CONTRACT NO. NAS 1-4105

NASA-CR-66122
GE DOCUMENT NO. 66SD4391

9.5-FOOT PARABOLOIDAL MASTER AND CONCENTRATOR

FINAL REPORT

Prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
LANGLEY RESEARCH CENTER
HAMPTON, VIRGINIA

CONTRACT NO. NAS 1-4105

NASA CR-66122
GE DOCUMENT NO. 66SD4391

9.5-FOOT PARABOLOIDAL MASTER AND CONCENTRATOR

FINAL REPORT

Prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
LANGLEY RESEARCH CENTER
HAMPTON, VIRGINIA
JUNE 30, 1966

G. L. YEO PROGRAM MANAGER

D. LEE PROJECT ENGINEER

GENERAL ELECTRIC
SPACECRAFT DEPARTMENT
A Department of the Missile and Space Division
Valley Forge Space Technology Center
P. O. Box 8555 • Philadelphia, Penna. 19101

BLANK PAGE

TABLE OF CONTENTS

APPENDIX

LIST OF ILLUSTRATIONS

LIST OF TABLES

ABSTRACT

Producing large high quality parabolic shapes by generally accepted cutting, grinding, hewing, and polishing methods consumes a considerable period of time and is quite expensive. Spincasting epoxy resins offers the immediate advantage of forming a theoretically perfect parabola which, when combined with the technique of electroforming, will produce excellent master tooling. The objective of this contract was to fabricate a 9.5 foot mirror master which would be of sufficient quality and durability for the reproduction of lightweight, high quality paraboloidal solar concentrators with the design objective of collector absorber efficiency of 75 percent of a 2000^{o} K black body cavity.

An epoxy spincasting was produced which had an adjusted slope error of less than 35 arc seconds. On this concave surface a 3/8 inch thick nickel master was electroformed which yielded a slope error of approximately 3 minutes.

A 9.5 foot nickel solar concentrator was then electroformed against the surface of the master. A nickel torus support ring was bonded to a transition cove ring located on the back of the mirror, after which the entire unit was successfully separated from the master.

The report discusses the various steps in the spincasting and electroforming processes as well as investigations into separation of mirror surfaces from masters using vacuum techniques and the improvement of nickel surfaces using Kanigen coatings. These investigations were conducted using a 30 inch nickel master and electroforming an aluminum mirror against the experimental surface.

BLANK PAGE

SECTION 1
OBJECTIVES AND SUMMARY

1.1 OBJECTIVES

The basic objective of contract NAS 1-4105 was to fabricate a 9-1/2 foot mirror master which would be of sufficient quality and durability for the reproduction of lightweight, high quality paraboloidal solar concentrators with the design objective of collector absorber efficiency of 75% of a 2000°K black body cavity. A 45-degree rim angle master and mirror was fabricated from a 10-foot epoxy spincasting so that the useable master area would produce mirrors 9-1/2 feet in diameter. The focal length was established at 68.8 inches.

The program was broken into three logical phases which permitted a review of progress and an opportunity for acceptance or rejection before expending additional funds. These phases were:

a. Phase 1

1. Refurbish a Government furnished mold backup structure.
2. Spincast a female mold master.
3. Perform optical inspection of the spincast female mold master.
4. Design and fabricate a male backup structure.

b. Phase 2

1. Electroform a nickel parabaloidal male master.
2. Design and fabricate a concentrator support structure.

c. Phase 3

1. Electroform nickel concentrator.
2. Optically inspect concentrator.
3. Aluminize concentrator.

Subsequent additions to this contract called for the following:

a. Investigate improvement of nickel master surfaces (Kanigen coating).
b. Investigate master concentrator separation problems.
c. Electroform a 30-inch diameter aluminum concentrator.
d. Optically inspect the 10-foot male master.
e. Investigate removal of warpage in the 10-foot male master.
f. Optically reinspect the male master following the experimental efforts of (e) above.

1.2 SUMMARY

In general, the objectives of the program were met. Technical problems did arise in the course of the contract, but were largely overcome. These are discussed in detail in the body of the report.

1.2.1 SPINCASTING

Three pours were planned for this phase. On the third pour, a leak developed in the pumping system after about one quart of epoxy was released, necessitating a shut down while repairs were effected. When the mold was opened, a minor line of optical distortion, five feet in diameter, was noted and it was determined that this was the result of the interrupted pour. It was mutually decided between General Electric and NASA-Langley that additional pours would be made in an effort to eliminate this slight imperfection. To reduce the possibility of cracking the epoxy due to excessive thickness, some of the epoxy from the earlier pours were removed by grinding, then additional pours were made. Visual inspection indicated the surface to be satisfactory and a thermal cure followed. Optical inspection was then performed providing raw and adjusted slope error information.

A major change was made in the mold cover over that used on JPL Contract No. 950239. 9. The cover was made of fiberglas fitted with large plexiglass viewing ports. It had, as an integral part, a receiving valve mechanism which improved the ease with which the epoxy could be poured and the mold could be sealed while it was spinning. In addition, it was light, rigid, and easily handled. To provide a shape which conformed to the surface of the mold (paraboloid), the cover was made using the spincast mold structure as a template. Two additional advantages of this design are: ease of inspection, and most important, a fixed height of the air space above the surface of the casting. This latter item has a significant effect on the surface quality of the epoxy and, thus, was optimized with the use of the conforming cover.

The backup structure for the electroformed nickel male master was fabricated during this period and was essentially the same as that used on the JPL contract (Reference 2-1). The basic change was the inclusion of a triangular steel structure to increase the strength of the assembly permitting higher loadings of the lift points.

1.2.2 ELECTROFORMED NICKEL MASTER

A major problem presented itself when the first attempt to electroform the nickel master failed after some 5-7 hours in the nickel solution. The failure manifested itself in a separation of the (2 to 5 mils) deposit of nickel from the epoxy mold and its subsequent breaking up under the agitation of the rotating anodes in the bath. In addition to the loss of the nickel skin, the surface of the spincast mold was badly gouged and scratched. Within a week following this failure, the epoxy cracked completely through, rendering it useless for any further consideration as a master. This was independent of the previous failure and was caused by thermal shock (sharp drop in room temperature).

A highly concentrated effort was then mounted to determine the cause of the failure (probable contamination of the bath by an unstable epoxy) and to evolve corrective action. This took the form of an epoxy formulation analysis and experimentation to eliminate the cause of the instability of the epoxy. Large numbers of samples were made and tested under a variety of environments including temperature, humidity, chemical exposure and electroforming conditions. Success was achieved and a new spincasting was made using only three pours. Optical inspection revealed an excellent configuration and the test samples indicated a relatively stable epoxy. The new mold was prepared for electroforming by stopping off exposed areas of the mold support, treating the edge of the epoxy with collodial silver to assure good current flow and then washing, sensitizing, and silvering the epoxy surface. Room and electroforming solution temperatures were brought up to 120°F. The mold was placed in the bath and electroforming of the master was completed without further incident. Approximately 20 days were required to obtain the 3/8-inch thick nickel master using an average current density of 20 amp/ft^2.

The fiberglass backup structure was foamed into place and separation of the master from the epoxy mold was effected by the technique of cold shocking and vibration. Visual inspection of the master indicated a very satisfactory product.

1.2.3 FEMALE CONCENTRATOR

Following acceptance of the master by NASA-Langley, the master was prepared for electroforming the mirror. This was accomplished by cleaning and polishing the master with french cotten, washing, flushing, and drying. It was then sensitized and silver sprayed. A copper cove ring was fitted to the surface at the scribe line and the center crown (grow-in ring) was secured with bakelite disc. The entire unit was then placed in the nickel sulfamate solution. Electroforming of the mirror was performed at 2200 amp or 27.5 amp/ft^2 for a period of 38 hours. Following an analysis of the mirror torus design, it was decided to fabricate a nickel torus ring similar to that made for the JPL concentrator (Reference 2-1), i.e., a rolled 3-1/2-inch diameter, 125 mil wall, nickel pipe. On this program, however, the unit was stress-relieved before it was epoxy bonded to the cove ring of the master to minimize the possibility of edge distortion. Separation of the master from the mirror was accomplished by cold shocking with relative ease. Three areas of localized distortion were noted which did not appear to be in the male master. These were pinpointed by the optical inspection. Mirror thickness measurements showed the average to be 0.037 inch or within 7% of design objectives.

The mirror was coated with vapor-deposited aluminum and SiO_2 and then shipped to Langley Research Center for evaluation. Because of distortions observed in the mirror produced from the master, it was decided that a complete optical inspection of the master should be made to determine how accurately the mirror duplicated the master. While small differences in comparative data were measured, the mirror in fact proved to be a true replica of the master.

An effort was then made to counter, or correct, the distortions in the master through the application of external forces to the master edge and backup structure. No permanent correction was introduced and only very small, highly localized improvements were made on a temporary basis.

1.3 ADDITIONAL TASKS

Three related tasks were also undertaken on this contract: the investigation of methods of improving nickel surfaces, examination of master/concentrator separation problems and the fabrication of an aluminum mirror from a nickel master. To accomplish this work, a 30-inch "scrap" master which had been Kanigen coated to reduce porosity, was machine and hand-polished, then placed in an aluminum electroform bath where a 30-inch concentrator was electroformed. Separation was accomplished by vacuum techniques. The overall results were encouraging in that an improvement in surface quality was noted and the vacuum separation technique showed promise.

BLANK PAGE

SECTION 2
EPOXY SPINCAST MASTER

The same mold used for the JPL spincasting was used for this contract. There were no structural changes made although refurbishing was required to prepare the surface for the epoxy.

A complete description of the backup structure is given in Reference 2-1, pages 5-1 through 5-6.

Two separate spincastings were made on this contract due to a failure of the first nickel master and subsequent loss of the epoxy mold. This section covers both spincast fabrications and the test program conducted in between.

2.1 MOLD STRUCTURE PREPARATION (Figure 2-1)

All spuncast plastic was removed from the backup spincast structure. This was accomplished by thermally shocking the backup structure with liquid nitrogen followed by chipping and grinding. The mold was sand blasted and cleaned and then painted on the outside with two coats of epoxy base stop-off paint. The first coat of the epoxy base paint was painted on in its clean undyed state. The second coat was colored with a dye to assure uniform coverage. The inner surface of the mold on the spincast area was painted with one coat of undyed epoxy paint. The purpose of the outer coating is purely to act as a stop-off against electrochemical attack while electroforming of the nickel master. The epoxy paint coat on the inner spincast surface acts as a bonding agent so that the spincast resin system will adhere. Formulation of the epoxy paint is as follows:

Resin source No. 571XK (75%), 45 parts by volume.
Pentamide No. 815, 35 parts by volume.

The epoxy paint was reduced with toluol to a brush coat consistency. The mold, after thorough curing, was then placed upon the spincast table where it was mated with its cover, checked for leak tightness, then the entire table, mold and cover assembly was statically balanced. The mold-cover-table assembly was then rotated and the total runout of the table adjusted so as not to exceed 0.002 inch.

2.2 NEW COVER DESIGN (Figure 2-2)

The cover used on the JPL contract was discarded in favor of a new design. It was fabricated of reinforced fiberglass polyester and was made using the spincast mold structure as a template.

This cover has, in each quadrant and in the center, a large plexiglass viewing window which allows visual observation of the resin flow patterns as the spincasting is being made. Included as an integral part of the cover is a receiving port and valving mechanism for the acceptance of the epoxy resin. A coating of the same epoxy paint that was applied to the mold was used on the cover as a sealant against any scale or foreign material contaminants.

The conforming nature of the cover provided a fixed height of air space above the casting, a condition which has a significant effect on the quality of the epoxy surface. Other advantages of this cover were its lightness, rigidness, and handling ease.

2.3 MALE BACKUP STRUCTURE (Figure 2-3)

It was decided to use a polyester fiberglas egg-crate backup structure very similar in design to that described in Reference 2-1, pages 6-8 through 6-12. The technique of construction and the load bearing metal inserts in the structure were changed, however. The same dimensional configuration was used with the exception that a triangular steel handling fixture was inset directly into the egg-crate structure then glass-bonded and foamed in place. This triangular inset was continuous so that every load point was connected with every other load point while picking-up all of the radial ribs of the egg-crate shell.

