FINAL REPORT

# GLASS SAMPLE PREPARATION AND PERFORMANCE INVESTIGATIONS

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# 1. ABSTRACT

This final report details the work performed under this delivery order from April 1991 through April 1992. The currently available capabilities for integrated optical performance modeling at MSFC for large and complex systems such as AXAF were investigated. The Integrated Structural Modeling (ISM) program developed by Boeing for US Air Force was obtained and installed on two DECstations 5000 at MSFC. The structural, thermal and optical analysis programs available in ISM were evaluated. As part of the optomechanical engineering activities, technical support was provided in the design of support structure, mirror assembly, filter wheel assembly and material selection for the Solar X-ray Imager (SXI) program.

As part of the fabrication activities, a large number of zerodur glass samples were prepared in different sizes and shapes for acid etching, coating and polishing experiments to characterize the subsurface damage and stresses produced by the grinding and polishing operations. Various optical components for AXAF video microscope and the x-ray test facility were also fabricated. A number of glass fabrication and test instruments such a scatter plate interferometer, a gravity feed saw and some phenolic cutting blades were fabricated, integrated and tested.

## 2. INTRODUCTION

The work performed under this delivery order by the Center for Applied Optics (CAO) at the University of Alabama in Huntsville for the Optical Systems Branch of Marshall Space Flight Center (MSFC) covers a number of analysis, design, fabrication, integration and testing tasks. The analysis work included the investigations into the development of an integrated optical performance modeling capability at MSFC. This performance model will take into account the effects of structural and thermal distortions, as well the metrology errors in optical surfaces to predict the performance of a large and complex optical systems such as Advanced X-ray Astrophysics Facility (AXAF). The purpose of this effort was to investigate the feasibility of automatically linking the structural, thermal and optical analysis programs so that the system performance can be predicted accurately with a minimum labor.

The MSFC has been awarded a contract by NOAA to design and fabricate a Solar X-ray Imager (SXI) to fly on a GOES satellite to photograph such solar features as flares, loops and coronal holes. The entire instrument will be designed, analyzed, fabricated and tested at MSFC. The CAO/UAH worked very closely with the Optical Systems Branch during the preliminary design/cost estimate phase (Phase A) in the areas of mirror assembly, material trade-offs for the structure and filter wheel assembly.

Another major effort under this delivery order was the fabrication of a large number of controlled glass samples for coating, strength and subsurface damage experiments in support of AXAF programs. The results of grinding, acid etching and polishing techniques used in the preparation of these glass samples will be used to define the fabrication processes for the full scale AXAF mirrors. The CAO/UAH also provided the manpower and technical expertise to enhance the fabrication and test capabilities at the MSFC Optics shop. This effort included the development and evaluation of new glass machining tools and various test instruments to check the surface figure of the optics fabricated at the shop. The details of the work performed on these tasks are given in the following sections.

## 3. INTEGRATED PERFORMANCE MODELING

The high resolution mirror assembly of AXAF shown in figure 1, consists of six pairs of nested cylinderical mirrors. Each of these 12 mirrors is supported at its center of gravity by up to 16 flat blade flexures made out of invar to match the CTE of zerodur. The final mirror assembly will be subjected to several distortions including the gravity induced figure changes, thermal distortions, and metrology errors during fabrication. The effects of x-ray source size, alignment, baffle system, mirror surface contamination and the detector system must all be taken into account to predict the image quality accurately.

