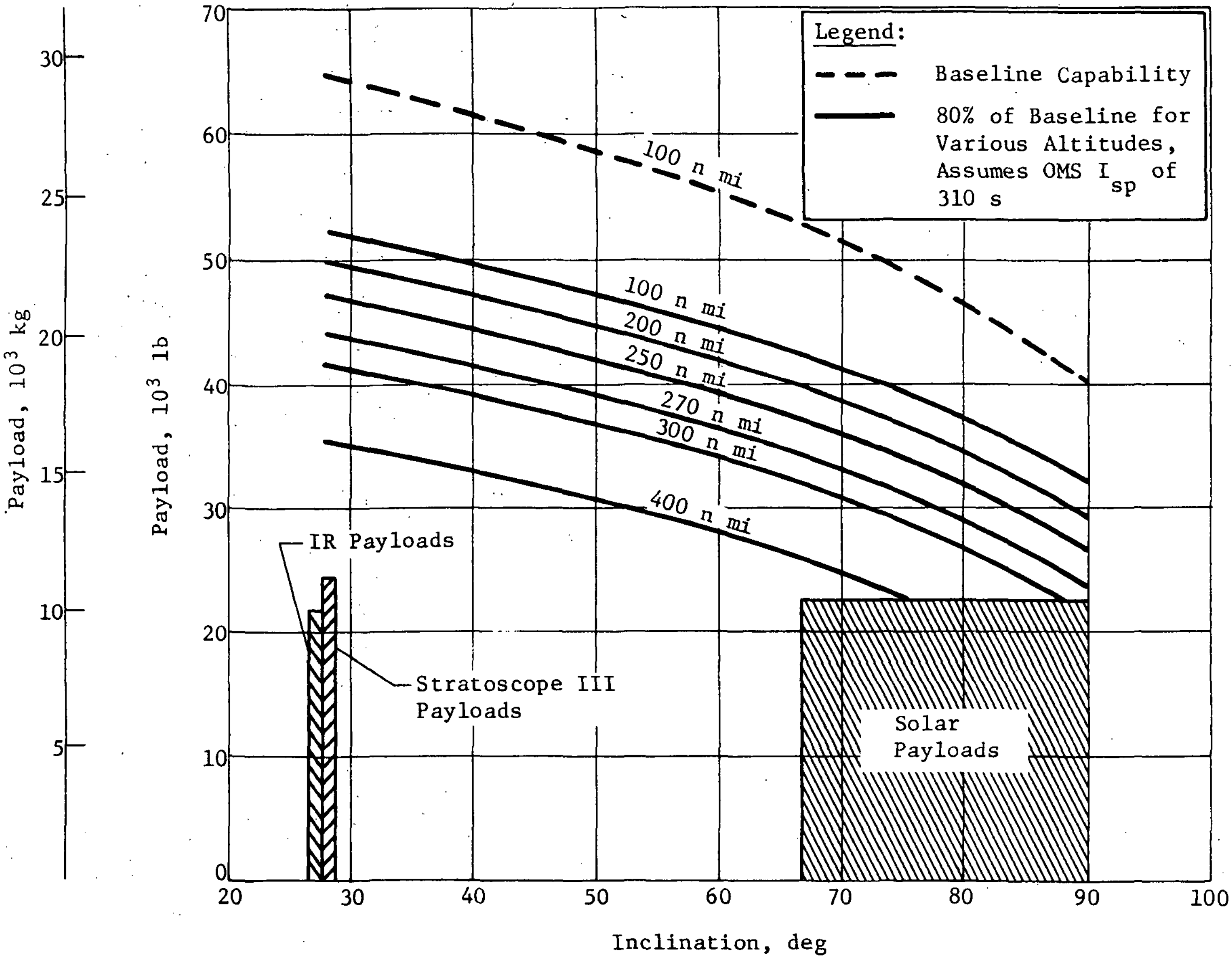

Fig. VII-3 Payload Weights vs Shuttle Capability

Also shown on the chart are typical weight values for the recommended IR, Stratoscope III, and photoheliograph payloads as a function of their preferred inclinations.