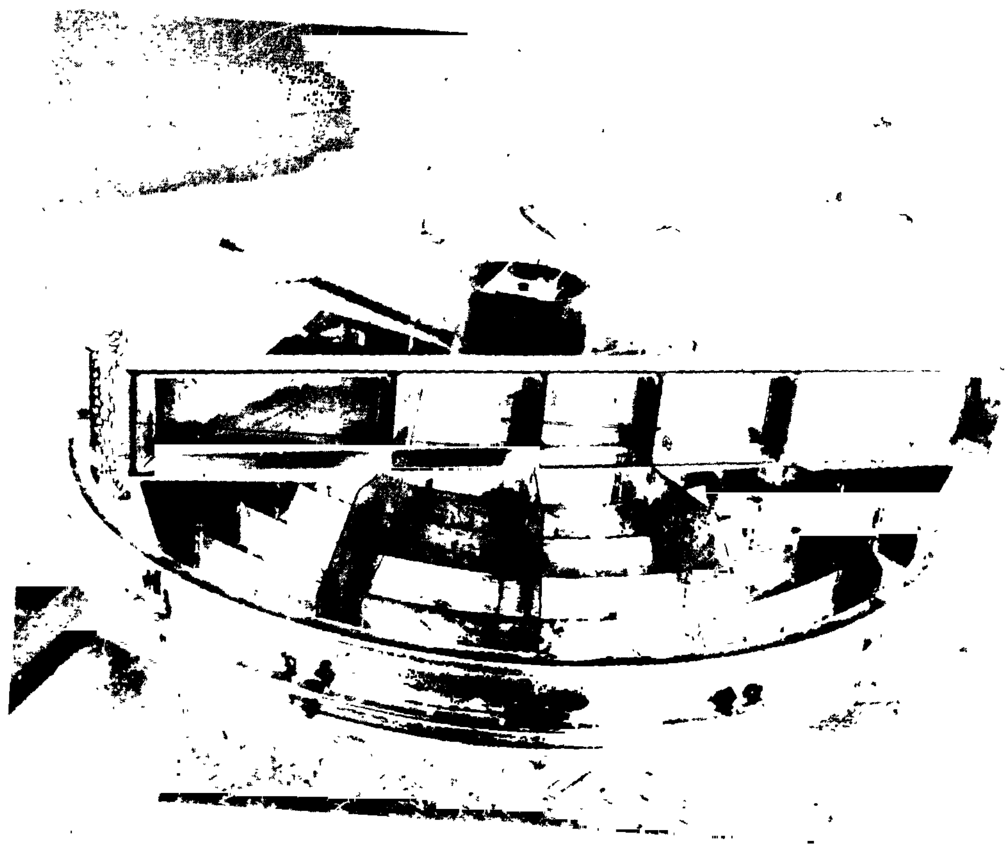


Figure 2-1. Spincast Mold Back-Up Structure

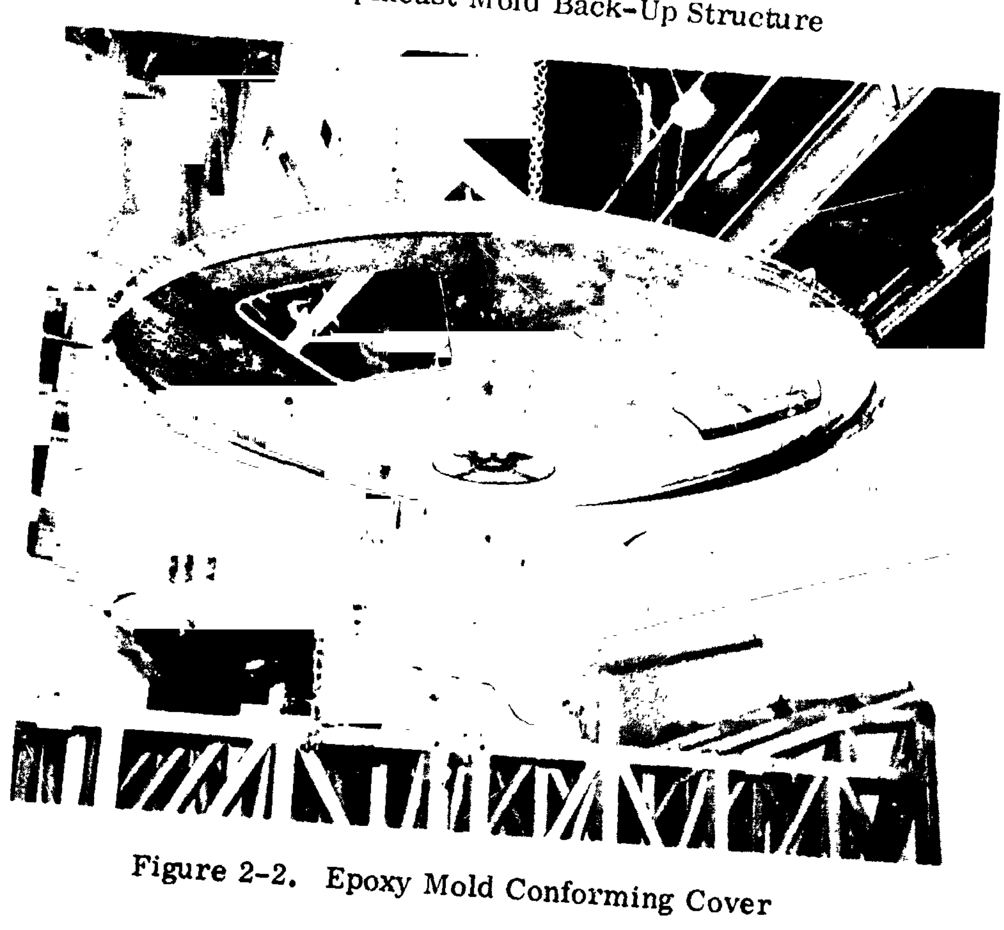
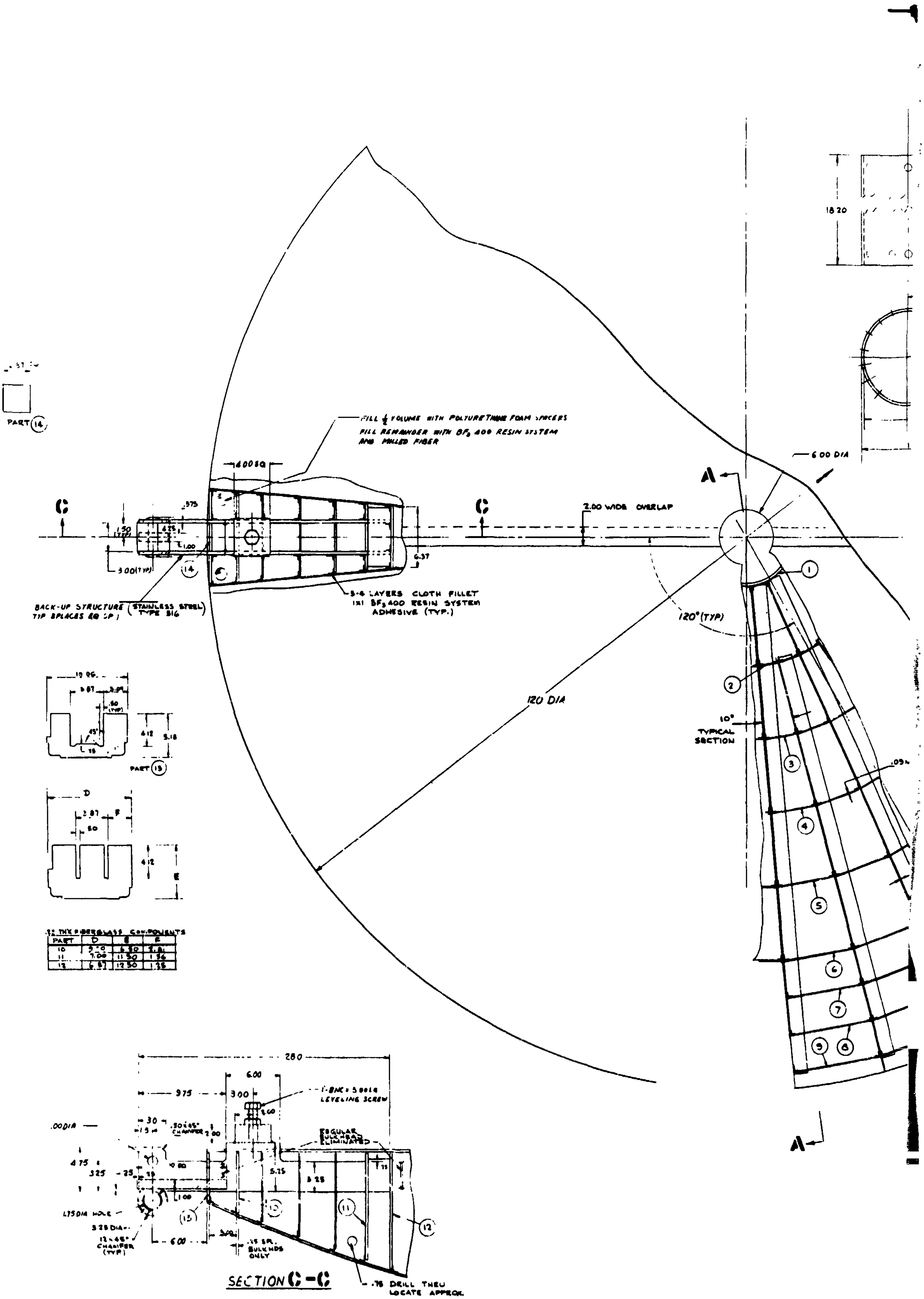
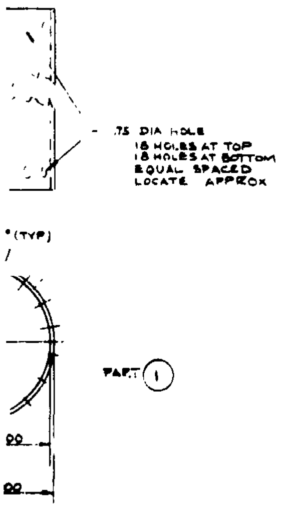
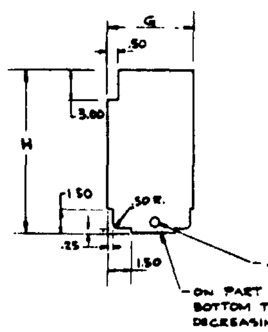


Figure 2-2. Epoxy Mold Conforming Cover



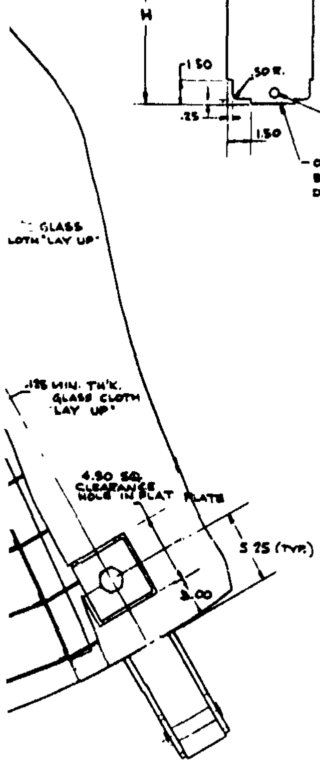
.32 THK FIBERGLASS COMPONENTS			
PART	D	E	F
10	[illegible]	6.50	[illegible]
11	7.00	11.50	1.56
12	6.87	12.50	1.25

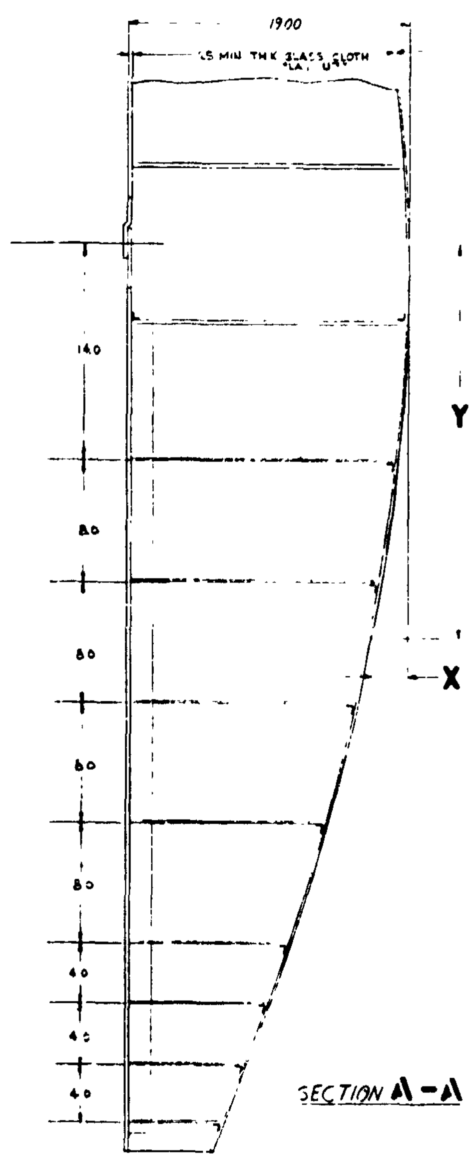




FIBERGLASS COMPONENTS

PART	G ALLOWING CLEARANCE ON EACH SIDE .125	F ALLOWING CLEARANCE ON TOP OF .25-.155
2	2.08	17.53
3	3.48	16.48
4	4.86	14.96
5	6.27	12.97
6	7.66	10.52
7	8.36	9.13
8	9.05	7.63
9	9.75	5.97





Y	X
0	0
2.396	.021
4.783	084
7.179	188
9.579	335
11.984	.524
14.396	757
16.818	1.032
19.251	1.353
21.695	1.718
24.154	2.129
26.627	2.588
29.118	3.095
31.627	3.651
34.157	4.259
36.708	4.919
39.283	5.633
41.886	6.403
44.516	7.233
47.176	8.123
49.869	9.076
52.595	10.096
55.360	11.185
58.163	12.346
59.913	13.100
59.960	13.121
60.008	13.142

Figure 2-3. Male Master Back-up Structure

BLANK PAGE

2.4 FACILITIES AND EQUIPMENT

Details of the equipment used in connection with the spincasting activity are found in the JPL report (Reference 2-1, pages 5-8 through 5-18) (See Figures 2-4 and 2-5).

2.5 SPINCASTING

Spin cast pour Nos. 1 and 2 were executed without complication. Upon the start of pour No. 3 approximately one quart of resin was pumped into the mold when the pumping system or evacuated resin containment system developed a leak. This one quart of resin continued to spin in the mold and flowed from the center of the mold covering an area of approximately 5 feet in diameter. After appropriate corrective actions were taken, Pour No. 3 was again made, this time without any technological breakdown. Following uncovering of the mold, the surface appeared to be acceptable in finish and geometry, with the exception of a minor optical distortion 5 feet in diameter coinciding with the wave front of the one-quart pour. It was estimated that the optical distortion, if any, caused by this one-quart pour would be approximately 1/10 of 1% of the total mirror area.

After careful evaluation of the risks and costs, it was decided that additional spins would be made to eliminate the circular ring pattern which would otherwise be duplicated in the final mirror surface.

This pattern was caused by the frontal edge of the aborted No. 3 pour. A photographic documentation of the surface characteristics was made* to show the excellent surface quality and to serve as a comparison for any future surfaces being inspected. Figure 2-6 shows the spincast mold on the spin table with cover removed. Figure 2-7 is a full size portion of the surface photoinspection in the vicinity of the objectionable line pattern. A small amount of

*Lee, D.E., Methods for Inspecting Large Parabolic Reflectors, GE-TIS R62SD170, 1961

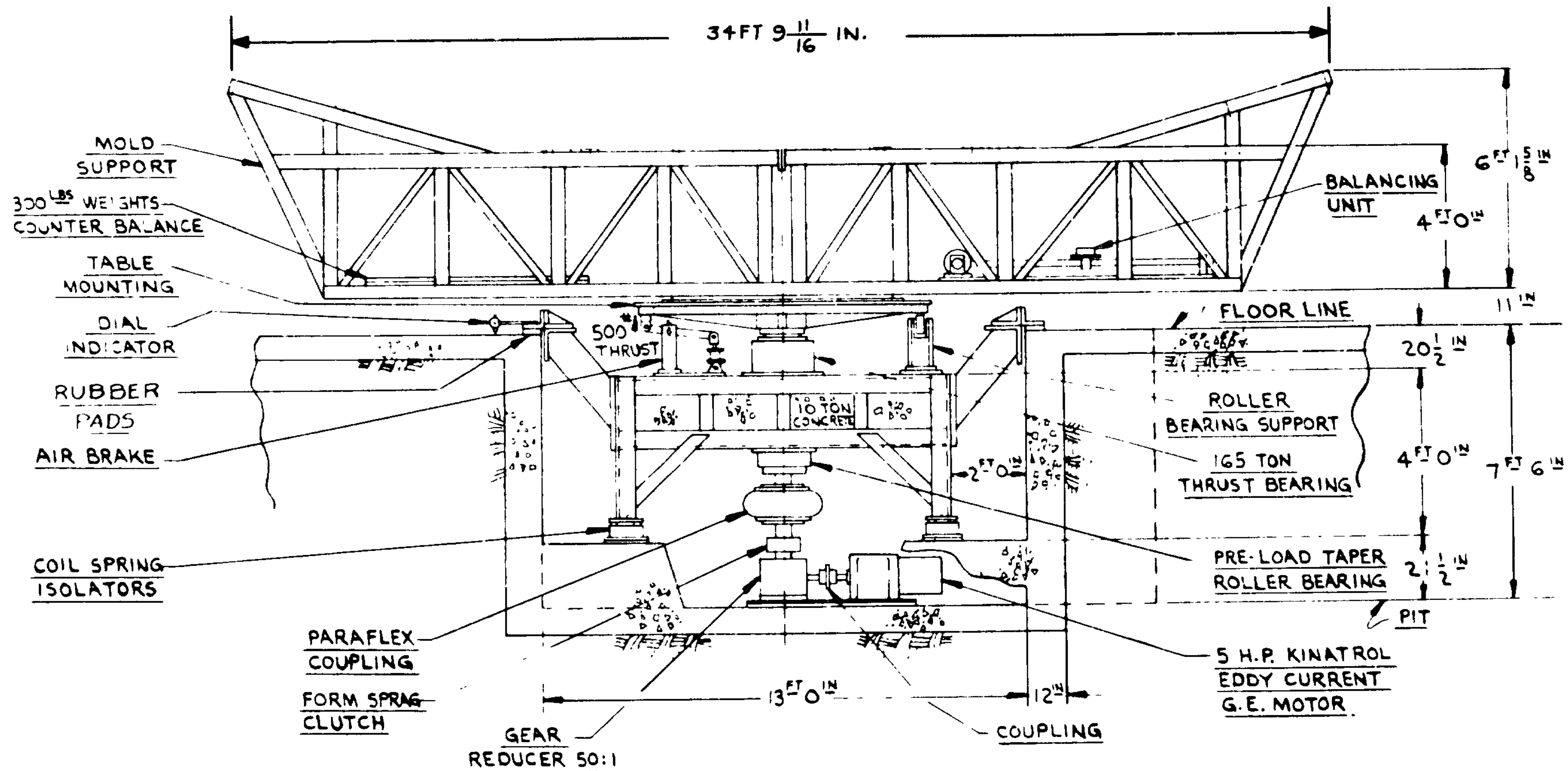
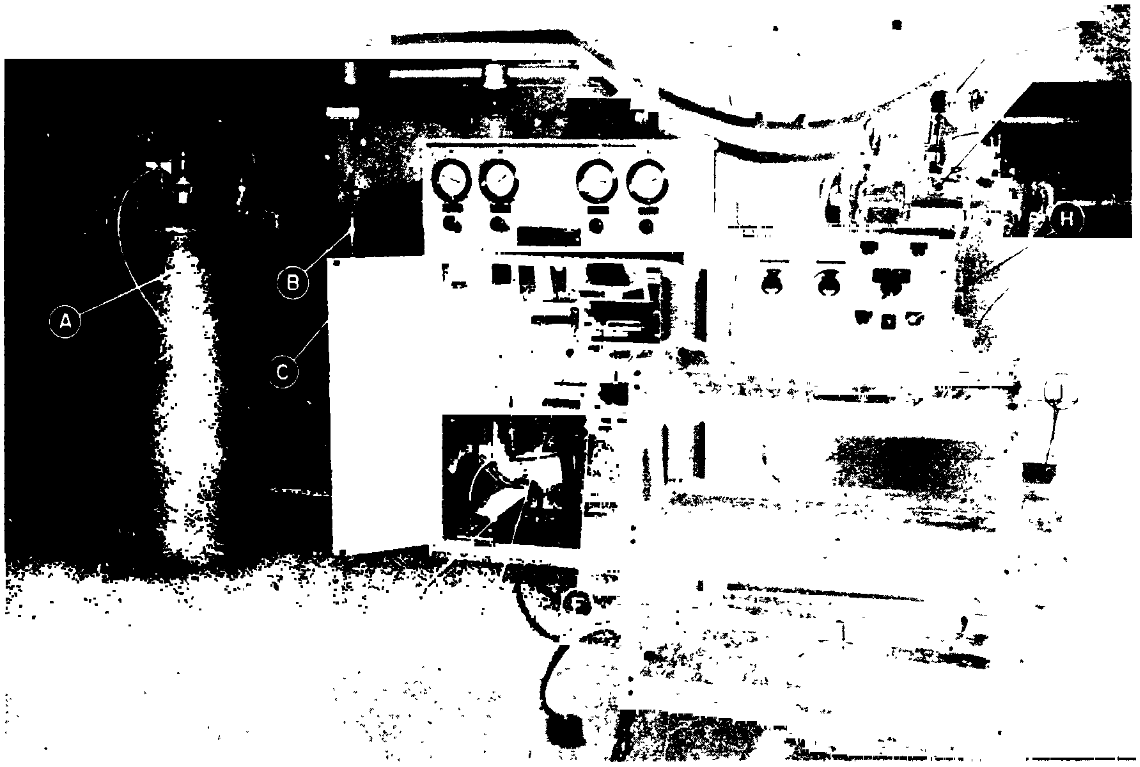


Figure 2-4. Spincast Machine Cross Section



A. Pressurized hardener reservoir
B. Mixer reactor
C. Mixer outlet
D. Solvent purge pump
E. Resin metering element
F. Hardener metering element
G. Combination vacuum and pressure resin reservoir with agitator
H. Control box
I. Vacuum pump

Figure 2-5. Proportional Metering-Mixing Equipment orange peel can be detected in the inspection photographs, although the amount is far less than normally observed on spincast epoxy surfaces. A slight radial pattern can be detected in Figure 2-8 near the edge of the mirror, although this is not significant in the performance of the collector.