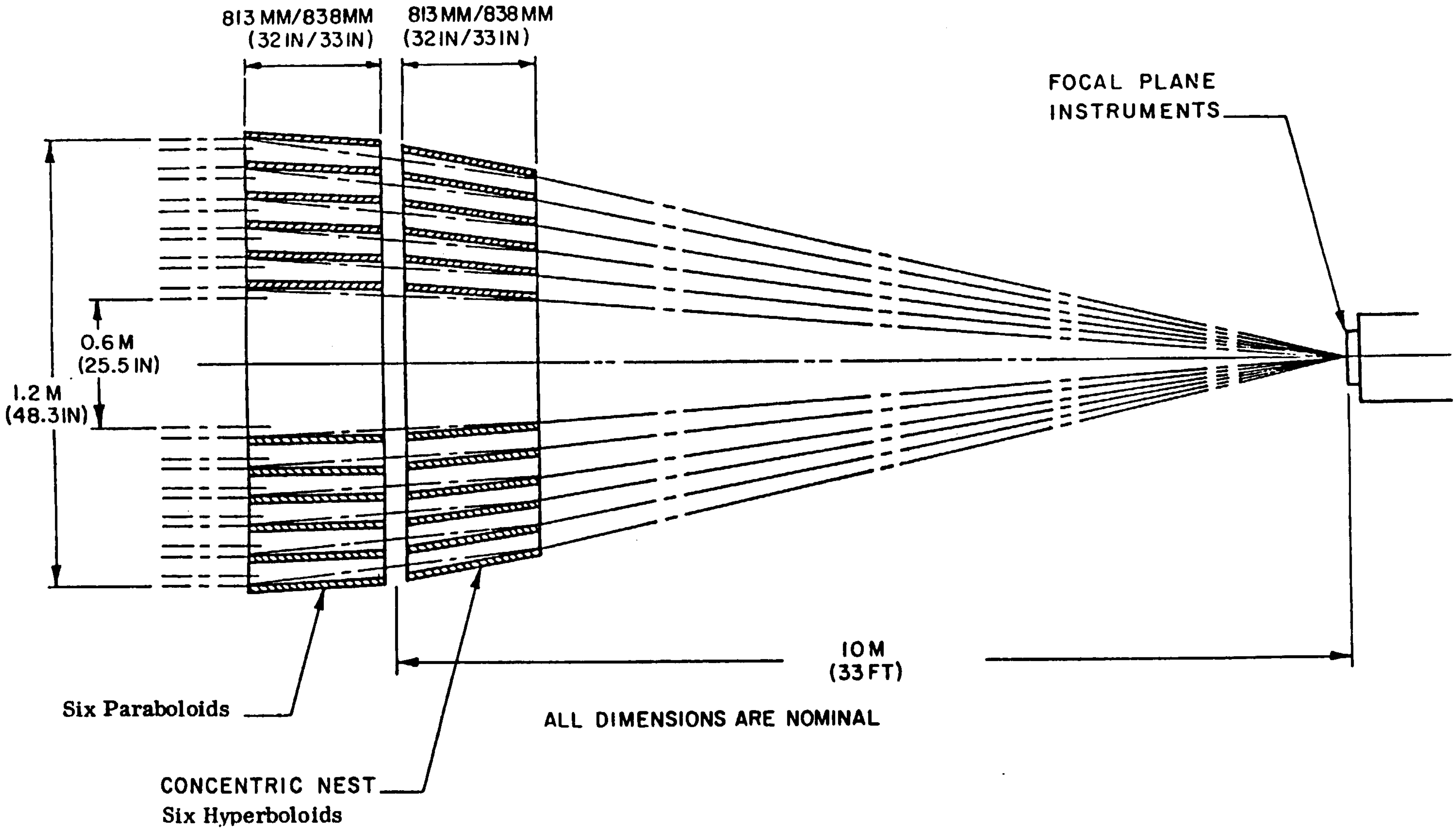


**FIGURE 1. AXAF MIRROR ASSEMBLY**

All structural, thermal and optical analysis work at MSFC is being performed with stand-alone software such as ANSYS, SINDA, OSAC, EEGRAZ, etc. The data input to all this software is manual, and is therefore, very cumbersome and error prone for large and complex optical instruments such as AXAF. Also, the output data formats from these programs are not compatible, so the results from one program can not be input directly into other programs. Moreover, no method is currently available to determine the cumulative effects of structural and thermal distortions, optical and metrology errors on the overall performance of an optical system. Therefore, it is essential to develop an integrated modeling software to predict the effects of these various errors on the image quality. This capability will potentially result in considerable manpower savings, and more accurate performance predictions when analyzing large and complex optical systems like AXAF.

The Integrated Structural Modeling (ISM) software obtained from Boeing was installed on two DECstations 5000 at MSFC. The first step was to learn to use ISM for the thermal and structural modeling of optical systems. The ISM has the capability for an automatic data file exchange between NASTRAN and SINDA. The manuals provided by Boeing were studied to become familiar with FEMNET (Finite Element Model to Nodal NETwork model). This program allows the use of a finite element modeler such as PATRAN or SUPERTAB to create a mesh that can be translated to a finite difference model for SINDA. Therefore, FEMNET offers a considerable time-saving in thermal model preparation by automating the creation of thermal conductors and capacitors.

Later on, this effort was discontinued due to some serious limitations with ISM software. It was discovered that the Beta release version of ISM did not have any optical analysis software package that could be used for AXAF type of grazing incidence optics. The ISM only provided an automatic link between thermal and structural codes. The technical staff at the Optical Systems branch decided that instead of using ISM, it may be better to develop new linking and translation codes for the structural analysis code (ANSYS) and the optical analysis code (EEGRAZ) on a Sun workstation. Later on, the development work on ISM at Boeing was also discontinued due to funding cut-backs. During the next phase of this program, automatic software links will be developed to take into account the mirror metrology errors and other effects also.

## 4. OPTOMECHANICAL SUPPORT FOR SOLAR X-RAY IMAGER (SXI)

The SXI telescope shown in Figure 2, consists a cylindrical graphite epoxy tube with a diameter of 9.5" and 30" long. The weight of the telescope is estimated to be 24 lb. The major parts of the telescope are an x-ray mirror assembly with an aperture plate at one end, and a filter wheel and a detector/camera assembly at the other end. The telescope will be insulated with MLI, and all uninsulated external surfaces such as the

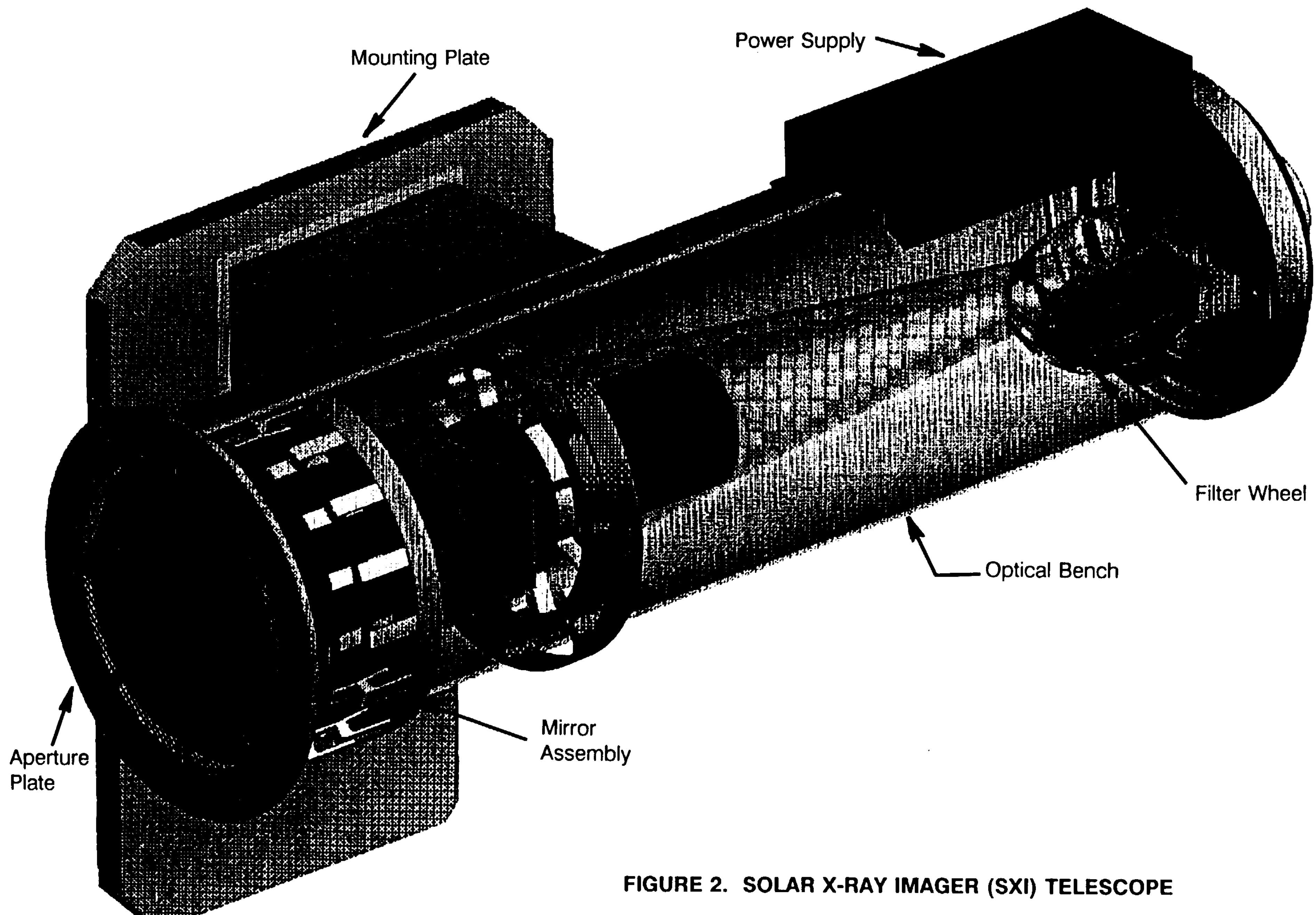


**FIGURE 2. SOLAR X-RAY IMAGER (SXI) TELESCOPE**

front aperture plate are painted white with Z93 paint. The CAO/UAH provided technical support to MSFC in the areas of materials selection and mechanical design of mirror assembly and other major components as briefly described below. The details of SXI structural design are given in Appendix A.