As can be seen, the IR and Stratoscope payloads have growth margins of approximately 90% when a 28.5-deg inclination and 463 km (250 n mi) altitude orbit is considered.

The solar payloads orbited at 370 km (200 n mi) have growth capabilities ranging from approximately 7711 kg (17,000 lb) to 3175 kg (7000 lb) depending on the orbit inclination (66.5 to 90 deg).

If it is determined that an ABES is required for the Astronomy Sortie missions, the payload capabilities would be reduced by approximately 7258 kg (16,000 lb), making the solar payloads marginal.

VIII. APPROVED ASTRONOMY SORTIE PROGRAM

This chapter summarizes the Astronomy Sortie program that was approved by the NASA/MSFC, COR as the baseline for the remainder of the study. Only those items from Chapter VII that were modified or deleted will be discussed.

A. GROUND RULES AND GUIDELINES

The following guidelines or ground rules were directed by the NASA/MSFC, COR for the remainder of the study:

1) The Sortie lab and pallet will be the baseline experiment carrier for the astronomy sortie missions replacing the RAM and pallet concept that was used for the first portion of the study. The baseline definition for the Sortie lab and pallet will be *Sortie Can Conceptual Design* NASA/MSFC document ASR-PD-DO-72-2, dated March 1, 1972.

2) The 100-cm photoheliograph, defined in Chapter II of this report will be the correct instrument for the study. No further reference will be made to the 65-cm photoheliograph.

3) The common gimbal system, defined in Chapter V, Section A was to be reduced from an inside diameter of 2.64 m (104 in.) to a maximum of 2.26 m (84 in.).

4) The payload grouping analyses of Chapter V, Section A of this report were to be reevaluated for the 2.26 m (84 in.) (inside diameter) common mount.

5) The requirement to fly a high-energy array group with all payloads was waived for the solar payload.

6) The baseline flight schedule was to be revised based on the new guidelines.

B. CONFIGURATION

Figure VIII-1 shows the approved hardware that was baselined for the remainder of the study. The primary differences between the recommended and approved hardware were the use of the Sortie lab and pallet in place of the RAM and pallet and the reduced size of the common mount.

Figure VIII-2 shows the common telescope mount that was approved. As stated previously, this mount has an 2.26 m (84 in.) inside diameter instead of the 2.64 m (104 in.) recommended.

Figures VIII-3 and VIII-4 show the operational configurations for the solar payload and the stellar payloads. The revised payload grouping (Section C, following) resulted in one solar payload that accommodated all of the solar telescopes using two of the common mounts. To operate this solar payload from a Space Shuttle that maintains an X-POP inertial attitude and an orbit with a 90 deg beta angle would require deploying the payloads out of the cargo bay at a 90-deg angle.

C. PAYLOAD GROUPINGS

To accommodate the telescopes with the smaller mount, it was necessary to regroup the experiments for the Astronomy Sortie program. Table VIII-1 shows the payload groupings that were approved for further definition work. The payload groupings shown were primarily based on the physical sizes of the telescopes and arrays.

D. BASELINE FLIGHT SCHEDULE

The baseline flight schedule that was provided during the study orientation meeting was revised to reflect the baseline payload groupings. Table VIII-2 shows the flight schedule adopted for the remainder of the study.