Pour No. 4 was made with no apparent problems during the pour. Although normal procedures include a "dust coat" pour before any final coat, it was decided to open the cover after pour No. 4 to inspect the surface. This was felt to be a reasonable risk because there had been a number of changes in the formulation and process since the "two-pour rule" was established, and care was used in cleaning the mold prior to spinning. Upon opening, the mold surface was found to be marred by a large number of small specks or pimples, probably several thousand. This type of surface flaw has been characteristically present on any first pour and has lead to the two-pour rule. This rule was, therefore, verified for the present as being a necessary factor in the spinning of paraboloidal reflectors.

To minimize the risk of mold cracking due to excessive thickness, it was decided to remove some of the epoxy from the mold by mechanical grinding and sanding. A large number of holes were drilled in the surface, using a depth gage on a hand drill, to assure a uniform amount of material removal. Material removal was accomplished using a 6-inch sander with the final surface achieved with a 100-mesh cloth on a vibrating sander. Approximately 80 square feet of mold surface was ground and sanded having an average approximate thickness of 1/4 inch of epoxy.

Pour Nos. 5, 6, and 7 were made without difficulty. Three pours were made to ensure good coverage over the remaining epoxy of the spincasting and to increase the probability of achieving a quality surface. Upon opening the mold, a combination of radial and circumferential lines were observed which were clearly the result of vibration in the machinery. It was concluded that the vibration pattern was caused by the increased shear gradient through the epoxy as a result of the reduced thickness of the pour, possibly combined with a noisy bearing in the drive motor. The coat thickness for pours 5, 6 and 7 was reduced approximately 50% in order to decrease the total spincasting thickness if an additional pour series

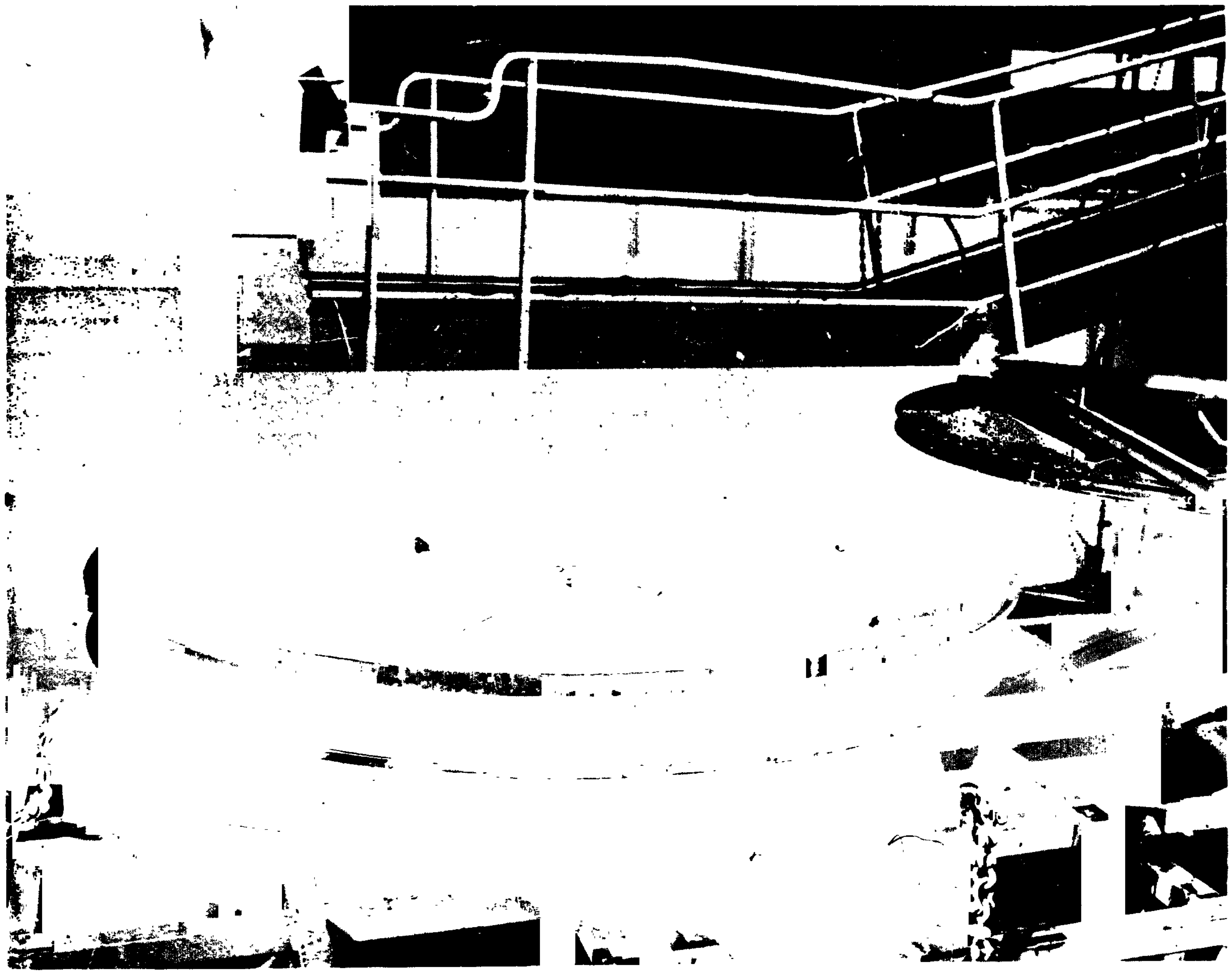


Figure 2-6. Spincast Mold with Cover Removed

Figure 2-7. Photoinspection of Pour 3 in Area of Line Pattern of 5-Foot Diameter

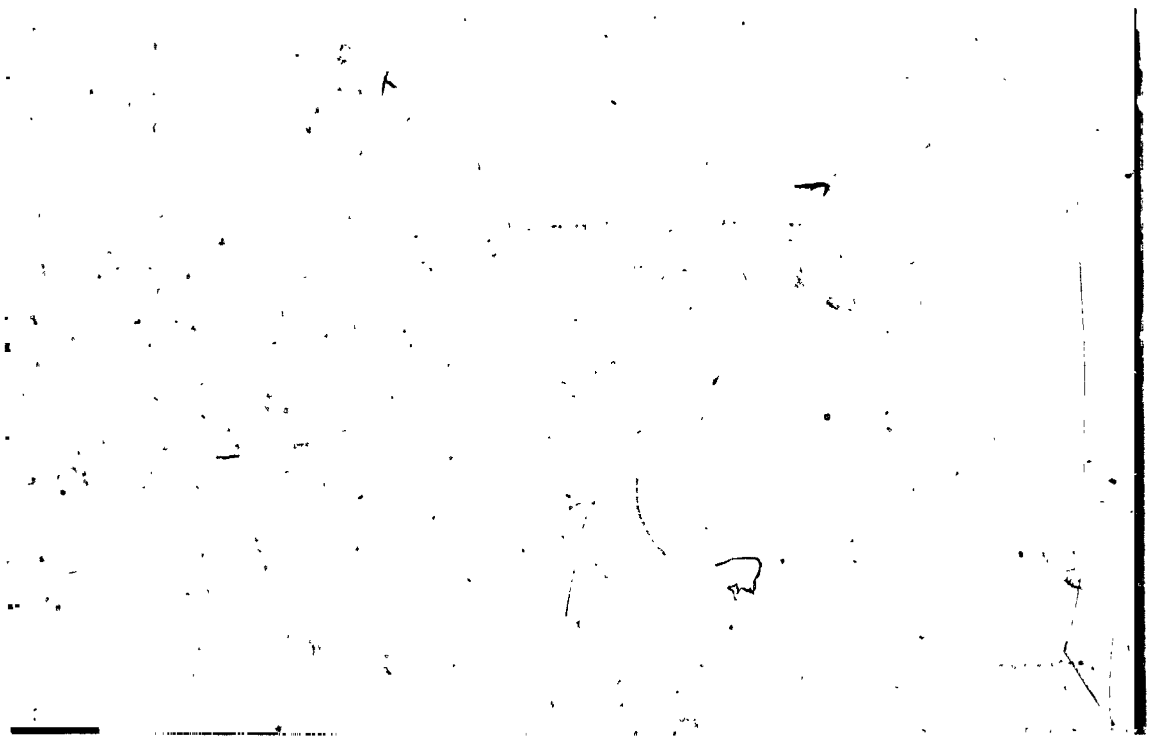


Figure 2-8. Photoinspection of Pour 3 in Area of Radial Pattern Near Edge of Mold

were required. It was concluded that there was a damping effect due to the thickness of the resin which attenuated any vibrations of the mechanical system if the shear gradient through the resin was kept below some critical value. A critical examination of the drive system revealed a very slight noise of an intermittant nature in the drive motor. The inner race of one motor bearing assembly was loose on the shaft and had a slightly burnished appearance. It had apparently been slipping on the shaft intermittantly, causing the unusual noise in the motor, and possibly contributing to the vibration pattern by torsional or axial accelerations on the motor shaft. The bearing was replaced, and both the motor and the rest of the spin-cast equipment were carefully aligned and balanced prior to making another pour.

The last series of pours, Nos. 8 and 9, were made without difficulty. A visual inspection showed the surface to be satisfactory and the mold was prepared for thermal curing prior to optical inspection.

2.6 THERMAL CURE OF EPOXY MOLD

The spincast epoxy master was thermally cured following the pouring of the ninth coat by removing the mold from the spin table and moving it to a large oven located in the same building. The oven temperature and temperatures at several significant locations on the mold were monitored by thermocouples. The oven temperature was increased from ambient to 120°F at a rate of 5°F per hour. Temperatures on the various monitor points showed that the heating was uniformly distributed and the mold temperature followed the oven temperature with little thermal lag. The temperature of the mold was held at 120°F for 10 hours and was then reduced to ambient at a rate not exceeding 3°F per hour.

Samples of the cured epoxy tested in the electroforming cycle did not prove as stable as desired. However, it was thought that by modification of the cleaning and sensitizing steps (reduction in exposure time) satisfactory electroforming could be carried out.

A summary of the spincast pours is shown in Table 2-1. Specific items which were either learned or verified were:

a. The long standing empirical rule that a dust-cover pour must be made prior to spinning the final surface was verified.

TABLE 2-1. SUMMARY DATA CONCERNING SPINCASTING POURS FOR THE 9-1/2 FOOT LANGLEY MIRROR

Pour	Date	Cure Hours	Approximate Days	Completion Date	Remarks
1	9/9/64	145	6	9/15	Good
2	9/15/64	144	6	9/21	Good
3	9/21/64	332	14	10/5	See Note 1
3a	10/5	164.5	7	10/12	See Note 2
4	10/27/64	138	6	11/2	See Note 3
5	11/14/64	97	4	11/18	1/8-in. Pour
6	11/18/64	98	4	11/22	1/8-in. Pour
7	11/22	186	8	11/30	See Note 4
8	12/10/64	120	5	12/15	1/8-in. Pour
9	12/15	188	8	12/23	See Note 5

NOTES

1. Pour was aborted after approximately one quart of formulation was poured because of large air bubbles which appeared in the resin tube. Formulation did not wet complete surface of mold.

2. Visual inspection showed surface quality to be excellent, except for a circular line of approximately 5 to 6 feet diameter caused by show-through from the aborted No. 3 pour.

3. Decision was made to open the mold after a single pour based on apparent quality of the surface as viewed through inspection parts to determine validity of the empiracal rule that a dust-cover pour is required prior to final pour.

4. Circumferential and radius lines appeared in the surface. These were the result of a combination of motor vibrations and possible shear gradients through the thin (1/8-in. thick) epoxy coatings.

5. Surface quality was acceptable. Mold was removed from the spin table for thermal cure.

b. If necessary to abort a pour prior to pumping a sufficient quantity of epoxy to cover the complete surface, it is better to dump rather than to continue to spin. This will minimize the thickness of any wave front developed at the edge of the partial pour.

c. Motor bearing noises, slight unbalance of the spintable, or other minor mechanical disturbances can cause radial or circumferential vibration patterns to show on the surface of the epoxy spincasting.

d. The viscous damping effect of the liquid epoxy can be a significant factor in attenuation of vibration patterns on the surface of the spincasting. Insufficient thickness of pour will cause the mechanical vibrations of the system to show through to the surface.

e. Defective pours can be readily removed from the mold to prevent excessive build-up by mechanical grinding and sanding techniques.

2.7 OPTICAL INSPECTION (See Appendix A)

Optical inspection was performed in the same manner as that described in Reference 2-1. Much of that technique is repeated herein to provide the reader with ready background information rather than referring to Reference 2-1.

This inspection of the surface was made with eight telescopes located for equal area representation and read at every 5-degree interval starting from the "A" position on the mold.* The adjusted mean slope error of 576 readings was 42.6 seconds of arc. A photographic record showed the surface quality to be good and with a minimum of local disturbances.

*Arbitrarily selected as one bearing foot of the mold as mounted on the spintable.

2.7.1 METHOD OF INSPECTION

a. Inspection Grid - If a light source is placed at the focal point of a perfect paraboloidal surface which is concave to the incident light, the light reflected from that surface will be collimated as paraxial rays (Figure 2-9). If the reflecting surface deviates from a true paraboloid, or has zonal errors (ripples, hollows, etc.), light will be reflected out of collimation (Figure 2-10). Thus, the magnitude of the surface errors can be obtained by measuring the angles between the optical axis and the reflected rays.

To measure the mirror geometry adequately by a limited number of measurements taken at discrete points, each measured point should be representative of a reasonably small portion of the mold. It was therefore decided to take error angle readings at 8 radial and 72 circumferential locations. Thus, a total of 576 error readings would be taken which corresponds to one reading for every 18 square inches. The mirror was divided into 576 zones (Figure 2-11) of equal area whose centers lie on 8 radial and 72 circumferential lines as shown in Figure 2-12. By reading surface measurements at these 576 points, a uniform coverage of the mirror surface was obtained which was sufficiently accurate to predict the mirror geometry, yet did not require an excessive quantity of measurements.