## 4.1 MATERIALS SELECTION

A trade-off study was performed to select an optimum material for the optical bench and other components to achieve maximum strength and focal stability at a minimum weight. A number of materials including aluminum, beryllium, metal matrix composite (MMC), titanium and graphite epoxy composite (GREP) were considered. The materials trade study indicated that the best candidate materials for the structure are graphite epoxy (GREP) composite, metal matrix composite (MMC) and aluminum. The GREP and MMC do not require active thermal control system to maintain focus. The final choice was based on other factors also such as the fabrication cost and outgassing characteristics. The results of this trade study are summarized in Table 4.1.

The GREP cylinder was selected for the baseline design because of its low weight and it does not require an active thermal control system to maintain the focal length, and it can be fabricated at MSFC. The NASTRAN analysis predicted a self-weight deflection of 0.004" for 3mm thick GREP tube. The thermal analysis took into account the effects of MLI blanket, front aperture plate and satellite interface. The temperature gradient between front to back is very strongly dependent on how the front aperture plate will be mounted to the tube. The analysis indicated that the structure will maintain focal length with a passive thermal control system.

It was recommended that the metal matrix composite truss still be evaluated as a backup.The MMC will be obtained to evaluate its machining characteristics at MSFC shops. A number of tests are also planned for GREP to determine the optimum fiber layup and the resin, and to determine the most effective coating to minimize the outgassing problems. A preliminary list of the materials selected for the major components is shown in Table 4.2, and the weights of major components are shown in Table 4.3.

## 4.2 SXI MIRROR ASSEMBLY

The SXI mirror assembly will consist of a zerodur mirror mounted in a suitable metal ring as shown in Figure 3. The interface between the mirror and its support ring will be designed to minimize the mirror distortion due to environmental effects such as gravity, temperature variations, shock and vibrations during shipping, handling and launch. The metal ring will have a 3-point kinematic assembly interface to the graphite epoxy optical bench (tube) to permit a strain free attachment and a convenient disassembly and an accurate reassembly without misalignment.

# TABLE 4.1

## MATERIAL TRADE STUDY

| MATERIAL | DENSITY LBS/IN^3 (WEIGHT) | MODULAS OF ELASTICITY 10^6 PSI | SPECIFIC MODULAS IN 10^6 | THERMAL CONDUCTIVITY BTU/FT HR F | COEFF. OF THERMAL EXPANSION 10^-6/F | ADVANTAGES | DISADVANTAGES | COST | FABRICATION |
|---|---|---|---|---|---|---|---|---|---|
| GRAPHITE-EPOXY CONE/CYLINDER | 0.055 (~4.5 LBS) | 33 | 600 | 6 | 0.1 | o NO THERMAL CONTROL REQ<br>o LOW DENSITY<br>o LOW CTE | o COATING REQUIRED<br>o GALVANIC PROBLEM<br>o CHARACTERIZATION REQUIRED | MODERATE | o IN-HOUSE |
| ALUMINUM TRUSS (NO SKIN) AL (2219) | 0.103 (~4.5 LBS) | 10.6 | 102 | 70 | 11 | o GOOD DATA BASE<br>o EASY TO MACHINE | o REQUIRES ACTIVE THERMAL CONTROL | LOW | o PURCHASE ROD<br>o ASSEMBLE IN-HOUSE |
| METAL MATRIX COMPOSITE TRUSS | 0.089 (~4.0 LBS) | 44 | 494 | 170 | 0.5 | o WELDABLE<br>o LOW CTE<br>o NO THERMAL CONTROL REQ | o NEW ON MARKET<br>o CHARACTERIZATION REQUIRED | HIGH | o PURCHASE ROD<br>o ASSEMBLE IN-HOUSE |
| TITANIUM 6A1-4V TRUSS | 0.16 (~6.0 LBS) | 16.4 | 102 | 12 | 4.8 | o LOW CTE<br>o STRENGTH | o HARD TO MACHINE<br>o REQUIRES ACTIVE THERMAL CONTROL<br>o REQ. SPECIAL TOOL | MODERATE | o IN-HOUSE |
| SILICON CARBIDE CONE/CYLINDER | 0.116 (~7.5 LBS) | 64.5 | 556 | 72.6 | 1.8 | o THERMAL INSULATOR<br>o LOW CTE | o BRITTLE<br>o REQUIRES ACTIVE THERMAL CONTROL<br>o CHARACTERIZATION | HIGH | o OUT-OF-HOUSE |
| BERYLLIUM TRUSS | 0.067 (~3.5 LBS) | 44 | 656 | 100 | 6.4 | o LOW DENSITY<br>o LOW CTE | o REQUIRES ACTIVE THERMAL CONTROL<br>o TOXIC | MODERATE | o OUT-OF-HOUSE |
| ALUMINUM-LITHIUM Al-LI 8090 TRUSS | 0.092 (~4.0 LBS) | 11.2 | 121 | 50 | 11.9 | o LOW DENSITY | o REQUIRES ACTIVE THERMAL CONTROL<br>o NEW ON MARKET<br>o CHARACTERIZATION | MODERATE | o PURCHASE ROD<br>o ASSEMBLE INHOUSE |
| MAGNESIUM TRUSS | 0.064 (~3.5 LBS) | 6.5 | 101 | 45 | 16 | o LOW DENSITY | o REQUIRES ACTIVE THERMAL CONTROL | MODERATE | o OUT-OF-HOUSE |

## TABLE 4.2

## BASELINE COMPONENT/MATERIALS LIST

| COMPONENT | MATERIAL |
|---|---|
| Aperture Plate Assembly | |
| Aperture Plate | Aluminum 6061-T6 |
| Pre-Filters | Aluminum Nickel Mesh |
| Optical Bench | Graphite Epoxy |
| Rear Flange | Titanium Ti-6Al-4v |
| Detector Housing Assembly | |
| Detector Housing | Aluminum 6061-T6 or Steel |
| Detector Housing Door | Aluminum 6061-T6 or Steel |
| Spacer | Aluminum 6061-T6 |
| MCP/CCD | |
| Main Support Assembly | |
| Rear Plate | Aluminum 6061-T6 |
| Top/Bottom Plate | Aluminum 6061-T6 |
| Side Plate | Aluminum 6061-T6 |
| Saddle | Titanium Ti-6Al-4V |
| Mirror Assembly | |
| Mirror | Zerodur glass ceramic |
| Mirror Mount | Titanium or Graphite Epoxy |
| Filter Wheel Assembly | |
| Filter Wheel | Beryllium/Magnesium |