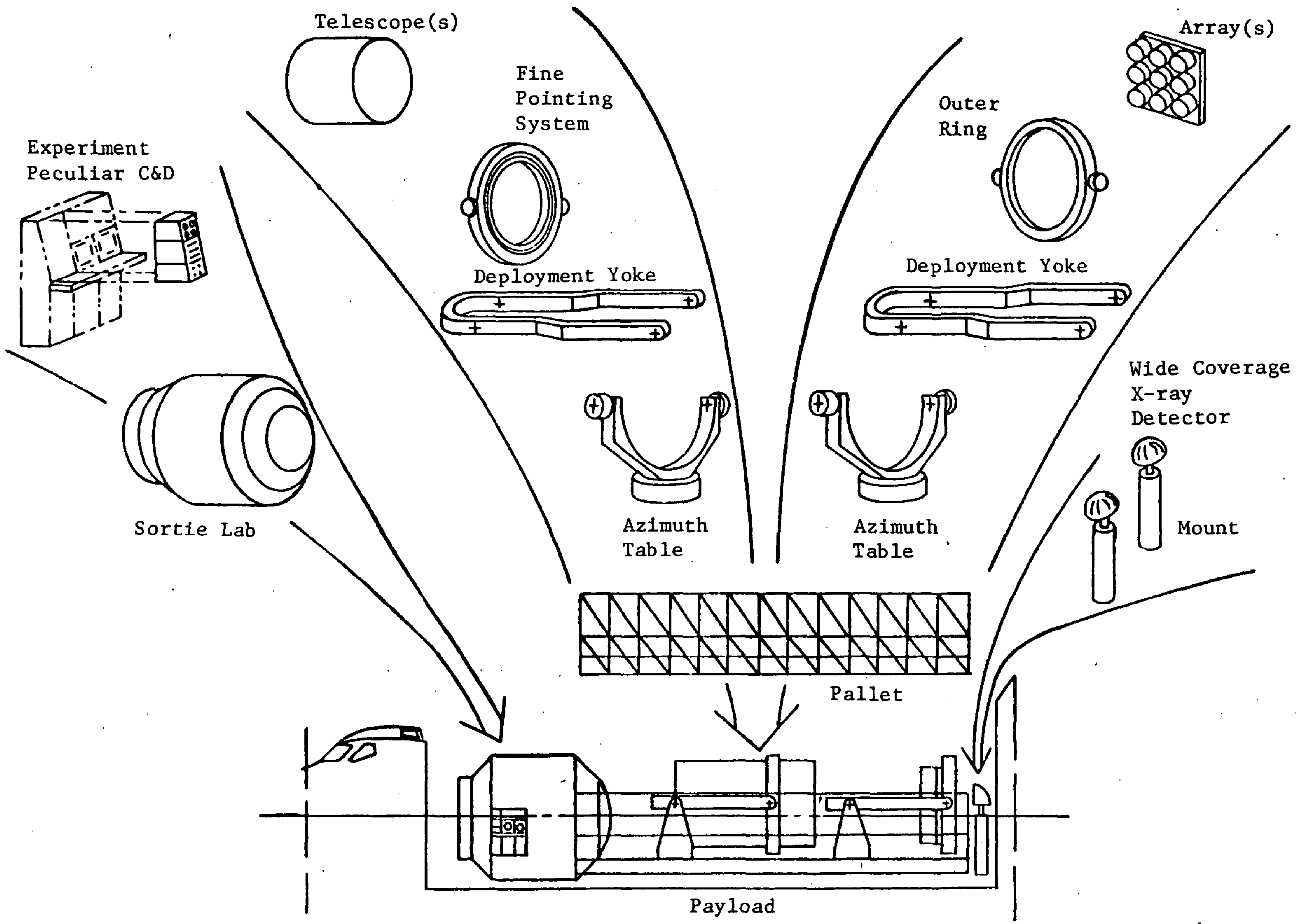

Fig. VIII-1 Approved Support Hardware

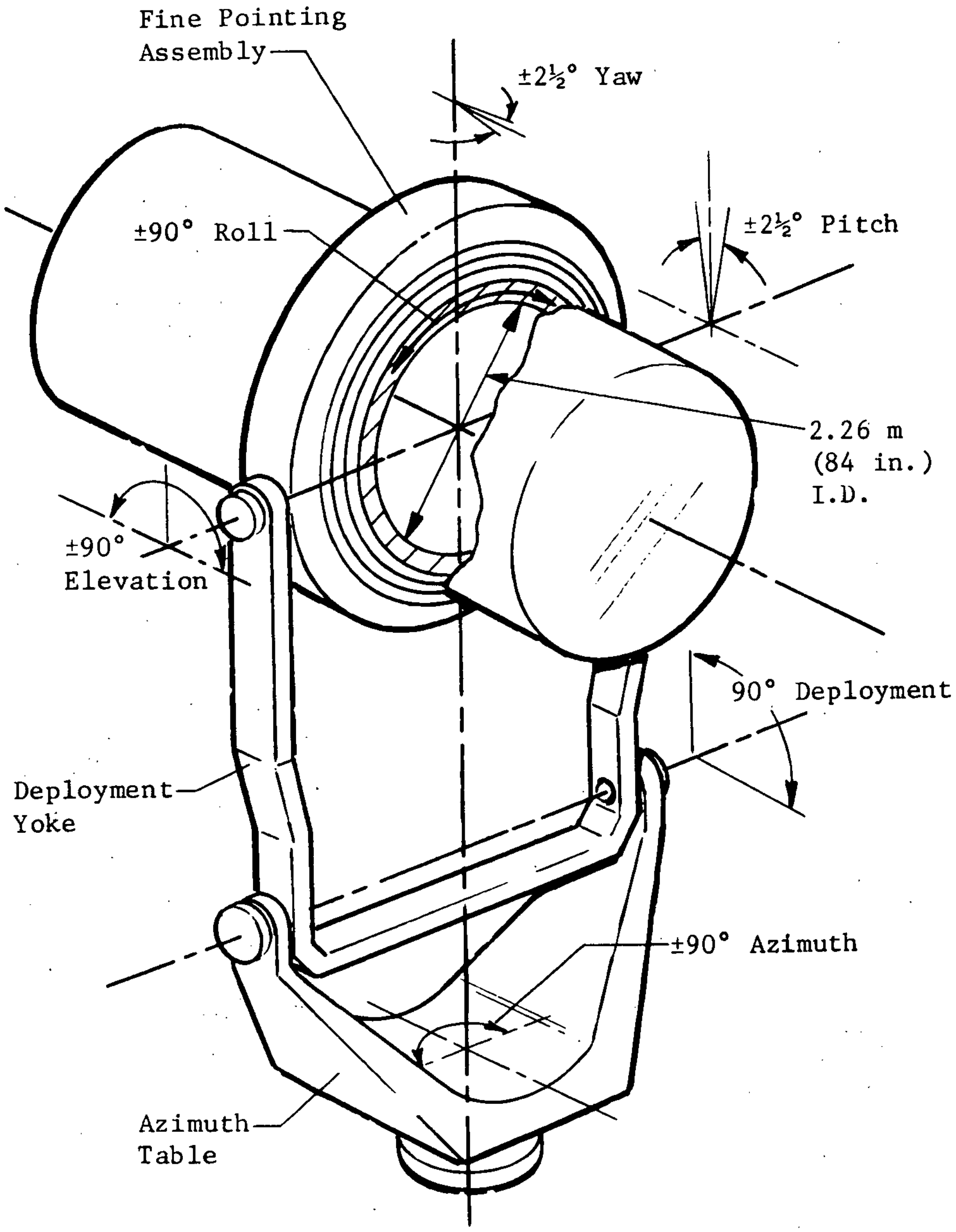