The test setup used for the optical inspection of the epoxy mirror master consisted of a light source placed at the focal point and eight telescopes aligned with their optical axes veritcal. During the optical inspection, the epoxy master was located on the spin-table in the identical position it held during the spincasting process. Since the master had to be rotated during testing, this arrangement guaranteed the axis of rotation to be coincident with the optical axis of the paraboloid, because the spincast had been generated by rotation about this same axis.

b. Preliminary Arrangement - The general arrangement for optical inspection is shown schematically in Figure 2-13. The light source used was a miniature point

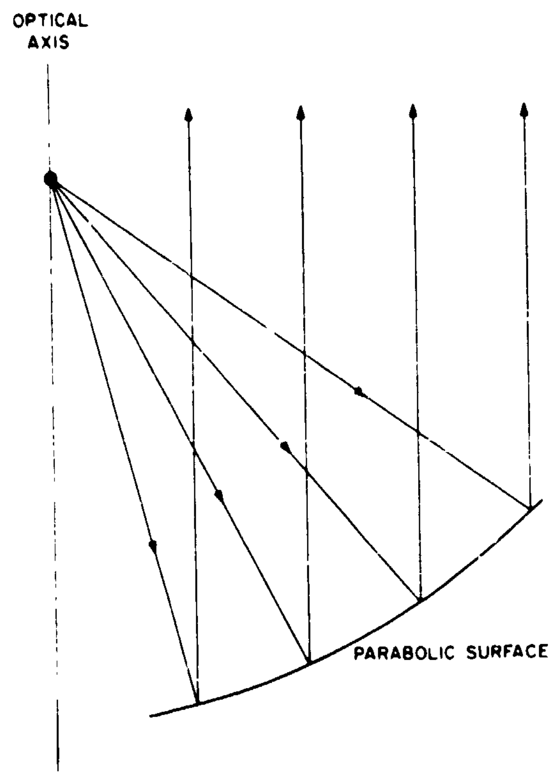


Figure 2-9. Paraxial Reflection from a Perfect Parabolic Surface

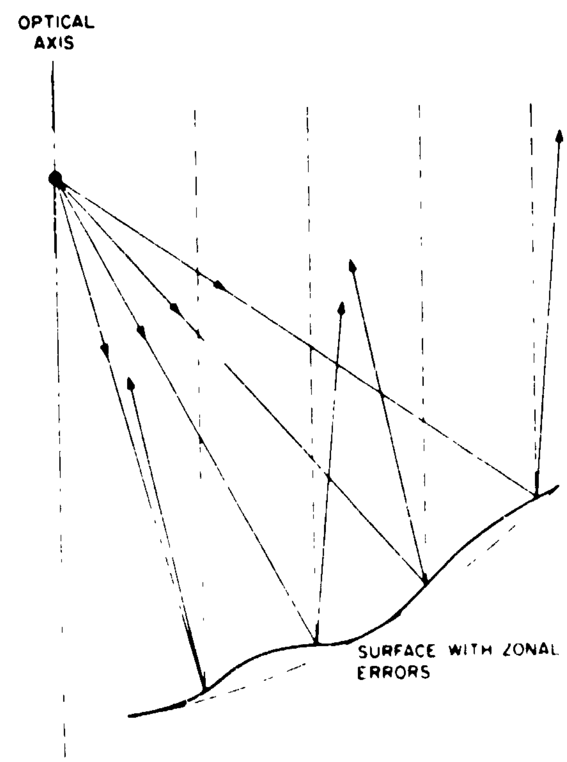


Figure 2-10. Uncollimated Reflections Due to Zonal Errors

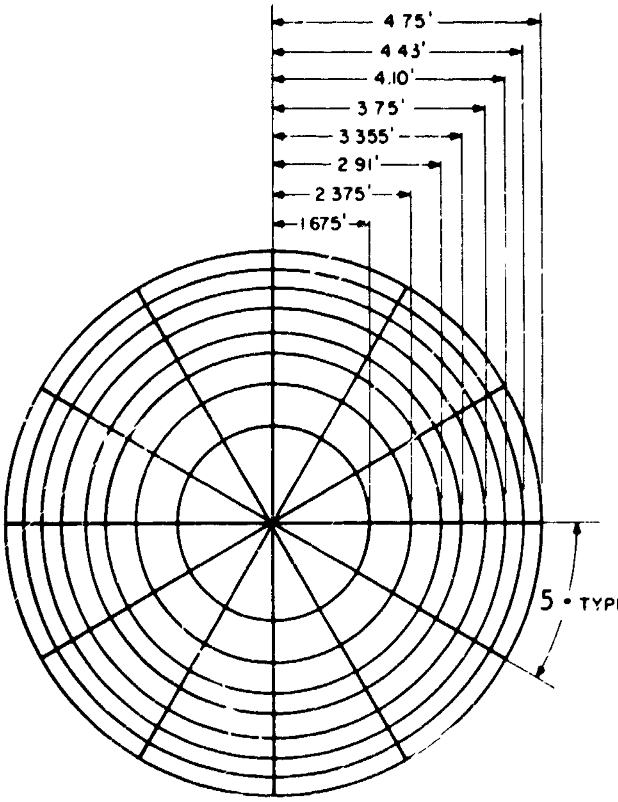


Figure 2-11. Subdivision of Mirror Surface Into 576 Equal Areas

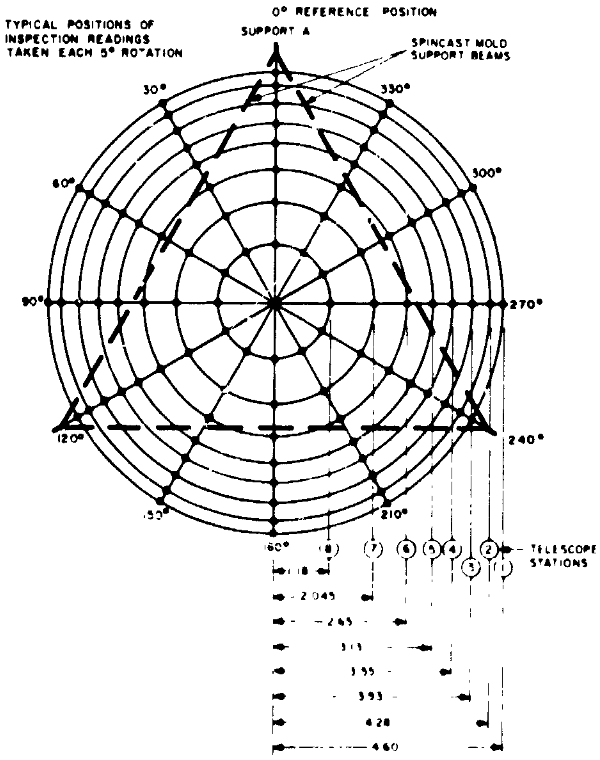


Figure 2-12. Location of 576 Optical Inspection Points Relative to Spincast Mold Support Structure

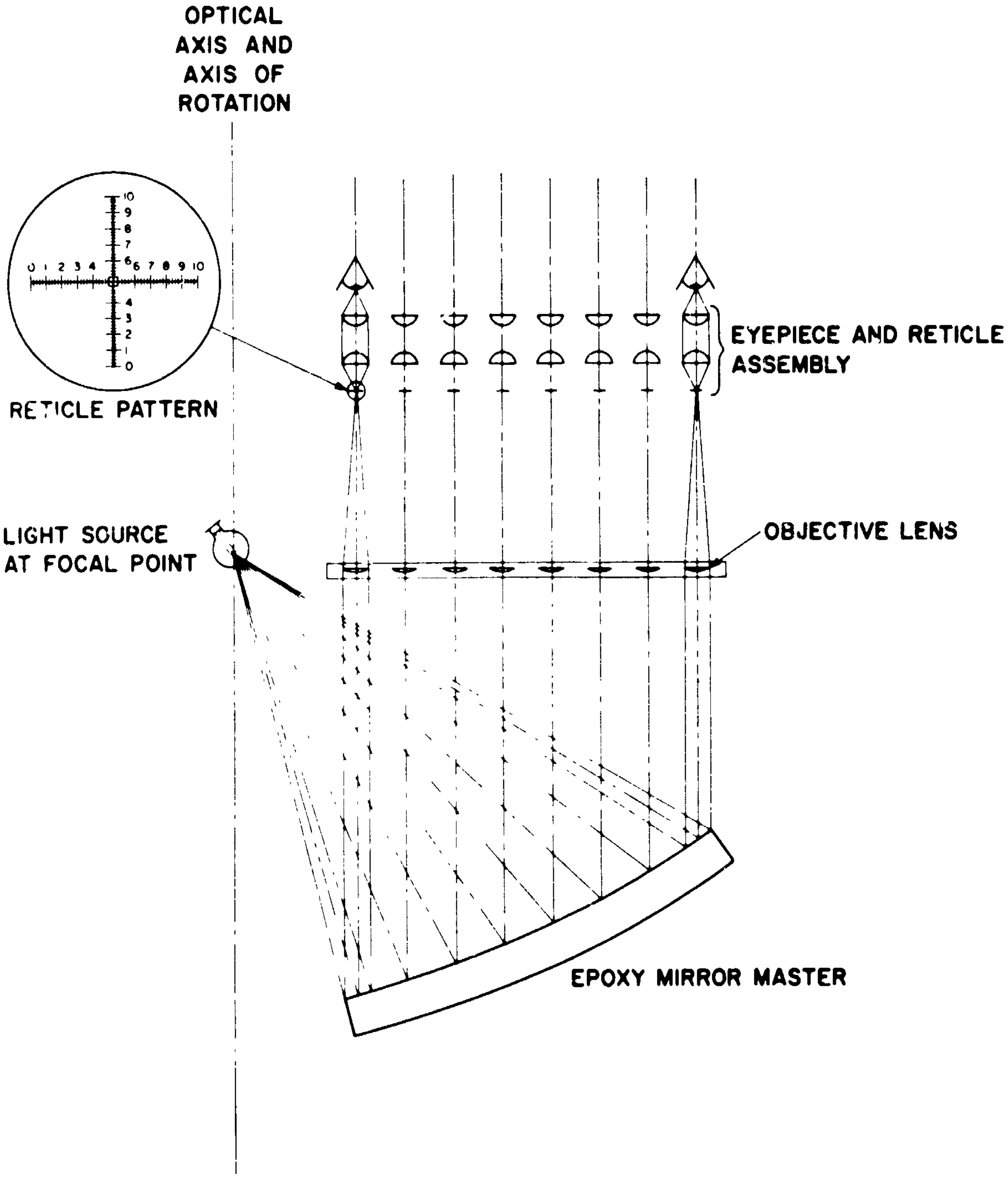


Figure 2-13. General Arrangement of Test Elements

source operated at 1.5 volts. It consisted of a 0.015-inch clear-glass bulb containing a tungsten filament which measured approximately 0.005 inch across the coils. The lamp and lamp holder were mounted approximately at the focal point in a device which allowed for movement in any direction.

The objectives of the eight telescopes were simple plane-convex lenses. These lenses had a clear aperture of 25mm and a focal length of 2019mm. They were mounted in a wooden 2 x 4 with the plane of the lenses normal to the spin axis (Figure 2-14). As explained below, no special care was necessary to mount the lenses accurately or parallel.

The eyepieces of the test telescopes were of the Ramsden type and had an effective focal length of 1 inch. A 10mm crossed reticle with 100 divisions each in the X and Y axes was located at the focal plane of each eyepiece (see insert in Figure 2-15) such that the X axes were along a radial line. The eyepiece and reticles were mounted in simple draw-tube adapters (Figure 2-15) and arranged in a line on another wooden 2 x 4. Adjustment of the adapters in any direction was made possible by a simple clamping arrangement. The mounted eyepieces were then located at the infinity focus of each of the eight objective lenses.

c. <u>Alignment of Test Telescopes</u> - A vital aspect of the test setup was the alignment of the optical axis of each telescope parallel to the axis of the paraboloid. Since the production of the master surface by rotation ensured a perfectly vertical optical axis, it was only necessary to align the axis of each telescope system vertically. A collimating theodolite was used in aligning the eight inspection telescopes. The theodolite, which was adjusted to project a cross-hair reticle at infinity, was located under one of the telescope objectives by use of a plumb line and was aligned vertically by use of the adjustments on the instrument.

The image of the theodolite reticle was then viewed through the eyepiece of the telescope being aligned. When the optical axis of the theodolite is coincident with

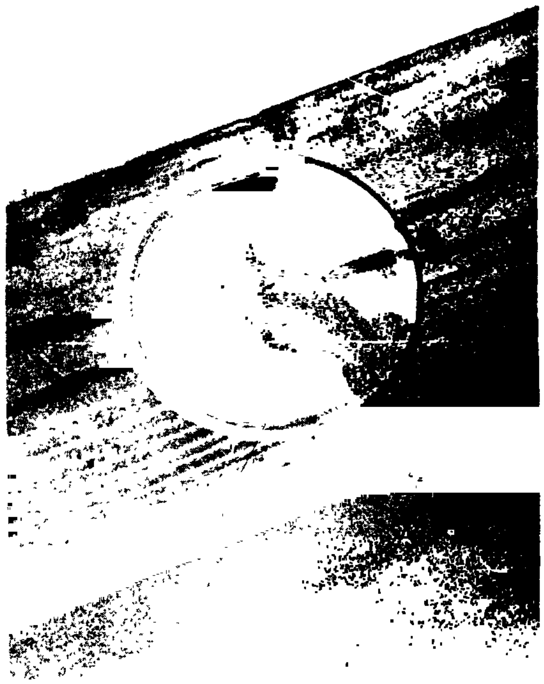


Figure 2-14. Mounted Telescope Objectives

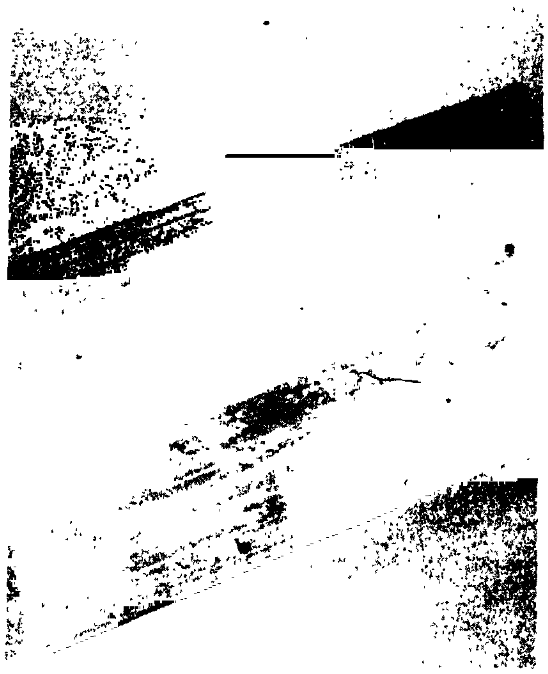


Figure 2-15. Mounted Eyepiece and Reticle Adapter

the axis of the test telescope, the intersection of the theodolite cross hairs will be seen at the center of the reticle in the test telescope. The eyepiece adapter was adjusted until the two reticles were superimposed. This alignment procedure was repeated for each of the eight test telescopes.

d. Location of Focal Point - The final preparatory step was the location of the test lamp filament at the exact focal point of the paraboloid. If the test telescopes are properly aligned and the mirror is a perfect paraboloid and the test lamp is located precisely at the focal point of the mirror, each telescope will produce a sharp image of the lamp filament at the exact center of the telescope reticle. If the test lamp is placed in a position other than at the focal point of the mirror, the filament image will be displaced from the center of the field. The direction and amount of image displacement is an indication of the correction required in lamp position.

If the light source is located on the axis of the parabola beyond the focal point of the mirror, the reflected light will converge and the images in the telescopes will be displaced toward the optical axis of the parabola. If the light source is placed inside the focal point of the mirror, the reflected light will be diverging and the images will be displaced away from the mirror optical axis. When the light source is moved to the right of the optical axis, all eight images move to the left and vice versa. It becomes obvious, therefore, that by simply manipulating the position of the light source until the filament image is centered in each telescope, it is possible to precisely locate the light source at the focal point of the paraboloid. For example, a 1/16-inch shift in lamp position can cause an average change of 50 to 60 seconds in the reflected light beam with a resulting image shift of 5 to 6 divisions on the telescope reticle.

Location for perfect alignment on all telescopes is prevented by local slope errors on the paraboloid. Therefore, the lamp was adjusted until a best-fit condition was achieved; that is, the light source was manipulated until the filament image was as close to the center of the reticle of all the test telescopes as possible. This procedure located the mean focal distance of the paraboloid to within one-quarter of an inch. A refined method of locating the focal points within the focal plane is discussed in Section 2.7.1f.

e. Slope Error Measurement - Since the displacement errors have a considerably smaller effect on mirror efficiency than the slope errors, it is common practice to assign the entire surface error to slope error. This practice was followed in this report.