## TABLE 4.3

## MASS PROPERTIES

| TELESCOPE COMPONENT | WEIGHT lb | WEIGHT kg | SOURCE |
|---|---|---|---|
| Graphite Epoxy | 3.47 | 1.572 | Calculated |
| Rear Mounting Flange | 1.62 | 0.735 | Calculated |
| Spacer | 0.21 | 0.096 | Calculated |
| Detector Housing Flange | 0.58 | 0.264 | Calculated |
| Detector Housing | 0.26 | 0.117 | Calculated |
| Detector Door Mechanism | 0.50 | 0.227 | Estimate |
| EUV Inner Support Ring | 0.17 | 0.076 | Calculated |
| EUV Outer Support Ring | 1.27 | 0.575 | Calculated |
| Aperture Plate | 0.47 | 0.211 | Calculated |
| Fasteners | 0.50 | 0.227 | Estimate |
| EUV Support Brackets | 0.03 | 0.012 | Calculated |
| Pre-Filter for Aperture Plate | 0.03 | 0.014 | Calculated |
| EUV Assembly | 3.00 | 1.361 | Specification |
| Mirror | 5.81 | 2.635 | Specification |
| Mirror Support Clips | 0.19 | 0.085 | Calculated |
| Mirror Support Ring | 0.57 | 0.258 | Calculated |
| Ion Pump | 0.42 | 0.191 | Estimate |
| MLI | 1.60 | 0.726 | Calculated |
| Filter Wheel/Motor | 1.50 | 0.680 | Estimate |
| Main Support | 0.94 | 0.424 | Calculated |
| MCP/CCD | 0.50 | 0.227 | Estimate |
| High Voltage Power Supply | 1.00 | 0.454 | Estimate |
| Totals | 24.64 | 11.167 | |

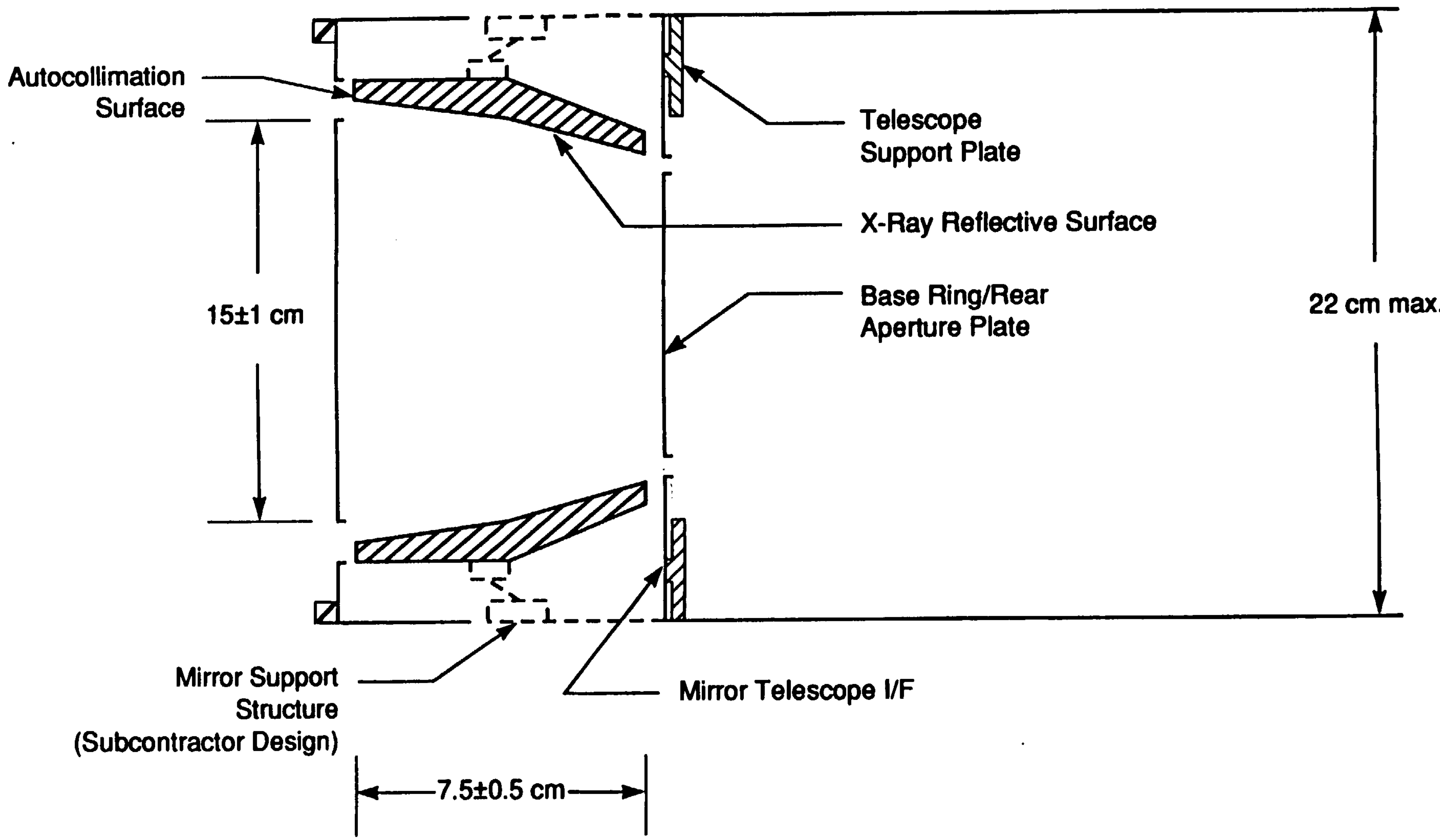


FIGURE 3. SXI MIRROR ASSEMBLY SCHEMATIC

### Flexure Design

A number of concepts have been investigated in detail for mounting the mirrors in AXAF and SXT programs. These concepts include mounting the mirror to a single ring at its axial center of gravity, or mounting the mirror at each end via flexures. The AXAF design uses multiple tangential flexures to support each mirror at its axial centroid. The flexures are bonded to the mirror using superinvar pads and a thin epoxy joint. The number of flexures needed and the size of the blades are determined by the size of the mirror, and self-weight distortion, resonance and thermal strain requirements.

The SXT mirror was supported at its axial centroid in a titanium ring by six equally spaced flexible fingers. The interface with the mirror was through superinvar pads, which were bonded to the mirror and the fingers. The AXAF and SXT mount designs will both be evaluated for SXI, and the design which meets the SXI performance specifications (optical, structural and thermal) will be selected.

### Epoxy Bonding

The proper sizing of the bond area between the mirror and invar pad is also critical. It must be large enough to prevent creep, debonding and localized fracture of the glass under handling and launch loads. However, a very large bond area will affect the thermal sensitivity of the mirror due to relatively large CTE's of epoxies ( ~ 60 ppm/°C) as compared to those of zerodur and invar ( ~1 ppm/°C).