Fig. VIII-2 Approved Telescope Mount and Fine Pointing Assembly

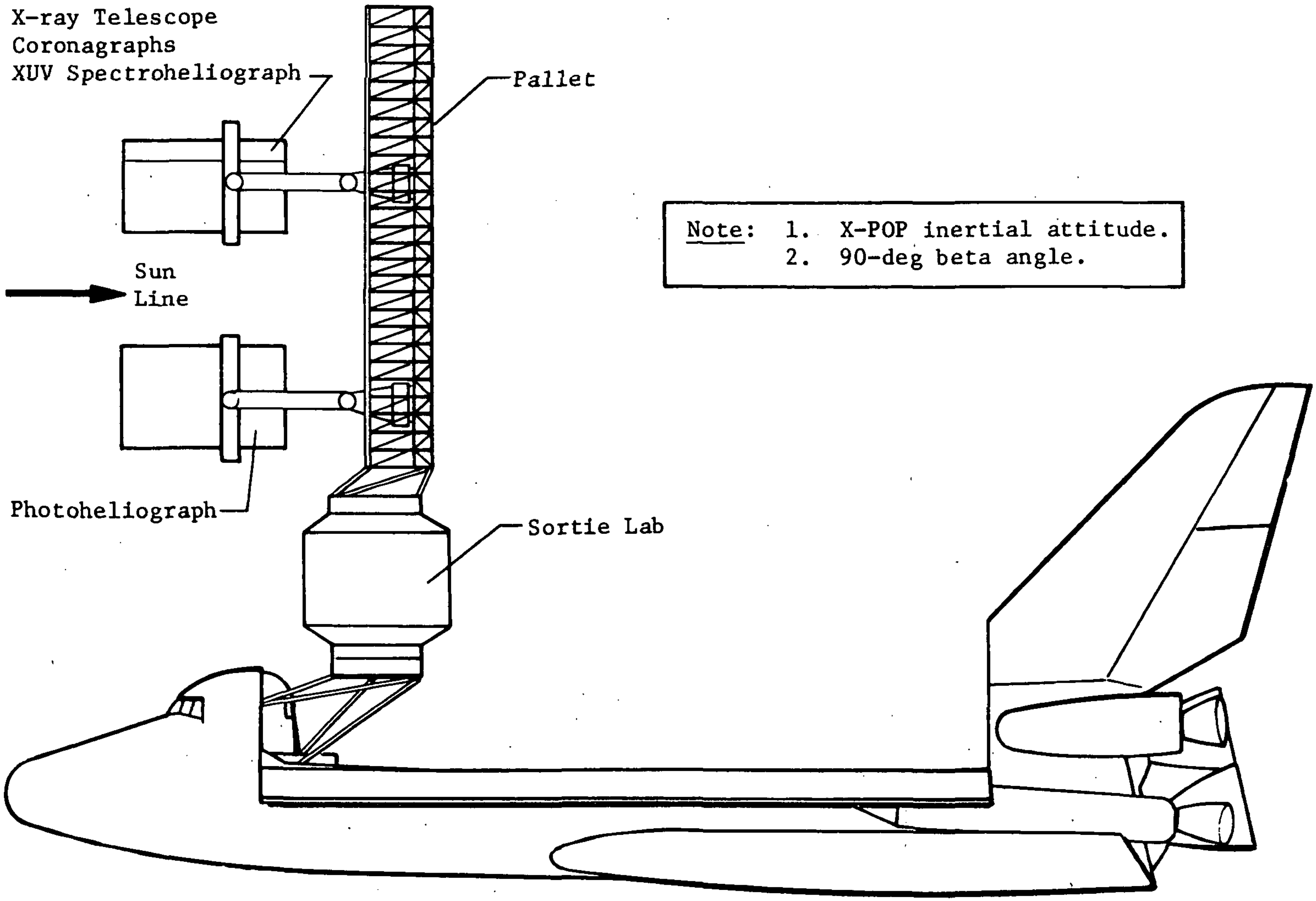

Fig. VIII-3 Solar Payload Configuration

Note: 1. X-POP inertial attitude.
2. Wide-angle gimbals provide hemispherical coverage.