With the source located at the mean focal point of the mirror, any deviation of the filament image from the center of field of the eight test telescopes is due to geometric errors of the mirror surface. Thus, the local slope error at any point on the eight arcs under the telescopes can be obtained directly by reading the displacement of the filament image from the center of the telescope reticle.

The first step was to calibrate the telescope reticles. This is a simple trigonometric process, and the calculation used for the epoxy mirror test arrangement is shown below. The calculation was checked by theodolite measurements and found to be satisfactory.

1. Theoretical Calibration

Focal length of telescope objective	2019mm
Size of reticle scale	10mm over 100 divisions
Field of view	Angle the sine of which equals 10/2019 = 0.00495
Angle the sine of which equals 0.00495	0.291 degrees or 17.5 minutes
Calibration in seconds of arc per division	17.5 x 60/100 = 10.5

2. Calibration Check by Theodolite

Immediately following the test telescope alignment as described in Section 2.7.1c, the theodolite was depressed from the vertical by a vernier adjustment of the elevation until the image of the theodolite reticle was observed to shift 50 divisions on the test telescope reticle. The theodolite reading was 9.25 minutes. It follows then that:

$$\text{Full scale} = \frac{100}{50} \times 9.25 = 18.5 \text{ minutes} = 1110 \text{ seconds}$$

$$\text{thus, each division} = \frac{1110}{100} = 11.1 \text{ seconds of arc.}$$

Since the slope deviation of the light entering the telescope is twice the slope error on the paraboloidal surface, the actual surface slope error can be read directly on the telescope by considering each division as 5.55 seconds of surface slope error.

The accuracy of the reticle readings on the spincasting master was ± 1 division which equals $\pm$ 5 seconds of slope in the radial and circumferential directions each. The total slope error of the master is, therefore, measured accurately to within approximately $\pm$ 7 seconds.

f. Adjustment of Measured Data for Errors in Lateral Focal Point Location - As described in the preceding sections, all telescope eyepiece and reticle assemblies are accurately aligned vertically by means of a collimating theodolite. The focal point of the paraboloid, however, is obtained by a trial and error best-fit of the reflected image in all the reticles. The accuracy of the slope error measurements depends on the location of the inspection lamp filament of this approximate focal point.

An error in filament location will be read as an apparent slope error of the surface. This is indicated in Figure 2-16 by the dashed lines. If the error in focal point location is denoted by e, the apparent slope error $d\beta = \Delta/L$ is measured. This angle is given by the following expression:

$$d\beta = \frac{\Delta}{L} = \frac{e \cos^2 \alpha}{f-y} \qquad (2\text{-}1)$$

From Figure 2-16, $\cos^2 \alpha$ can be expressed in terms of f, x and y

$$\cos^2 \alpha = \frac{1}{1 + \tan^2 \alpha} = \frac{1}{1 + \left(\frac{x}{f-y}\right)^2} \qquad (2\text{-}2)$$

Simplifying the denominator, and substituting the value 4 fy for x^2,

$$\cos^2 \alpha = \frac{(f - y)^2}{4 fy + (f - y)^2} = \frac{(f - y)^2}{(f + y)^2} \qquad (2\text{-}3)$$

Substituting this value of $\cos^2 \alpha$ in (2-1) gives

$$d\beta = \frac{\Delta}{L} = \frac{e (f - y)}{(f + y)^2} = \frac{e (1 - y/t)}{f (1 + y/f)^2} \qquad (2\text{-}4)$$

$$d\beta = \frac{\Delta}{L} \cong \frac{e}{f} \qquad (2\text{-}5)$$

If the simplified expression (2-5) is used for the apparent slope error $d\beta$ due to an error, e, in the focal point location, this error can be calculated from the inspection data by obtaining the average radial and average circumferential deviations of all the reticle readings. If both of these averages are equal to zero, the best-fit (least-square error) focal point location has been obtained.

If they are not equal to zero, the raw readings can be adjusted by subtracting the average radial deviation from each radial deviation reading and the average circumferential deviation from each circumferential reading. Vector addition of these two adjusted readings at each point yields the adjusted slope error. This value corresponds to the actual measured slope error if the filament had originally been located at the exact focal point.

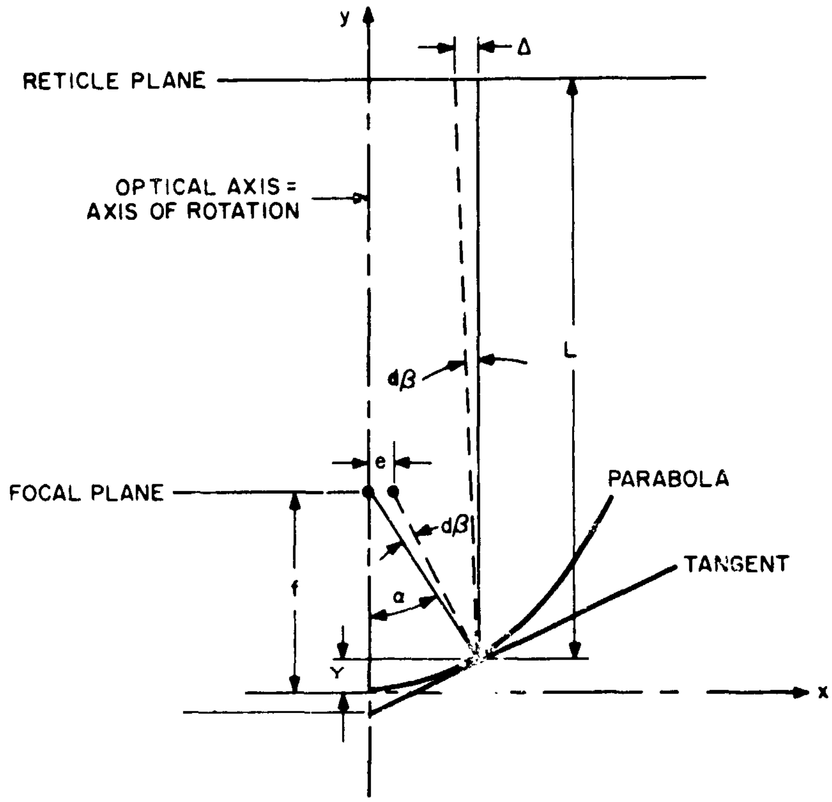


Figure 2-16. Slope Error Due to an Error in Focal-Point Location

The maximum error introduced by using the approximate expression Equation (2-5), rather than the more accurate Equation (2-4) for the 9.5-foot diameter master and mirror, is 38% for points along the outer rim. Since this expression is only used for a least-square error djustment, it was deemed sufficiently accurate. The adjusted slope errors shown in this report were obtained by the use of the average radial and circumferential values of all telescope readings without the use of the y/f correction factor in Equation 2-4.

2.7.2 INSPECTION RESULTS FOR FINAL SPINCAST

Optical inspection of the final spincast surface was made after thermal cure.

Slope errors for the spincast mold surface were calculated by use of a Fortran program using a 7094 computer. The Fortran program and the computed results are included in Appendix A. Although it is known that the light source was not located precisely at the focal point, the slope errors are calculated using the raw data for comparison purposes. Adjustments were made to make a first approximation of a correction in readings to account for errors in position of the light source.

Calculations for apparent slope error using the raw data were made as follows:

$$S = \left[(X-50)^2 + (Y-50)^2 \right]^{1/2} \times 5.55$$

where: S = slope error in seconds

X, Y = telescope readings in divisions

Calculations for adjusted slope error using a first approximation correction for errors in lamp filament position were made as follows:

$$S = \left[(X-\overline{X})^2 + (Y-\overline{Y})^2 \right]^{1/2} \times 5.55$$

where: S = slope

X, Y = telescope readings.

$\overline{X}, \overline{Y}$ = average of all X and Y readings

Mean values and standard deviations were calculated for each telescope and for all telescopes combined. The median value was also printed out for comparison purposes.

2.8 FAILURE OF THE NICKEL MASTER

This section describes the events leading to and following the failure of the first attempt to electroform the nickel master. This completely unexpected catastrophe was agrivated by the ultimate loss of the epoxy master necessitating an extensive epoxy evaluation program and the subsequent successful spinning of another epoxy master.

The epoxy samples made during the pouring cycles did not demonstrate the desired resistance to silvering and electroforming solutions, and, therefore, additional one-inch diameter samples were taken from the edge of the mold beyond the scribe lines. This latter sampling was considered desirable to ensure that the actual mold surface was tested against the various solutions. Samples tested indicated that some etching of the epoxy surface might occur, causing a slight haze although the effect on the nickel master was not expected to be significant. The decision was made to go ahead with the electroforming of the master recognizing some risk was involved.

The processes and technique used in the electroforming are described herein in sufficient detail to provide an understanding of the sequence of events and the rationale for the test program that followed the failure.

2.8.1 SUMMARY OF EVENTS LEADING TO THE FAILURE

The spincast mold was shipped from GE in Philadelphia, where it was made, to Newark, N.J. where the electroforming was to take place. Provisions were made for protecting the shipment from thermal shock by the use of electric blankets mounted within the insulated crate. Road shock was minimized by mounting the mold and its integral support structure on expanded polyethelene foam cemented to plywood. Lateral and forward motion were prevented with cleats secured around the mold bearing plates.

Upon arrival, the crate was opened and the mold cover lifted; the epoxy surface was visually inspected for damage, signs of deterioration or changes as a result of the shipment. None were found. The cover was replaced and work was started to prepare the mold for the electroforming process. This basically consisted of masking off all areas of the structure which were not already "stopped off" to prevent attack by the electrolyte. This was accomplished by applying a combination of tape and stopoff to all exposed bare metal. Copper electrodes were attached to the side of the mold structure after removing "stop-off" at those points to provide metal-to-metal contact. The edge of the mold beyond the outer scribe line was rounded off, smoothed and then treated with collodial silver. A layer of aluminum foil was layed over the rounded edge, held in place with additional collodial silver to assure good current flow and to minimize the chance of "hang-up" at this point of contact when the male master was separated from the epoxy mold.

The electroforming bath and equipment were thoroughly checked out before the start of the process. The solution was purified, (chelated, carbon treated and dummied), analyzed and stress measured in the laboratory. Finally, large 3 x 6 feet test plates were electroformed in the bath immediately prior to the introduction of the mold. The nickel deposit on these test plates was acceptable, bright and ductile. Stress level at this point was 4000 to 6000 psi having come down from better than 18,000 psi at the start of the purification process.

Tests run on epoxy samples taken from the final pour and from the edge of the mold outside the scribe line indicated that the epoxy would probably be subject to some chemical attack if standard cleaning and sensitizing processes were used. By limiting the cleaning and sensitizing steps, the chemical attack was reduced to a degree where the chances of producing an etched nickel master surface were minimized.

The procedure used was to clean with a 5 percent detergent solution for two minutes (versus 30 minutes with stronger cleaners), sensitize for one minute with dilute stannous chloride (versus 15 minutes with strong, acidic solution). The surface accepted a good silver film, the adherence of which was tested and found to be satisfactory.

The epoxy mold was cleaned, sensitized and silver sprayed and then immersed into the electroform bath with the auxiliary anode current on and with the mold cathodic. Conditions appeared normal for approximately 6 hours when sections of the nickel deposit apparently lifted from the mold. Some of these pieces caught in the rotating anodes, scratched the epoxy and caused current shorts. The run was immediately terminated and the mold was withdrawn from the bath shortly thereafter. (See Figure 2-17 for Schematic of Electroforming Cell.)

Inspection showed that the nickel was about 4 mils thick at the time of failure and was exceptionally brittle. The nickel surface appearance, however, was very good compared to masters electroformed on previous programs. The epoxy surface was slightly etched and the scratches were largely confined to an area out to about one half radius from the center. Depth of the worst gouging was prehaps 10-15 mils deep and the width up to 1/8 inch.

Approximately one week later when NASA Langley and GE representatives jointly inspected the mold, a large deep crack was observed on one side of the mold extending for a number of feet across the surface. This crack was not present at previous inspections. This type of mold failure rendered it useless for further application to this program.

The cause of the cracking was attributed to thermal shocking when the outside temperature dropped suddenly, over the week end, with a parallel reduction in the room temperature where the mold was placed.

Large sections of epoxy were stripped away from the aluminum substrate after it was deter mined that the epoxy had separated from it. Small quantities of electroform bath fluid were found lying between the mold substrate and epoxy.

2.8.2 EVALUATION OF FAILURES

An early analysis of the various potential failure modes indicated that the bath had been contaminated by organic materials going into solution from the epoxy.

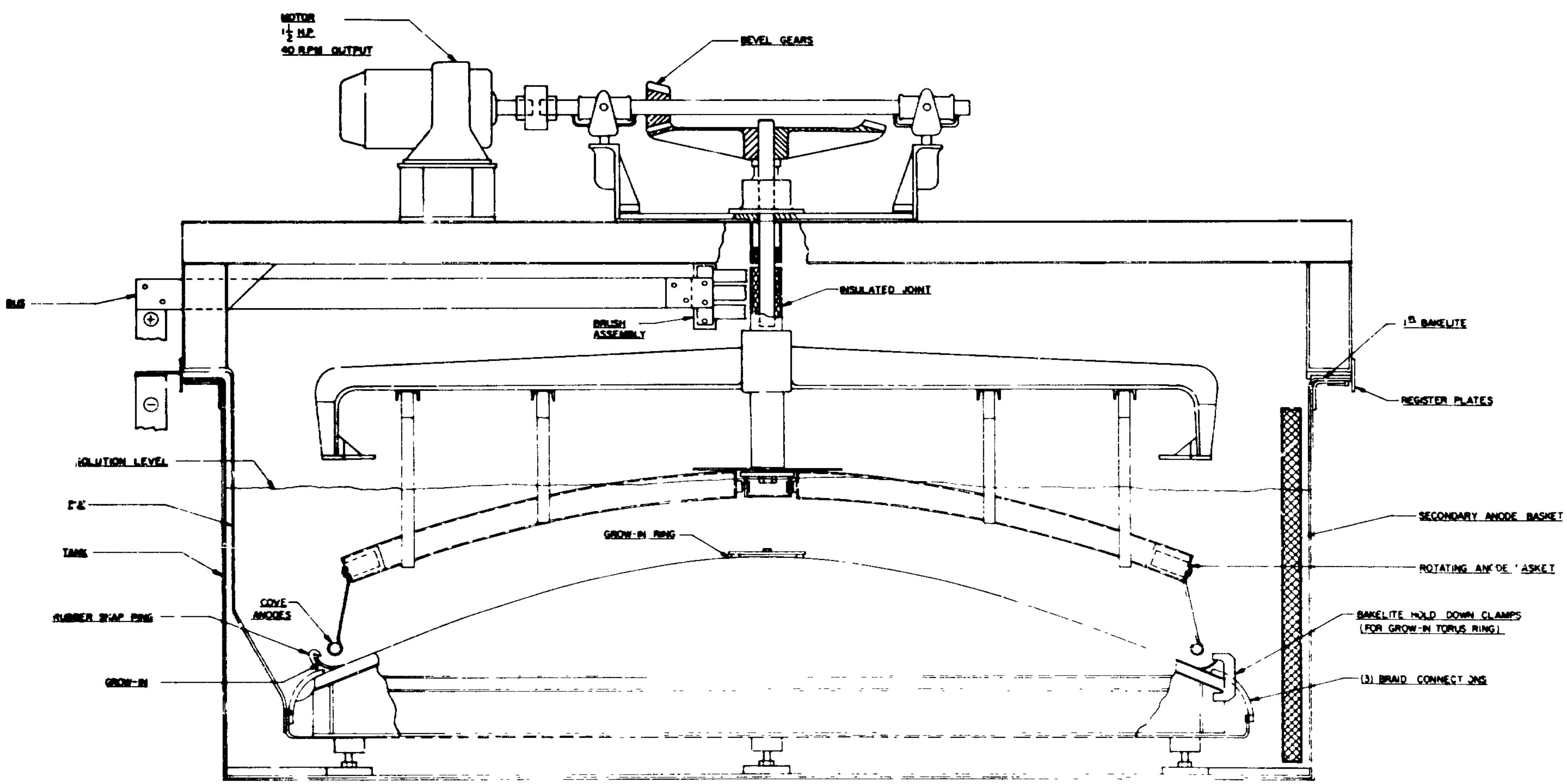


Figure 2-17. Schematic of Electroforming Cell

The items which could possibly have initiated the type of failure which occurred were:

a. The polyester-fiberglass ring around the edge of the spincast epoxy.

b. The polyester-fiberglass cover reacting with the spincast epoxy.

c. The spincast epoxy.

d. The epoxy stopoff applied to the mold structure by GE.