The shear, peel and shrinkage characteristics of a number of glass to metal epoxies have been investigated for the AXAF and SXT programs. These epoxies include Hysol 9313, Eccobond 55, Scotch-weld EC 2216A/B and glass-filled epoxies. An epoxy, which provides optimum strength, shrinkage and outgassing properties will be selected for bonding the invar pads to SXI mirror. The bond strength and integrity is also dependent on how well the bonding metal and glass surfaces are cleaned and prepared. This process will involve acid etching and cleaning the surfaces with proper solvents such as acetone, alcohol and deionized water.

### Mounting Ring

The mirror mounting ring will provide the main structural interface with the optical bench of the telescope. As mentioned earlier, this interface will be of a 3-point kinematic type to facilitate the assembly and disassembly of the mirror assembly from the structure of the telescope. The three interface pads on the ring will be lapped coplanar, and must be orthogonal to the optical axis of the mirror. The ring must be made from a strong, stable, and a low CTE material that can be precision machined to achieve the required assembly tolerances. Titanium (Ti-6AL-4V) and Beryllium are the two possible materials for this application. The final choice will be based on cost, weight, machinability and structural properties of the material.

**Thermal and Structural Considerations**

Extensive finite element analysis will be performed on the mirror assembly to ensure that it meets survival and operating performance criteria. The size and shape of the mounting ring, flexures, invar pads and the mirror wall thickness will be optimized based on the results of these analyses. The mirror assembly envelope is limited to 22 cm diameter x 13 cm axial length. The weight budget for this assembly is 3 kg with a goal of 2 kg. Therefore, an extensive analysis will be performed to achieve a resonant frequency of above 200 hz, and to provide adequate safety margins for the stresses due to launch loads and temperature changes in storage and orbit within the size and weight constraints. These analysis results will be verified by the impact and full spectrum shake tests to demonstrate the survivability under launch loads.

## 5. PREPARATION OF GLASS SAMPLES

The CAO/UAH staff performed and assisted in a number activities in the Optics shop including the fabrication of hundreds of glass samples, setup of new glass fabrication equipment and the integration of various types of glass cutting and test equipment. These activities are described here briefly.

The glass fabrication activities involved the fabrication of 1"x 1" x 6" synchtron bars for SAO for the x-ray measurements at grazing incidence angles. These bars were finished to the specifications except for surface roughness, which was slightly above the specification. Also a gate valve window for AXAF alignment chamber was fabricated. The window was tested under vacuum for wave front errors, and all parameters were found to be better than the specifications. The transmission of this window was measured after coating. The transmission averaged 96.5% at 632.8 nm, as compared to the designed value of 98%.

A number of optical components for the AXAF video microscope were also fabricated. These included a 146x89x6.4 mm viewing mirror, four 6x9x1 mm mirrors, four 6x6x1 mm mirrors (made from microscope slides) and an elliptical mirror with a major diameter of 24 mm.

A scatter plate interferometer was assembled to measure the polished optical surfaces. UAH trained some Marshall employees in the procedure for exposing and processing the scatter plates. A folded path set up was used to measure an f/6 spherical concave mirror with the scatter plate interferometer. The fringe pattern was photographed to determine the type and magnitude of the error. The processing of high resolution film used for scatter plates was tested in depth, and a better quality was obtained. Some attempts were made to photograph the interferometer fringe patterns, and it was found to be more complex than expected.

A 13" dia x 1" thick BK7 window was also fabricated. The surface figure requirement was 8 fringes p-v power, 1 fringe irregular over the entire aperture, and 1 fringe p-v power and 0.25 fringe irregular over a 3.8" diameter sub-aperture. The specified wavelength was 589 nm, and the scratch/dig tolerance was 80/40.

A mold for making the glass cutting blade was designed, machined and assembled. A number of blades were molded with silicon carbide powder in a phenolic material. The results of this effort were not very successful, and this effort will be continued in the next phase of the contract.

A gravity feed saw for cutting various types of crystalline materials was also designed, fabricated and tested. A number of modifications were made to improve the clamping of the materials, and to use various size blades. Several pieces of MgF were sawed off with very encouraging results. This saw will also be used to "dry" saw KDP material. A number of tests and improvements are planned for this saw in the next phase. A picture of this saw is shown in Figure 4.

The glass sample preparation activity included the fabrication of 100 zerodur coating samples for TRW. These 3"x4"x.075" thick flats were taken through a controlled grind and polish. The surface figure requirements were 0.5 wave p-v, and 5 Å rms or less roughness. Some 3" x 4" x 0.5" zerodur samples for SAO were also fabricated. The figure requirement was $\lambda/2$ p-v, and 5 Å rms surface finish. Various steps in the preparation of these samples are shown in Figures 5 through 8.

Over 200 zerodur samples zerodur samples (60mm dia x 6mm thick) were processed through controlled grinding and polishing, and delivered to the Materials Lab at MSFC for bend and break tests for material strength evaluation. These samples were polished to a roughness of 5 Å rms.

Other support activities included the installation of a new Tub grinder and polishing of the new grinding laps. A new curve generator was also installed in the optical shop.

## 6. CONCLUSIONS

The tasks identified in the scope of work for this delivery order have been successfully completed. The hardware and software required for the development of an integrated optical performance model was identified. After a careful investigation into the current modeling capabilities at MSFC and the AXAF contractors, it was decided to evaluate the ISM code developed by USAF Weapons Lab installed on a DECstation 5000. The evaluation process indicated that ISM was not suitable for the AXAF modeling work, and it was decided to develop our own modeling software during the next phase.