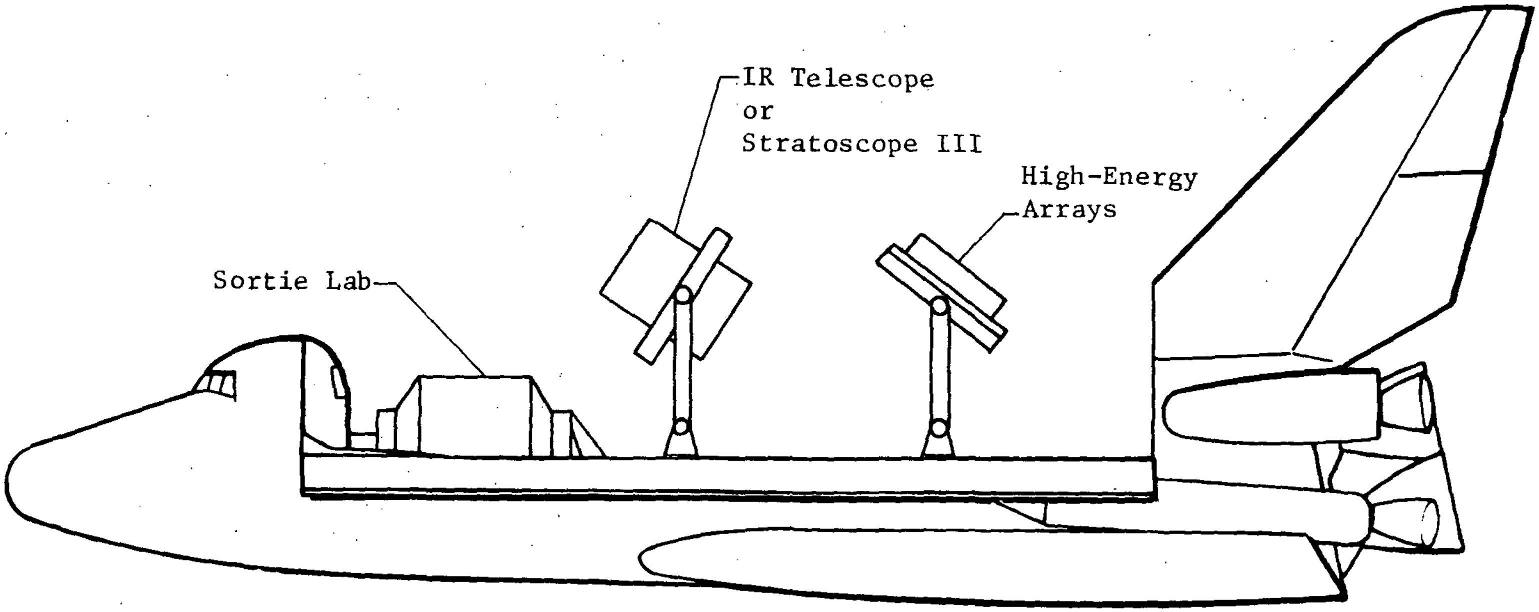

Fig. VIII-4 Stellar Payloads Configuration

Table VIII-1 Baseline Payload Combinations

Experiment Groups \ Payloads	Solar Payloads	Stratoscope III Payloads				IR Payloads			
	1-2	3AB	3AC	3AD	3AE	4AB	4AC	4AD	4AE
<u>Telescope Groups</u>									
1. PHG	X								
2. XUV SHG + X-Ray + Coronagraphs	X								
3. Stratoscope III		X	X	X	X				
4. IR Telescope						X	X	X	X
<u>Array Groups</u>									
A. Wide Coverage X-Ray		X	X	X	X	X	X	X	X
B. Narrow Band Spectrometer/Polarimeter		X				X			
C. γ-Ray Spectrometer + Low Background γ-Ray Detector			X				X		
D. Large Modulation Collimator				X				X	
E. Large Area X-Ray Detector + Collimated Plane Crystal Spectrometer					X				X

PHG = 100-cm photoheliograph.
XUV SHG = 25-cm XUV Spectroheliograph.
X-Ray = 32-cm X-Ray Telescope.

Note: Combinations are based on the 2.26 m (84 in.) inside diameter telescope mounting tube adopted for remainder of study.

Table VIII-2 Baseline Flight Schedule

Payload		Calendar Year												
		79	80	81	82	83	84	85	86	87	88	89	90	Total
Solar 1-2		X	XX	XXX	XXX	XXX	XX	XX	XX	XX	XX	XX	XX	26
Strato-scope III	3AB				X		X	X		X	X	X		6
	3AC						X	X	X		X	X	X	6
	3AD					X	X		X	X	X		X	6
	3AE					X		X	X	X		X	X	6
IR	4AB		X		X	X		X	X		X	X	X	8
	4AC	X			X	X	X		X	X	X		X	8
	4AD			X	X		X	X		X	X	X	X	8
	4AE			X		X	X	X	X	X		X		7
Total		2	3	5	7	8	8	8	8	8	8	8	8	81

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