The cause of the cracking and separation of the epoxy from the aluminum mold surface was also investigated. The following possibilities presented themselves:

a. Large shear forces resulting from differential coefficients of expansion for the epoxy and the metal.

b. Improper formulation or processes for applying the epoxy primer to the metal.

c. Chemical attack by the nickel sulfamate bath on the epoxy primer layer.

d. Improper cleaning of the metal substrate prior to application of the epoxy primer.

e. Excessive thickness of the epoxy spincasting.

2.9 EPOXY TEST PROGRAM

Since the apparent source of contamination of the electroforming solution and the ultimate failure of the master and epoxy mold was attributed to the unstable epoxy, a program designed to provide assurance of the stability of the epoxy which would be used for additional spincastings was undertaken. A test procedure was developed which would provide a means for evaluating each step of the process so that should failure occur it could be pinpointed.

An abridged version of the program plan to conduct these tests is found as Appendix B.

Twelve separate epoxy formulations were hand mixed, cured and tested for chemical resistance and electroform bath contamination. Four of the twelve samples gave excellent results and were considered stable. The best two samples (both cured at 72 - 73°F) were immersed in a nickel-sulfamate bath after appropriate cleaning, sensitizing, and silvering. A 5-mil nickel plate was then electroformed against them. The resulting nickel was bright and ductile. It compared favorably to the reference nickel plated in the same bath against a stainless steel sheet. One of the twelve formulations tested was identical to that used for the 9.5-foot epoxy mold which failed and this formulation did not pass. (This confirmation was gratifying in that it highlighted the critical nature of the relationship between the two catalysts used.)

The formulation which gave the best total results was then machine mixed in the equipment located at the spincasting facility to evaluate the effects of machine mixing. Twenty samples were pured and ambient cured, followed by a post cure at 120°F. These samples did not successfully survive the chemical treatment. Failure began to occur at the end of the one hour cleaning step and further deterioration took place in the sensitizing solution.

An evaluation was then conducted to isolate the cause of failure. A check of the temperature recorder charts used during the ambient cure showed that the actual temperature was 68° and not 72 - 73°F as set. To determine what effect this lower ambient cure temperature had on the epoxies, hand mixed samples were cured at 68°F and 75°F. None of these failed at the lower scale while random results were obtained at the upper limits, as expected.

Two other causes of failure of machine mixed samples were investigated. One was the possibility of incorrect ratios of resins and hardeners. Since the formulation was performed by two fully experienced personnel, each checking the other, and because their logs verified the accuracy of their measurements, this source of error was dismissed. The other failure mechanism considered was the degassing, pumping, and mixing equipment; to check these out, the following tests were run:

a. Hand mixed samples from the mixing/degassing tanks.
b. Hand mixed samples from the outlet side of the proportional pumps.
c. Machine mixed samples from the mixing head.

These samples were ambient cured for the 48-hour period required, followed by a post cure of 10 hours at 120°F. Chemical resistance tests were run against these samples and they failed to pass.

The explanation for these failures was found in the temperature recorder which showed that the cure chamber failed to maintain the preset 72-73°F. Further investigation showed that there were two contributing factors, namely the control of the CO_2 used to cool the environmental chamber failed to operate in a constant manner and the building air conditioning also failed during the cure period with the net result that temperatures in the chambers reached 80°F on occasion. Since the previous tests conclusively showed how critical the upper limit of the ambient cure temperature is to the stability of the epoxy, it was apparent what had caused these failures.

The test program showed that stable epoxies can be repetitively produced providing appropriate attention is given to quality control. It further demonstrated the critical part that ambient cure temperature plays in successfully formulating a resistant surface.

Based on the results of these tests, the following conclusions were drawn:

a. The ultimate stability of the epoxy formulation being used is ambient temperature cure dependent. The upper limit is approximately 75°F, above which failures occur in a predictable fashion. Samples cured below this temperature were chemically resistent and produced good nickel. The lower limit was not established but it is known to be below 68°F.

b. Post curing at 120°F is most effective with the epoxy exposed to the ambient environment, i.e. the mold or sample cover is removed.

c. Epoxies which are not subject to chemical attack (H_20, cleaning solutions, sensitizing solutions, silvering) will not contaminate nickel sulfamate baths during the electroforming process.

d. The basic formulation is stable if properly mixed and cured and will, therefore, produce good nickel when used as a plating surface.

e. Close temperature control in the immediate vicinity of the spincasting table is essential to the production of a successful epoxy mold. This temperature control must be maintained throughout the period of spincasting, ambient, and post curing.

f. The ratio which exists between the catalysts used is critical. Slight variations will cause either excessive exotherm or incomplete curing. In either case, the result is an unstable epoxy.

g. A high degree of quality control effort throughout the entire fabrication phase is the best assurance of success. This requires material, procedural and equipment inspection, monitoring, and modification as needed at each step of the process. It also dictates a thorough and continuous sampling test program be conducted in parallel with the primary spincasting effort.

h. The successful formulation of stable epoxies which can be used for electroforming precise, high quality surfaces, is a developing art, many of the problems of which have been solved or identified.

2.10 SPINCASTING NO. 2

Based on the results of the epoxy test program, the decision was made to go ahead with a new spincasting. A number of precautions were taken to ensure that the quality of the epoxy was protected throughout the process. An enclosure was built around the spin table and the entire area was temperature and humidity controlled.

The entire surface of the mold was cleaned down to bare metal using a high speed disc grinder with a coarse grit wheel. All signs of the previous primer were removed. The mold was then flushed, cleaned and treated in accordance with Appendix C. "Cleaning of Spincast Mold & Cover". A good water break test was obtained indicating the surface had been thoroughly prepared and cleaned. Similar treatment was given the polyester mold cover as well.

Because of the nature of the separation that had occurred between the epoxy and the mold substrate it was decided to make lap shear tests of the bonding or primer epoxy. A number of different primers were considered and two were chosen for testing.

a. Pentamid 815 and Teta
b. Pentamid 815, Cabosil, Toluene and Araldite resin No. 571Kx.

Five lap shears of each were prepared. The results of this testing are shown in Appendix D. The second formulation noted above gave the best results both in actual strength and in cohesive rather than adhesive failure.

The mold and cover were then sprayed with the selected primer, air and elevated temperature cured in accordance with PIR 4622 - 103, (Appendix E). Quality Control samples were prepared and bonded in the same manner. During the post cure, the cover was elevated above the surface of the mold to permit the removal of vapor by free circulation of the air in and around the mold. After allowing the temperature to drop to 100°F, the cover was lowered and fastened to the mold prior to removal from the oven. Scratch tests of the thickness specimens indicated a complete cure without any of the "cheese-like" characteristics observed on the back of pieces of epoxy taken from the failed mold.

The lap shear samples were prepared with the mold and showed good strength characteristics. The hardness of "hockey puck" specimens of the primer was checked and found to be 70-75 Shore A instantaneious and 20-22 Shore D instantaneous. Tests made on a piece of the mold which failed showed 85-90 Shore A and D indication. The primer used for that casting was less flexible than the one applied to the substrate for the second spincasting. The thickness of the primer as measured on 12 x 12 inch sample panel was shown to be 5 to 15 mils.

The mold structure was successfully aligned to the pre-established holes and pins and leveled with the adjusting screws in each corner of the triangular support structure. The table was spun to observe wind effects within the new enclosure built to provide close temperature control around the mold. The turbulence was materially less than experienced in previous pours since the air was pushed ahead of the table around the octagonal room. The environmental enclosure built around the spintable was designed to maintain temperature control to within $\pm 2^{o}$F with a 72^{o}F ambient. Six thermocouple locations were selected to observe room temperature.

Balancing of the table was done at 16 RPM with the use of dial indicators. Maximum deviation of 0.001 inch vertical and 0.003 horizontal were observed. This was well within tolerances previously established. The dial indicators were left on during all spin operations and were read periodically to ensure that deflections did not exceed those established as acceptable. Motor drive current required was also less. The table RPM counter checked out well and showed excellent speed control was being maintained by the Kinetrol drive unit. The table operated satisfactorily throughout all pour and spin cast periods.

Emphasis was placed on quality control throughout the contract. The primary consideration was given to the use of epoxy samples produced prior to and immediately following the three pours. The resins and catalysts were put in their respective tanks which were then degassed and pressurized with N_2 for feeding to the pumping equipment. Samples were taken from each pump and weighed to be sure that the proper amount of each would be delivered to the mixing head. Samples of the resulting mixture (epoxy) were then poured into 10 inches pyrex pie plates and allowed to cure at ambient and elevated temperature.

Sample identification is found in Appendix F. In addition to duplicating the cure conditions of the mold (i.e., 72°F ambient cure), it was decided to cure samples both above (77°F) and below (67°F) ambients as a further check on the effects of temperature on the quality of the epoxy. In each case, ambient cure was followed with an elevated cure of 120°F for a period of approximately 15 hours. Ambient temperatures other than the 72°F were obtained in a small environmental chamber located outside the spintable room. Other samples were cured in the room with the mold.

All mixing and pumping equipment was thoroughly flushed and cleaned immediately following each pour as a precautionary measure. Pump calibration was conducted prior to each sample run and pour to assure proper proportions going to the mixing head.

Pours 1, 2, and 3 were made by pumping directly from the mixing equipment through polypropylene tubing into a flow controlled funnel placed in the pour pipe located on the top of the mold. Prior to each pour, the mold was purged with dry nitrogen for a period of 4 to 5 hours. Each pour took approximately 45 minutes and consumed roughly 12-13 gallons of epoxy. Samples were taken following each pour, again for determining the expected quality of the mold. In addition, a pour from batch one and batch two was made on the small (30 inches) spintable to permit determination of the completion of the "setting" time of the epoxy after which the large table could be stopped. In general, this ambient spin cure was about 42 hours in length. No difficulty was encountered in any of these operations.

Observation through the glass ports in the mold cover during the three pours indicated the surface was irregular during pours 1 and 2. The flow of epoxy from the center to the outer edges was uneven. Some irregular lines were observed near the center following pour No. 2. Pour No. 3, however, flowed very evenly suggesting irregularities in the No. 1 pour surface were effectively corrected by pour No. 2.

Following completion of pour No. 3 and the normal (32-42 hours) spin cycle, the thermal cure cycle was started. Temperature in the spincast room was raised at a rate of 5^{o}/hour from 72^{o}F to 120^{o}F. The cover of the mold was raised about 6 inches to allow free air circulation during the thermal cure. Again, to make sure that the test samples "saw" the same environment as the mold, the plastic and aluminum sheet covers were removed. The total period of elevated or post cure was 19 hours. This is somewhat longer than previous cure periods and was purposely extended to provide additional assurance that all vapors (amines) were driven off prior to lowering the temperature.

Temperatures were lowered from 120^{o}F to 85^{o}F (with the cover back in place) at a rate of 3^{o}F per hour. Samples were removed from the room and sent out for chemical compatibility tests. Samples which were cured in the same manner as the mold tested satisfactorily. Two of the samples were subjected to electroforming tests. These produced bright ductile nickel indicating a stable epoxy had been produced.

The cover was removed from the mold and visual inspection made. The surface was considered to be excellent in appearance and an optical inspection was begun immediately. The adjusted mean slope error was found to be 34. 8 arc seconds. Results of this inspection are found in Appendix G.

2.11 REFERENCE

2-1 Final Report--9. 5 Diameter Master and Mirror, GE Document No. 64SD540 dated March 20, 1964

BLANK PAGE

SECTION 3
ELECTROFORMED NICKEL MALE MASTER

This section describes the work conducted in fabrication of the nickel male master from the second epoxy spincast mold. It includes the optical inspection and efforts to introduce minor realignment of distortions observed during the optical inspection.

3.1 PREPARATION OF EPOXY MOLD FOR ELECTROFORMING

Critical steps in electroforming nickel on epoxy masters are the preparation of the epoxy surface, the backup structure and dry running of the entire system into the empty tank prior to placing the mold in the nickel sulfamate bath.

It was necessary to mask off all areas of the mold support structure which were not already stopped-off to prevent attack by the electrolyte. This was done by applying a combination of tape and microstop to all exposed bare metal. The edge of the mold beyond the scribed line was treated with collodial silver to assure a good current flow and to minimize the chance of hangup at this point of contact when the male master was separated from the epoxy mold. A center plug of epoxy was removed from the mold to permit flow of nickel sulfamate bath around and "through" the mold. The edge of the hole was rounded off, smoothed and collodial silver applied to assure good current. This sample was also used to permit a test (chemical and nickel plating) of the actual mold epoxy material prior to placing the mold in the bath.

The nickel sulfamate temperature was brought up to 100°F while the room temperature was approximately 90°F. This was done to minimize thermal shock to the mold when lowering it into the bath and to minimize delay time between surface preparation and the start of electroforming.

The cleaning, sensitizing and silvering of the surface followed. The cleaning was accomplished by spraying a solution of $Na_2 Co_3$, $Na H_2 Po_4$ and a wetting agent directly on the face of the mold. This was continued until a water break-free condition was achieved. The surface was then sensitized with a stannous chloride solution and then silvered by a chemical reduction of an ammoniacal silver solution. Each of the above steps was accomplished without difficulty.

The mold was lowered into the bath slowly, allowing the bath temperature and mold to reach equilibrium before submerging it completely. Secondary or auxiliary anodes were used to provide a cathodic condition for the mold. Bath stress levels for the selected plating conditions were 1100 psi at this point. Solution temperature was gradually raised to 120^{o}F.

During the first 24 hours, a rise in stress level was noted. Based on the stress cell readings current density was reduced while an evaluation of the cause was made. It was found that the filters in the recirculating system had not been properly charged with carbon; consequently, impurities were building up. Following a carbon charge, the stress markedly decreased and current density was again brought up to 20 asf. Stress levels did not reach an alarming level at any time and there was no indication of any damage to the mold or the electroform.

Deposition proceeded at a average plating rate of approximately one mil per hour. It was determined that at the end of 19-1/2 days enough time had elapsed to permit the deposition of 3/8 inch of nickel on the epoxy mold. This was the predetermined amount desired to produce a satisfactory mirror master. The current flow from the generator was discontinued and a trickle drain from the backup battery took over. The tank was drained of sulfamate solution, the electroforming cell was removed and the mold was then flushed down with 120^{o}F water.

Inspection of the back surface of the master showed it to be generally smooth; however, there were a few nickel nodules ranging from 1/4 to 1 inch high. They were localized and were not considered to be of any real significance. It was noted that some iron had deposited on the anode bags and that some peeling of the epoxy paint on the liner of the tank had taken place. This condition explained the presence of the nodules, but because the change did not occur during the early plating time period, the front surface of the master was considered to be "safe". (This was shown to be true based on inspection following separation.)

3.2 SEPARATION OF NICKEL MASTER FROM THE EPOXY MOLD

It was decided that separation of the master and mold would be attempted by a mild thermal sh ing rather than the more severe shocking required by the JPL mold/master. To accomplish this, two parallel 1/2-inch copper tubes were epoxy-bonded to the back side of the nickel master. Liquid fittings were attached to the open ends to permit the attachment of hot and cold water and/or liquid nitrogen lines. All nodules which exceed 1/4 inch were removed by cutting wheel. The entire surface of the nickel back side was coated with a primer coat (Ferroprene) to assure good bonding when the backup structure was foamed into place. The structure itself was abraded with a grinding tool using a heavy grit paper and it, too, was coated with the same primer.

A bonding epoxy used to secure the conforming fiberglass backup structure ' the nickel male master. It is a closed-cell urethane employing a fluorinated hydrocarbon as the expanding agent. The foam is generated by mechanically mixing approximately equal quantities of resin and catalyst and then pouring into the area between the nickel master and the backup structure. Curing time is rougly 24 hours.

Hot tap water (150^{o}F) was directed through one of the embedded coils and allowed to circulate all night. Temperature at the coil entrance and a point on the nickel master midway between the coils was monitored by thermocouples. A previous analysis showed that a temperature differential of 50^{o}F was perfectly safe. Temperature of the nickel the following morning was only 120^{o}F. Cold water (50^{o}F) was then directed through the parallel coil, but it failed to bring down the nickel temperature with any noticable degree of rapidity. Obviously, insufficient thermal shocking was being effected by the coils.

The mold was then inverted with the backup structure on the bottom, but raised an inch or so from the floor. Liquid nitrogen was directed across the back side of the aluminum epoxy mold and the structure was vibrated with hammers until separation occurred. Visual inspection of the master showed it to be of excellent quality with only one or two very minor etch marks.