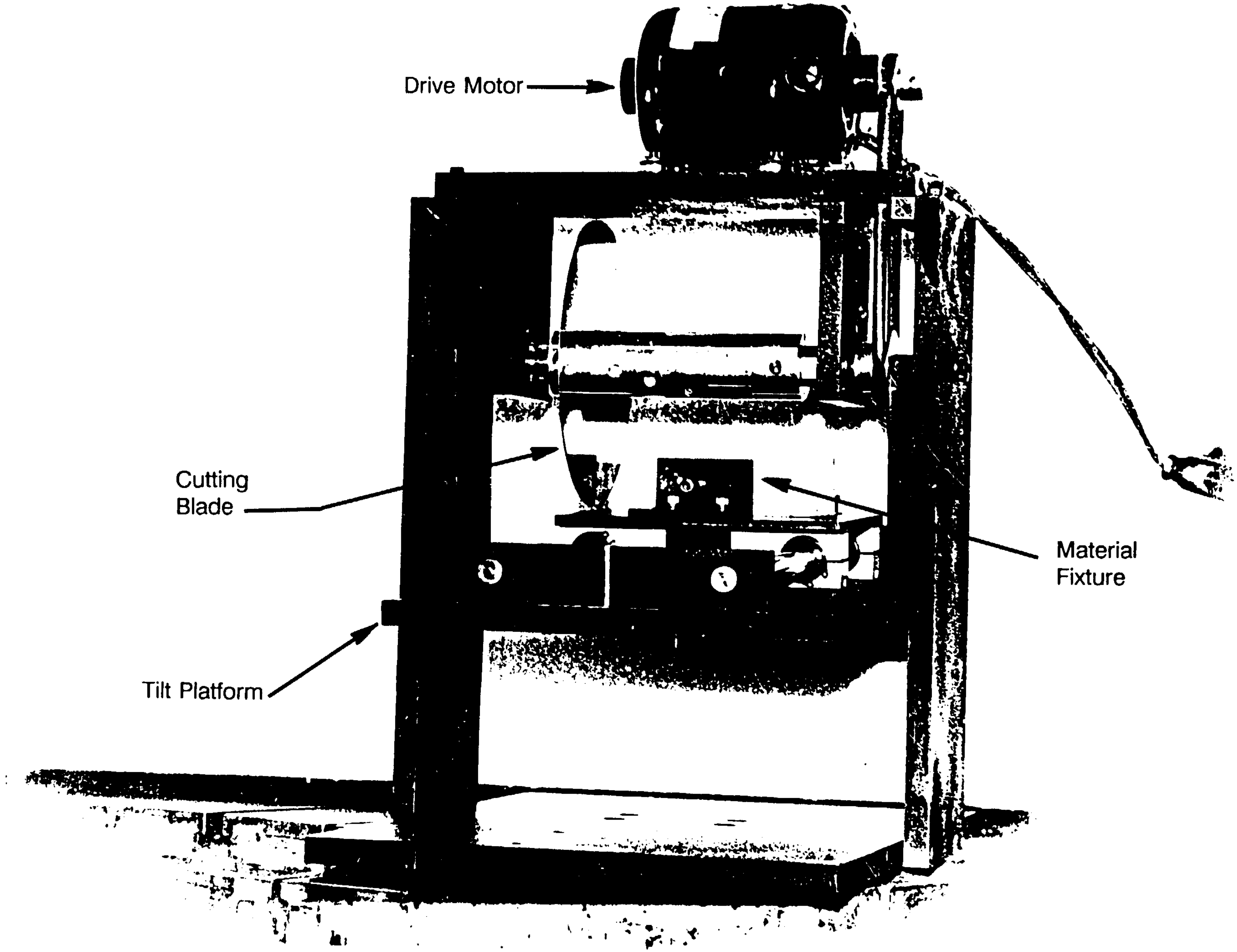


FIGURE 4. GRAVITY FEED SAW

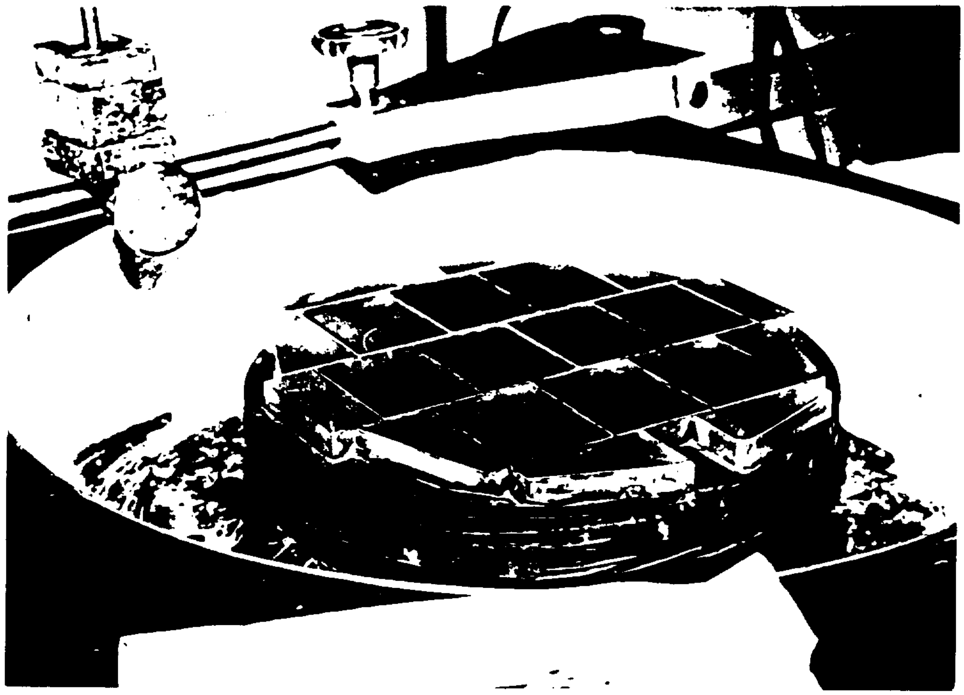

Figure 5: Blocking of 3"x4" zerodur samples for grinding

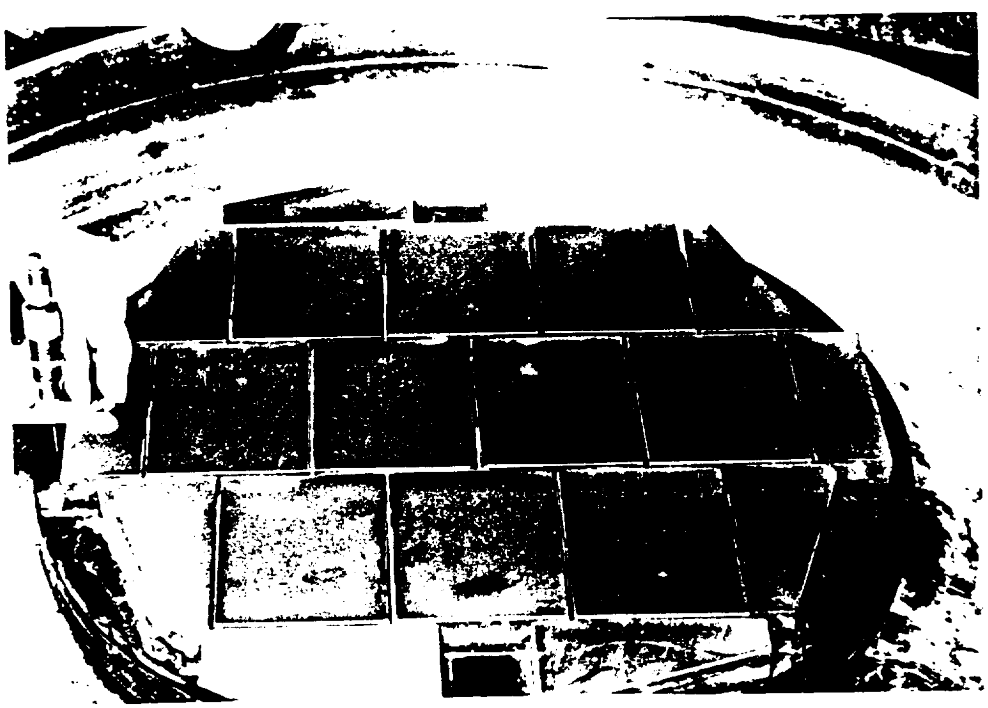

Figure 6: Measurement of material removal for 3"x4" samples

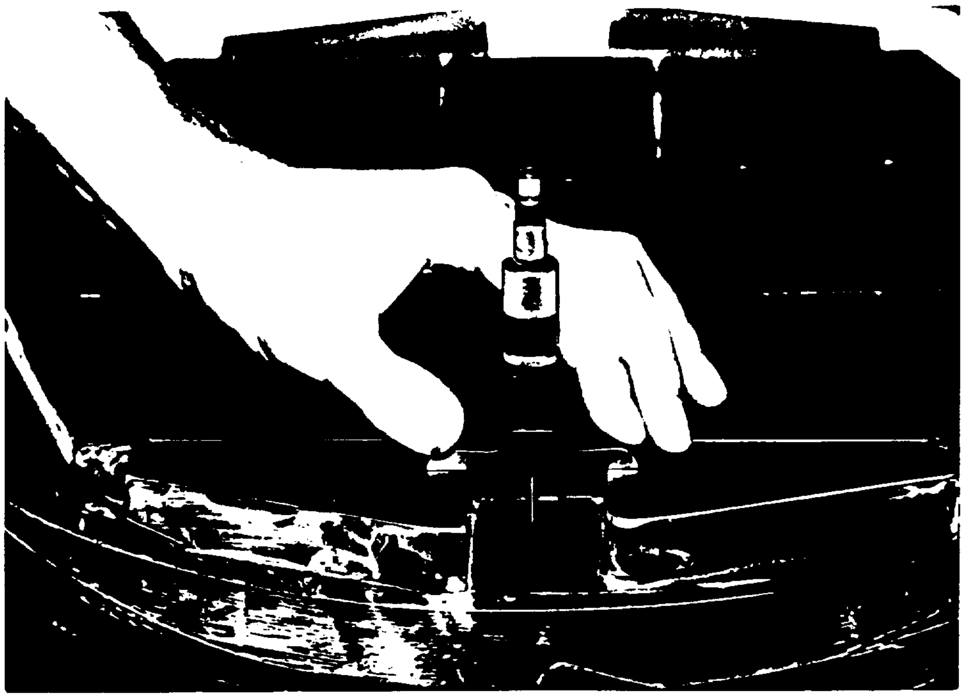

Figure 7: Thickness measurement of coating samples (3"x4" Zerodur)

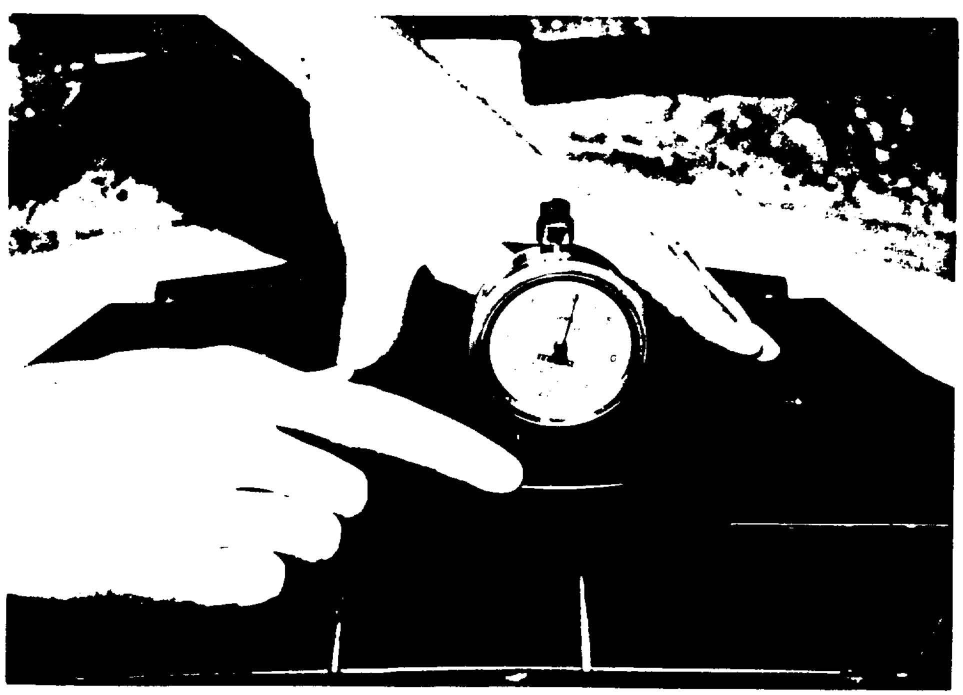

Figure 8: Flatness measurement of coating samples

The optomechanical engineering support was provided for the SXI program during the Phase A. This included the preliminary design of the optical bench, mirror assembly, filter wheel and the material selection for the major components.

The tasks accomplished in support of the Optics shop include the fabrication of AXAF video microscope components, a BK-7 gate valve window and synchtron bars for AXAF test activities. A scatter plate interferometer was also integrated and tested. A gravity feed saw for cutting crystalline materials was designed and successfully tested.

Finally, over 300 samples of zerodur were prepared in various sizes and shapes by cutting, grinding and polishing techniques. These samples were used at MSFC and outside contractors to study the effects of various manufacturing methods on the subsurface damage such as microscopic cracks, crevices and residual stresses. The results of these experiments will be used to select the optimum manufacturing methods and coating procedures for the full scale AXAF mirrors.

# APPENDIX A

# SOLAR X-RAY IMAGER (SXI) STRUCTURAL DESIGN

# SXI STRUCTURAL DESIGN

## 2.2.1 INSTRUMENT DESCRIPTION

The SXI telescope consists of a number of components whose locations are maintained through attachment to a graphite epoxy optical bench. The optical bench is supported by a saddle-shaped structure which mounts to the instrument mounting panel inside the gimbal on the yoke of the GOES satellite.

The major instrument components consist of an x-ray mirror, an aperture plate and pre-filter assembly located of the mirror, a filter wheel, and a detector/camera assembly located at a precise distance behind the mirror at its prime focus. The separation between the mirror and the detector and their co-alignment have to be maintained accurately if the telescope is to meet its performance requirements. In order to operate the telescope on the ground the detector has to be contained inside a vacuum box with a one-time door which opens on orbit. Any static or transient loadings, mechanical or thermal, that could affect the alignment and focus have to be assessed. However deviations from the required values is allowed during launch if the system returns to specification on-orbit.

## 2.2.2 DESIGN REQUIREMENTS

The major structural design requirements for the SXI instrument are the physical and structural constraints imposed by the satellite, launch loads, and the thermal environments in which the SXI must survive and operate. MSFC standards relating to structural strength, fracture control, fasteners, NDE, drawing standards, etc. shall be used in designing the instrument. The defined requirements are listed in the following three sections.

### 2.2.2.1 PHYSICAL CONSTRAINTS

Size: Envelope of cylindrical form with a diameter of 9.5 inches (24.1 cm) and a length of 30 inches (76.2 cm)

Weight: Telescope Assembly - 24.25 lb (11 Kg)
Electronics Assembly - 19.84 lb (9 Kg)

Center-of-Gravity: 18.9 inches (48.0 cm) maximum from the front of the telescope

### 2.2.2.2 STRUCTURAL CONSTRAINTS and LAUNCH LOADS

SXI will be designed to withstand the environments described in document SS|L-TR00750 A, Table 10.2-1. These include an acceleration of 15 g's in any direction and various specifications for vibration, acoustic noise and shock. The fix-based natural frequency design goal is above 100 Hz. SXI will not experience any deformations which will degrade its performance after exposure to these environments.

### 2.2.2.3 THERMAL ENVIRONMENT

During operations the SXI is always pointed at the Sun and variations in its thermal environment are largely controlled by its exposure to reflected sunlight from the spacecraft's south panel and the solar array/yoke interface. The maximum reflected sunlight occurs at the winter solstice when the solar arrays are inclined at an angle of 60° to the solar vector. This is identified as the hot case. The cold case occurs when the arrays are perpendicular to the solar vector. Under these circumstances eclipses, lasting up to 70 minutes are possible and these have to be taken into consideration.

Thermal variations have two main effects upon the SXI. First are the introduction of changes in shape and/or size arising from mismatches in the CTEs of the various materials used in the fabrication of the support structures etc. These can translate into changes in the focal length or if they are not azimuthally symmetric in distortions of the mirror through its support structure, resulting in image degradation. The second requirement is the maintenance of the electronic systems within their operational and/or survival temperature ranges.

The Thermal Control System (TCS) has been designed to meet these requirements passively through careful selection of materials, coatings, multi-layer insulation etc. The use of heaters has been considered only as a last resort but may be necessary during eclipses to keep certain critical components within the required temperature range.

## 2.2.3 DESIGN GOALS - MECHANICAL DESIGN

The primary goals for the mechanical design was to provide a stable focal length of 65.0 +/-. 01 cm, to keep the microchannel plate/charge couple device under vacuum conditions, and to allow for easy access and removal of the internal and external components without affecting the focal length calibration or the mirror/focal plane alignment.

The factors that affect alignment are thermal gradients in the optical bench, gravity, and loads occurring at the spacecraft interface. Loads at the spacecraft interface include bolt-up misalignment and thermal gradients in the spacecraft yoke.

## 2.2.4 CONCEPTUAL LAYOUT

The SXI conceptual Layout is shown in Figure 2-7. The telescope is housed in a graphite epoxy structure called the optical bench. The front section of the telescope contains the aperture plate/pre-filter assembly, the mirror and the EUV grating spectrometer. The aft section of the telescope contains the filter wheel assembly, and the MCP/CCD housed inside a vacuum chamber. In addition to the components within the optical bench, there are external components. They include the high voltage power supply for the MCP mounted to the optical bench at the aft end, the ion pump also mounted at the aft end, the electronic box mounted to the yoke, HASS sensor mounted to the instrument mounting panel, and the HASS electronic box mounted to the yoke. The telescope assembly and each external component is insulated with multi-layer insulation. Uninsulated external surfaces are painted white with Z93 paint.

### 2.2.4.1 OPTICAL BENCH

The optical bench must provide a stable, light weight, rigid mounting structure for the optical/mechanical components. It must also provide a light tight environment for the sensitive optics. Several materials were considered in baselining the optical bench. Material parameters such as density, elasticity, thermal conductivity, coefficient of thermal expansion, cost, and in-house capability were considered. The top three material choices were graphite epoxy composite, aluminum, and metal matrix composite. Each material has its own unique problems. The graphite epoxy absorbs water and outgasses water vapor under vacuum and would require an additional barrier coating, the aluminum is relatively heavy and would require an active thermal control system to maintain a precise focal length, and the metal matrix composite is higher cost, new on the market and would require extensive characterization testing. A filament wound graphite epoxy composite material was baselined for the optical bench for the following reasons:

1) low weight
2) No active thermal control system needed
3) Coating will eliminate risk of outgassing
4) Structure can be fabricated in-house.

The optical bench barrier coat will be applied using either a plasma spray technique or a vapor deposition technique. The metal matrix material is still being considered as an option. Samples of the material will be obtained early in Phase B to start characterization tests.

### 2.2.4.2 APERTURE PLATE

The aperture plate mounted in the front of the telescope is made of aluminum and will be painted with Z93 white paint to minimize heat absorption. One layer of prefilters are mounted to the aperture plate. The prefilters consist of thin aluminum films supported on 80% nickel mesh substrates. The aperture plate also supports the front end of the EUV spectrometer. During ground operations a protective cover will be manufactured to fit over the front of the telescope in order to protect the prefilters. This cover may be removed to perform functional tests and will be red tagged for removal prior to buttoning up the satellite.

### 2.2.4.3 EUV SPECTROMETER SUPPORT STRUCTURE

The EUV Spectrometer main support structure is located in the aft section of the instrument. A wagon wheel type structure is bonded to the outer case. This assembly is then bolted to a structure which is fastened to the optical bench. The Spectrometer assembly slides inside the mirror until the stops are reached on the optical bench structure. The assembly can then be rotated to align the bolt holes and bolted into place.

### 2.2.4.4 FILTER WHEEL ASSEMBLY

The filter wheel assembly is mounted to the detector housing flange directly in front of the focal plane in the aft section of the telescope. The wheel has 12 filters mounted to it and is driven by a single winding 12 position stepping motor with encoder. The availability of a suitable motor has been discussed with Shaeffer Magnetics of Chatsworth, CA. The filter wheel will carry the appropriate filter into position in front of the CCD camera, causing the x-ray path to pass through the filter. A failsafe mechanism will be incorporated in order to drive the filter wheel back to a preferred location in the event of motor failure. The 12 proposed filters are listed below:

| | | No. of Positions |
|---|---|---|
| Aluminized organic | | 4 |
| Beryllium | 12.7 micron | 2 |
| Beryllium | 25.4 micron | 1 |
| Beryllium | 50.8 micron | 1 |
| Indium | 1500 Å | 2 |
| Open | | 1 |
| Radiation Shield | | 1 |