3.3 OPTICAL INSPECTION (SEE APPENDIX F)

Since a prime objective of this contract was to provide a high quality master from which additional concentrators might be produced, it was improtant to determine the actual geometry of the surface. Therefore an optical inspection was undertaken to provide this information.

The master was placed on the spin table and leveled. During the leveling operation, a warpage was optically (with transit) observed such that the scribe line over the three support points was high, with an apparent "droop" between supports. Although it was felt that the backup structure was sufficiently rigid to prevent this distortion, one of the supports was replaced with two supports shifted approximately 60 degrees. No change in distortion was observed indicating adequate rigidity of the backup structure. The technique used for the optical inspection of the master is shown schematically in Figure 3-1. A light source and lens assembly were sequentially located to produce a converging beam of light on the nickel master at a point directly beneath the objective lens of telescopes 1 through 8. The eyepiece of the telescope was adjusted,when necessary, to provide a best-fit image in the field-of-view. This adjustment was made as a convenient "vernier" rather than making small changes in the location of the light source, and was considered acceptable for obtaining relative readings ot the optical quality of the master. Readings were made at 5 degrees increments for each of the eight telescopes, and the data was reduced by the 7094 computer program. The program has been improved to utilize a computer recorder to provide direct printout of the

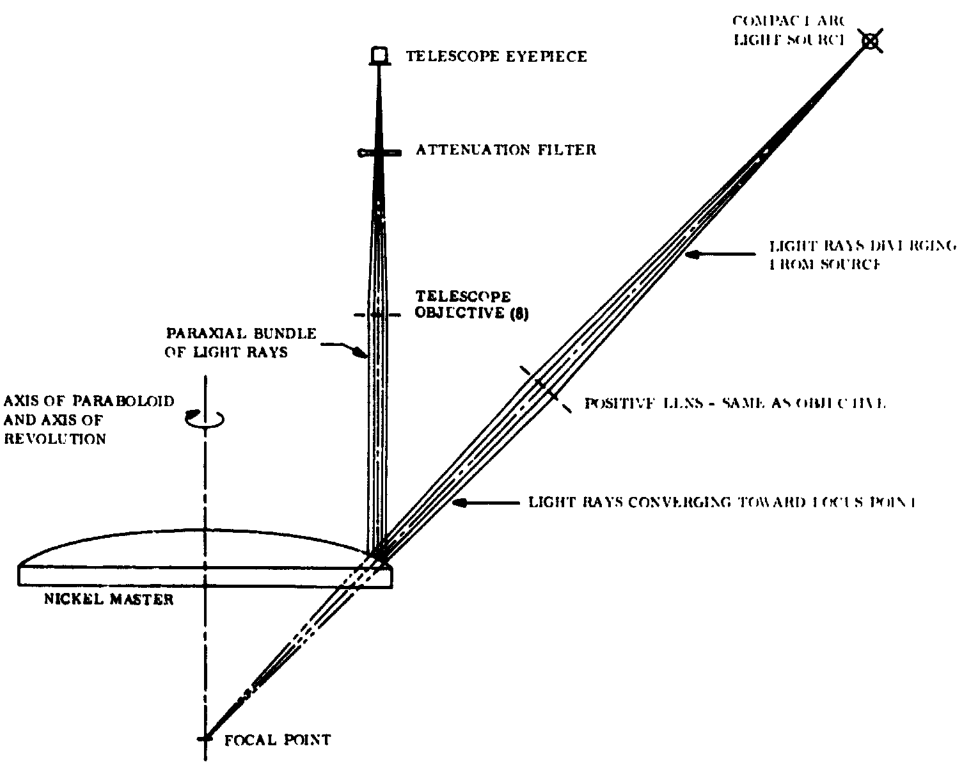


Figure 3-1. Optical Schematic For Inspection of Mirror Master

curve data. Curves were produced for both raw and adjusted data based on all 8 telescopes, the same as was provided for the mirror and spincast master. In addition, adjusted curves were produced based on individual telescope readings since a comparison between the 72 readings of any one telescope are the only valid indicators of the quality of the master surface. The formula for converting the telescope readings to slope errors is:

$$\text{Adjusted slope error} = \sqrt{(x_n - \bar{x}_n)^2 + (y_n - \bar{y}_n)^2}$$

where n = telescope Nos. 1 through 8

The similarity between the adjusted readings per telescope (above) and the raw and adjusted readings based on all telescopes indicated the alignment of all 8 light sources was such as to provide an average telescope reading near 50 for both the X and Y slope errors.

The average adjusted slope error for each telescope was as follows:

TELESCOPE	AVERAGE SLOPE ERROR (Minutes)
1	4.097
2	3.275
3	3.132
4	2.567
5	2.939
6	2.437
7	2.101
8	2.153

The average slope error for all telescopes is 2.838 minutes, slightly better than the raw or adjusted average slope error based on total readings of all 8 telescopes. Table 3-1 is a distribution of raw slope errors based on all readings for telescopes 1 through 8.

TABLE 3-1. RAW SLOPE ERROR DISTRIBUTION, 10-FOOT DIAMETER NICKEL MASTER

Telescope Number	SLOPE ERROR RANGE (MINUTES) 0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9
1	0	6	13	16	17	7	7	5	1
2	5	9	11	16	21	8	1	1	0
3	2	16	15	15	20	4	0	0	0
4	16	13	11	19	11	2	0	0	0
5	2	6	9	24	25	5	1	0	0
6	12	24	6	11	18	1	0	0	0
7	10	25	14	9	13	1	0	0	0
8	4	12	33	17	6	0	0	0	0
All Telescopes	51	111	112	127	131	28	9	6	1
Σ	51	162	274	401	532	560	569	575	576
%	8.9	28.2	47.7	70.0	92.5	97.5	99.0	99.9	100

Table 3-2 is a distribution of adjusted slope errors based on all readings for telescopes 1 through 8.

It was expected that the optical inspection of the nickel master would show it to be considerably better than the mirror duplicated from it. Inspection data showed, however, that the master was in fact closer to the mirror than to the epoxy spincasting.

Figure 3-2 is a curve showing the percentage of the slope readings equal to or better than any given error value for the original epoxy spincasting, the nickel master, and the electroformed mirror replica.

TABLE 3-2. ADJUSTED SLOPE ERROR DISTRIBUTION, 10-FOOT DIAMETER NICKEL MASTER

Telescope Number	SLOPE ERROR RANGE (MINUTES)								
	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9
1	1	7	7	25	12	7	8	4	1
2	5	12	13	12	17	11	1	1	0
3	1	17	19	13	16	6	0	0	0
4	11	20	11	12	13	5	0	0	0
5	3	8	7	27	22	5	0	0	0
6	18	18	6	10	13	7	0	0	0
7	19	16	15	10	11	1	0	0	0
8	3	20	33	12	4	0	0	0	0
All Telescopes	61	118	111	121	108	42	9	5	1
Σ	61	179	290	411	519	561	570	575	576
%	10.6	31.2	50.4	71.5	90.2	97.5	99.2	99.9	

The degradation of the nickel master compared with the epoxy master is related to the ±0.05-inch warpage which was observed when the master was being aligned on the spin table for optical inspection. There is a fairly good correlation between the measured distortion and the expected distortion due to a ±0.05-inch warpage in the paraboloid. As a first approximation, the angle formed by the 0.05-inch movement at a 60-inch radius is arc $\tan \frac{0.05}{60} = 0.0008 \simeq 0.00003$ arc minutes. The maximum slope error, however, is greater than a linear function of the radius and the deflection. It more nearly follows a cantilever beam, with the slope error increasing at increasing radii. The actual measured maximum slope errors were two-to-three times the three minutes obtained by the simplified approximation.

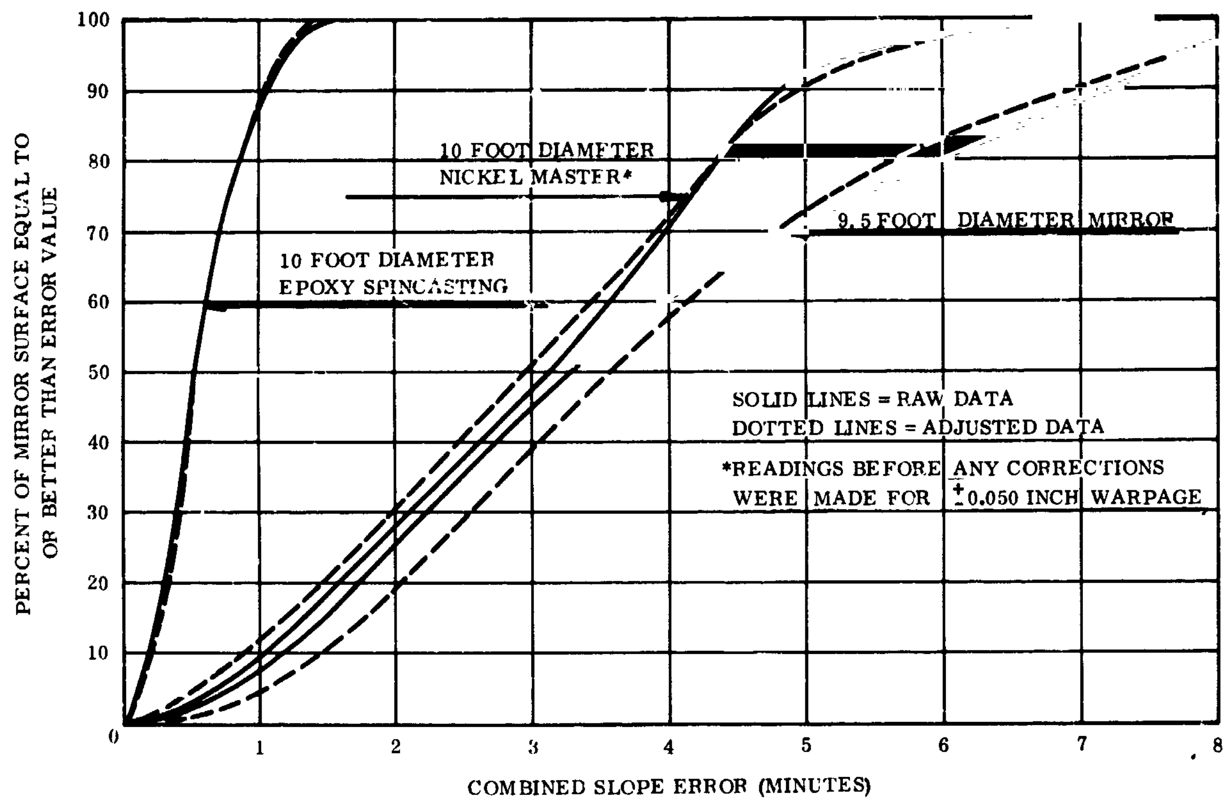


Figure 3-2. Combined Slope Error - Minutes

3.4 MASTER REALIGNMENT

An attempt was made to reduce the warpage in the nickel master by application of a radial compression force at the high points on opposite sides of the master (see Figure 3-3). Force was applied by tightening the loading bolts on a force input beam assembly. The load at each point was spread over a distance of 24 inches around the periphery of the master by a pair of conforming shoes in order to prevent local rippling of the nickel master. Approximately 5400 pounds of force was applied to the master, causing an average compressive load of 600 psi locally. Measurement was initially made by optical jig transits viewing the outer scribe line on the nickel master, the objective being to adjust the radial force input to the master to obtain a minimum variation in the elevation of the scribe line. A maximum of approximately 5400 pounds of radial compressive force was applied to opposite sides of the master at points where the scribe line was observed to be about 0.05 inch high. Measurements were made at 0, 1800, 3600, 5400, and again at 0 load; but no characteristic pattern could be detected in the results.

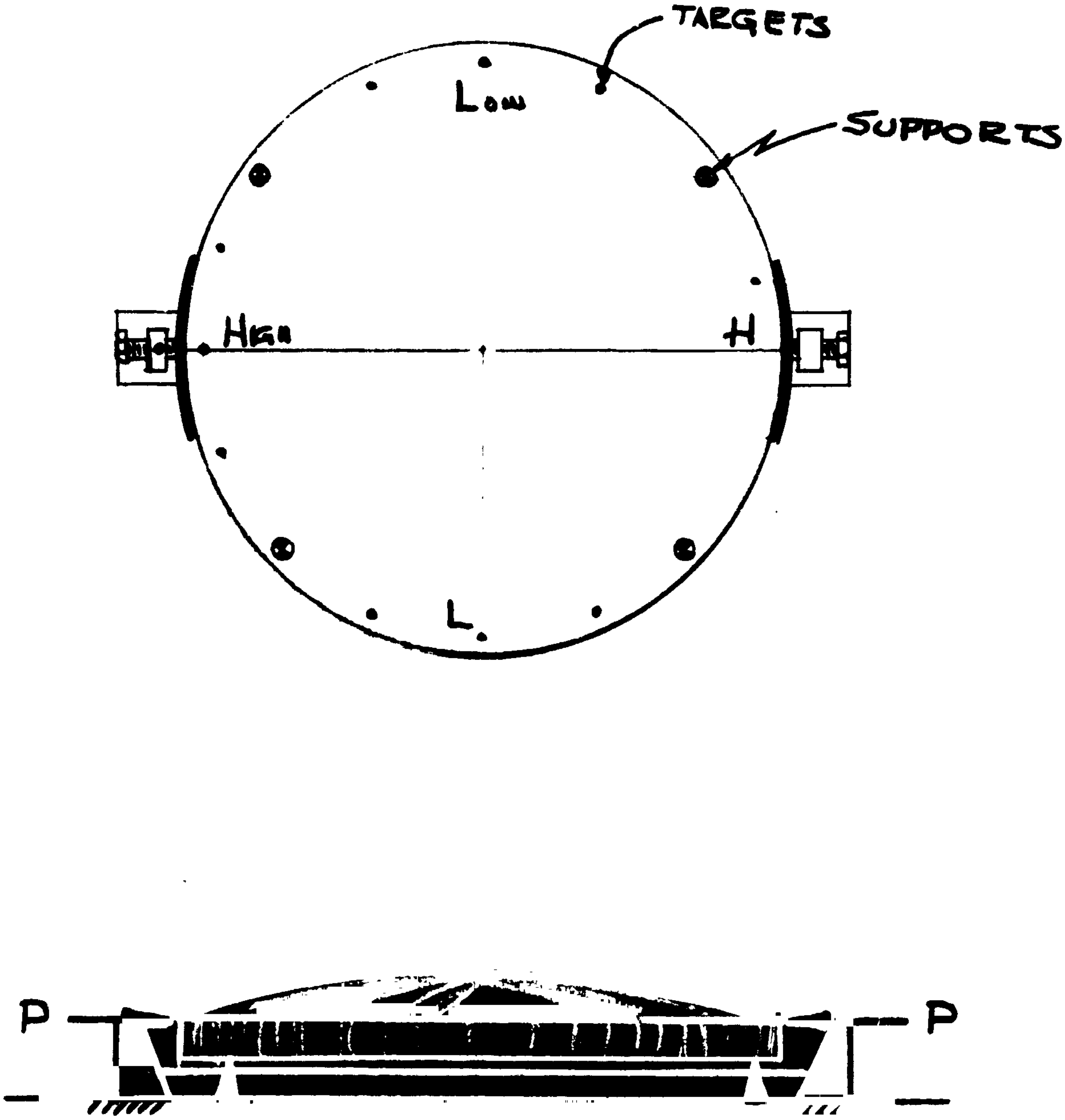


Figure 3-3. Force Input

A recheck of the optical inspection of the nickel master was then made to determine if any permanent changes were evident in the master, and to establish a base reference for observing the change in optical quality where loads are applied to the master. A complete check at 5-degree increments was made for all eight telescopes; the results are shown in Appendix I. In general, the performance appeared to be the same as shown for the first optical inspection of the master.

A load of 5400 pounds was then applied to the master by means of the force input beam assembly at the two high points on the master. The force was generated by applying 600 inch-pounds of torque to a load input bolt on the force input beam assembly. The force is related to the torque by:

$$T = FR \frac{P + \mu C}{C - \mu P}$$

where
- T = torque applied
- F = force in pounds
- R = mean radius of screw = 4.5 inches
- P = pitch of screw = 0.125 inch
- C = Mean circumference of screw = 2.83 inches
- μ = coefficient of friction $\simeq$ 0.2

Actual applied force can vary over a fairly wide range, probably $\pm$ 25% due to variations in the coefficient of friction.

Curve, Figure 3-4, shows the change in radial slope reading with 5400 pounds of compressive force applied at the 170 and 350-degree reference positions. Slope changes occurred to a greater extent on the No. 1 telescope which is at the maximum radius. The correction seemed to occur over an angular range of 20 to 25 degrees, which corresponds with the 24-inch length of the load input shoe. Slope change, which was noticeably smaller on the No. 2 and No. 3 telescopes, was not noticeable at all on the No. 8 telescope.

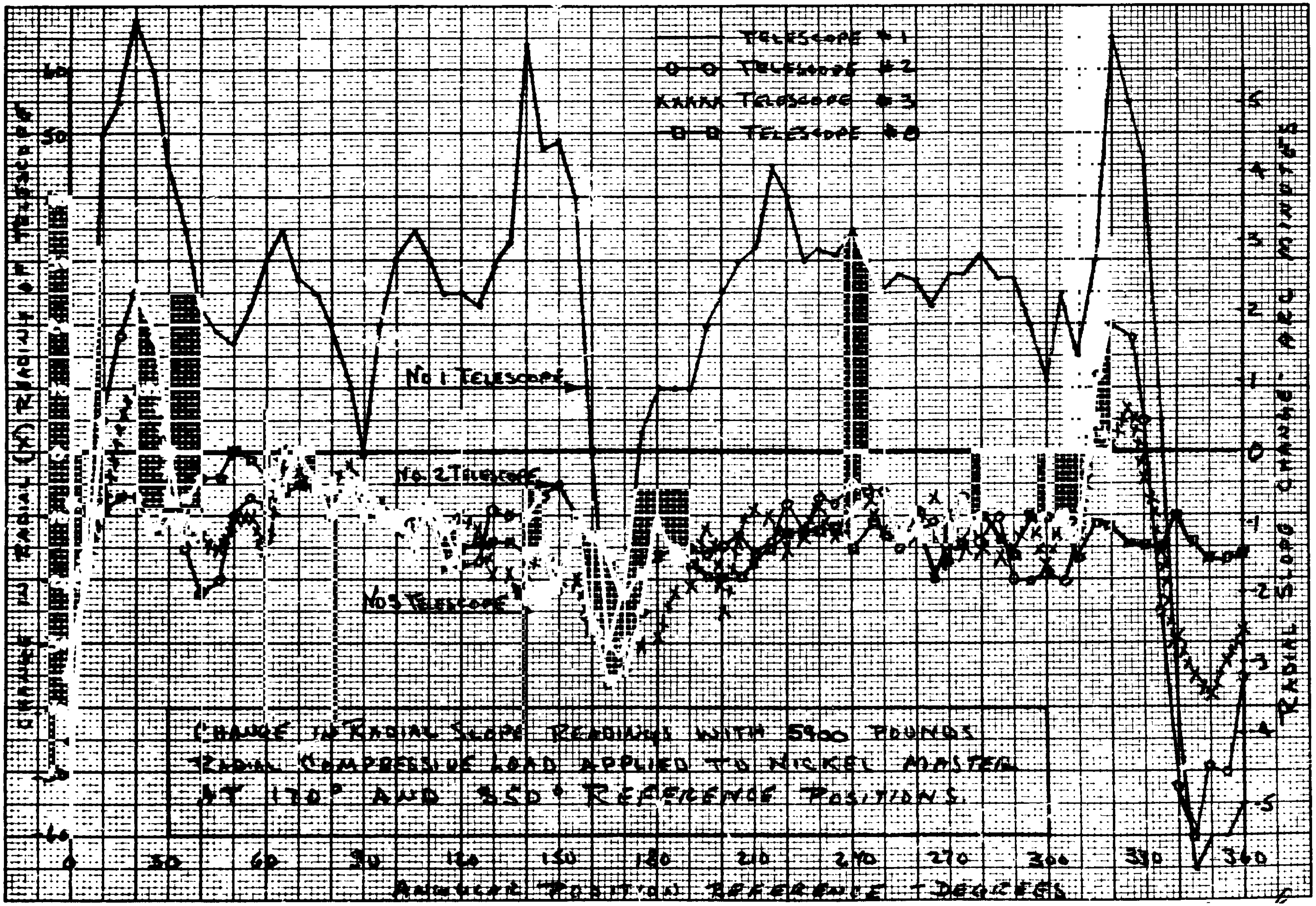


Figure 3-4. Change in Radial Slope Readings With 5400 Pounds Radial Compressive Load Applied to Nickel Master at 170 and 350-Degree Reference Positions

The next test was an attempt to develop a bending moment in the master by applying a downward loading at the points of load application with the force input beam assembly. A small (200-pound) force was applied to each end of the beam with the reaction being taken by the load support jacks. It was thought that some slight corrective action would be observed, although the differential readings on the No. 3 telescope showed no detectable effect. Later calculations showed that the tensile stress in the nickel master is in the order of 10 psi, much too small to cause a corrective action (Figure 3-5).

The best adjusted average slope error reading obtained during the effort to realign the master was 2.893 arc minutes versus the 3.008 arc minutes read prior to this undertaking.

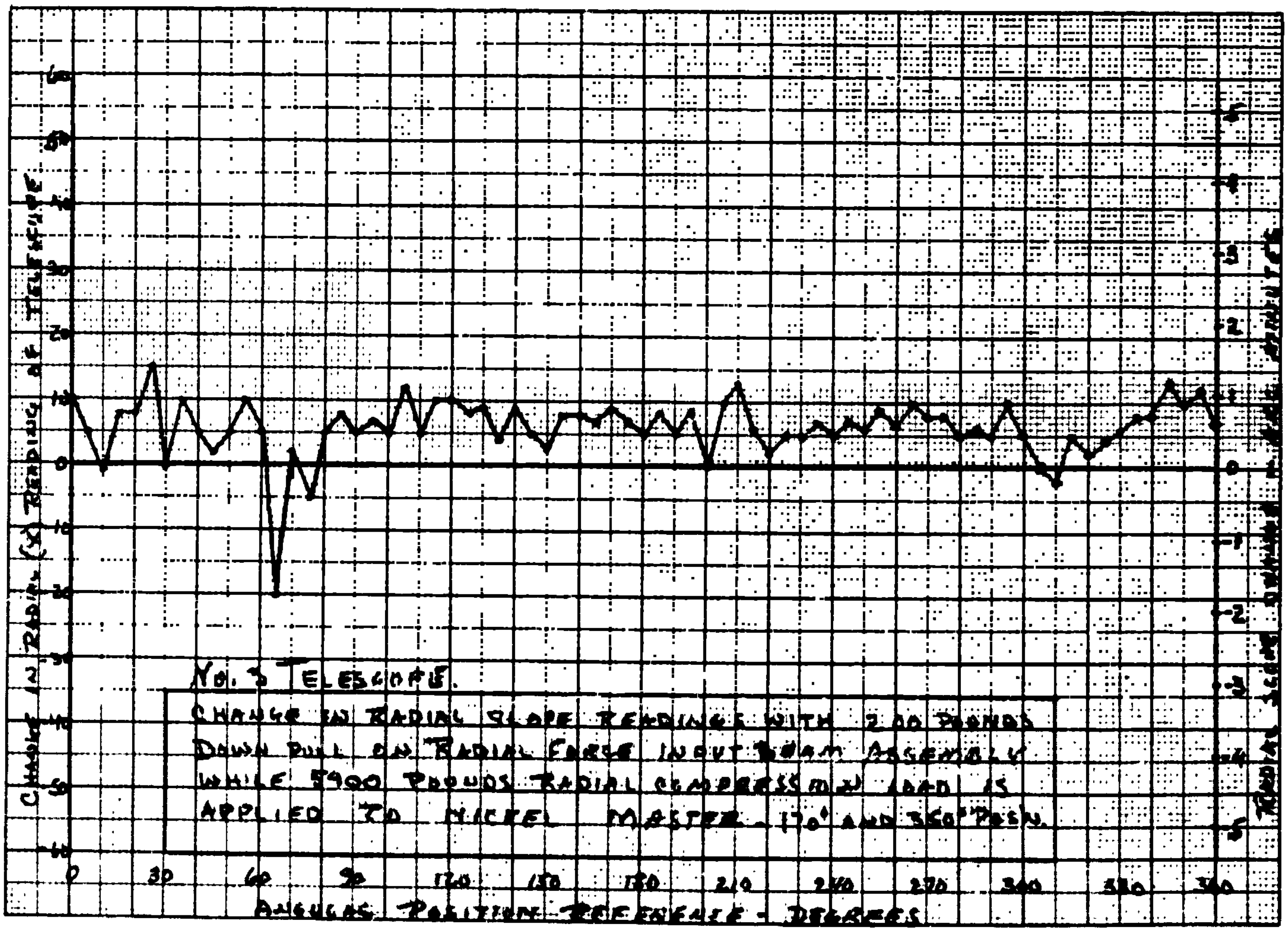


Figure 3-5. Change in Radial Slope Readings With 200 Pounds Down Pull On Radial Force Input Beam Assembly While 5400 Pounds Radial Compression Load is Applied to Nickel Master, 170 and 350-Degree Positions

SECTION 4
ELECTROFORMED MIRROR AND INSPECTION

4.1 ELECTROFORMED NICKEL MIRROR

Optical inspection of the nickel master reported in Section 3 did not take place until after the mirror was electroformed and inspected. In practice the master was made ready for electroforming of the mirror immediately after being removed from the bath, rinsed and visually inspected.

The following preparatory work was performed to ready the master for electroforming the mirror.

a. Excess bonding foam was trimmed away.

b. The cove ring (copper) used to form the nickel transition between the mirror and the torus ring was cleaned, fitted, knife edged and silver lacquer sprayed.

c. Bakelite clamps for securing the cove ring to the master were cut and shaped.

d. All of the silver on the nickel surface was removed by hand polishing with french cotton.

e. The anode baskets on the rotating mechanism were cleaned, inverted, filled with new nickel anodes, bagged and locked into position.

f. A specially designed anode conforming to the cove ring was fabricated and secured to the ends of the baskets.

g. The center or crown grow-in ring was plated with nickel and secured to the center of the master.

h. A rubber shield was cut and placed on the edge of the cove ring to ensure that the depositing nickel was directed to the critical point between the cove knife edge and the master.

i. A dry run was made in the tank to assure that the rotating anodes were at the right height from the master. Adjustments,as necessary,were made to the mechanism and the master.

j. The master was silver sprayed and the cove ring was clamped in place.

k. The entire assembly was then lowered into the nickel sulfamate bath.

Electroplating of the mirror was performed at approximately 2200 amps or 27.5 amps/ft^2 for a period of 38 hours. This combination was designed to yield a mirror thickness of approximately 40 mils. Stress readings were taken throughout the electroforming run in order to maintain as low a stress level as possible. Control of the stress was maintained by changing the current density, carbon filtration and bath temperature. Table 4-1 shows the actual readings recorded during the deposition period. The nickel mirror was electoformed at conditions yielding the lowest stress values practical and were in fact lower then any previous electroforming work completed by General Electric on similar configurations.

TABLE 4-1. DEPOSITION STRESS OF NICKEL SUFAMATE SOLUTION, IN PSI

STRESS RUN	CURRENT DENSITY RANGE, ASF 6 - 10	10 - 15	15 - 20	20 - 35
A - 11/22, 120°F	1100C	2300C	11300C	4200C
B - 11/22, 110°F	2600T	3800T	16000C	200C
C - 11/23AM, 110°F	1200C	3300T	8500C	1100C
D - 11/23AM, 120°F	1400C	750T	8500C	450T
E - 11/23PM, 120°F	1850C	2350T	1800T	2000T
F - 11/24, 120°F	2500C	200T	5000C	3500T

C Denotes compressive stress
T Denotes tensile stress

After shutting off the current, the bath was drained and the mirror/master was flushed thoroughly with fresh tap water.

4.2 SEPARATION OF MIRROR FROM MASTER

Plans were generated for separating the mirror from the master using vacuum techniques. A time period of one week elapsed between the completion of the electroforming and the arrival of the master/mirror combination at the vacuum chamber facilities.

While preparing for vacuum separation, it was noted, that partial separation had already taken place at the area between the cove ring and the nickel master. Tapping on the back of the mirror also indicated that areas of little or no contact between the mirror and master existed. Vacuum separation plans were therefore abandoned. The nickel torus ring was epoxy bonded to the cove ring and allowed to cure overnight. Steam lines were connected to the built-in copper tubing in the back of the master and a plastic sheet was spread over the top of the back side of the mirror.

Crushed ice was dumped on the sheet while steam was passed through the coils.

To provide for a constant pull upward on the mirror, three spring balance scales were attached to a triangular sling and secured to the hard points of the torus. Lifting action was accomplished by applying a constant pull with a sensitive overhead crane on the sling (120 pounds on each scale).

After approximately one-half hour of cold shocking, separation was completed and the mirror was moved away from the master and placed on a specially constructed wooden frame. Visual inspection of the mirror was made and the distortions noted below were observed. In addition, staining or discoloration was apparent from the outer edge inward for approximately 2 feet. This was attributed to oxidation of the silver and interaction of the silver and sulfamate atmosphere during the period the master/mirror combination was in the drained bath tank at the electroforming vendors. The stain proved to be easily removable with french cotton polishing. It was also observed that the silver adhesion to the mirror was excellent and none was left on the master.

A brief discussion of the local distortions follows:

4.2.1 TORUS ATTACHMENT

An unexpected difficulty was experienced in the attachment of the torus to the electroformed reflector. Care was taken during the fabrication of the torus to relieve the rolling and welding stresses by annealing. A small amount of trueing up was required after stress relieving to achieve a roundness and flatness within $\pm 1/8$ inch. This tolerance was established to provide a maximum thickness of epoxy bond no greater than one-fourth inch. Unfortunately, the alignment of the copper cove ring was not held within tolerance when it was applied to the electroformed nickel master. This out-of-tolerance condition was not taken into consideration during the bonding of the torus to the cove ring, with the result that serious mismatch occurred between the two. Furthermore, excess epoxy remained on the cove ring, stiffening the ring and adding to the distortion of the reflector.

4.2.2 LOCAL STICKING OF REFLECTOR TO ELECTROFORMED MASTER

Two points were observed where the electroformed reflector formed a strong electro-chemical bond to the master. These points were not apparent when the separation was initiated, resulting in localized areas of distortion in the immediate areas of the sticking. Performance of the reflector was not affected appreciably by these distortion areas since the percentage of the total surface is small - in the order of 0.1 to 0.2 percent of the total reflector area. These attachment points could have resulted from localized imperfections in the nickel master, although it is believed that they were caused by dirt particles failing on the nickel master after chemical silvering and before placing the master in the electroforming solution. Salts from the electroforming baths in the dirt particles can react with the H_20 on the surface of master to activate the surface and cause a strong electrochemical bond to the nickel master.

4.2.3 SEMICIRCULAR DISTORTION AREA

A localized area of distortion occured at one edge of the mirror where a large number of small "dimples" were observed. This area was surrounded by an arc of a circle where there was a noticable change in slope.

Mirror thickness measurements were taken using the same ultrasonic technique described in Reference 2-1. The average thickness was 37 mils or within 7 percent of the design of 40 mils (Table 4-2).

4.3 OPTICAL INSPECTION

Optical inspection of the mirror was made using a 75-watt xenon lamp at the focal point and eight telescopes located at various radii such that each telescope represented an equal area on the mirror surface. The aperature of each telescope was stopped down to less than one-fourth diameter. The focal distance was measured and was found to be 68 11/16 inch from the flat front surface of the ring at the center of the mirror. Telescopic readings were taken at 5 degrees increments around the mirror on each of the 8 telescopes, yielding a total of 576 inspection points. There were 37 points where the reading fell outside the field-of-view of the telescopes, although in many cases, some light could be seen indicating that the point was near the field-of-view. (The field-of-view is approximately 7 minutes of slope error). A conservative estimate of the value of these points was made by assuming a telescopic reading of 150 - 150 for these points. This gave an assumed slope error of 13 minutes for these points which is believed to be much greater than the actual value. The average adjusted mean slope error was found to be 4.320 arc minutes. (See Appendix J.)

Preliminary analysis of the results showed that there was an area in the region of 110 to 220 degrees where the readings were greater than about two minutes of slope error. One support point was moved approximately 10 inches to force the mirror into a more desirable position (due to its own weight). Readings were then taken at 10-degree increments at which time all except three of the 288 readings were within the field-of-view of the telescopes. This data is shown in Appendix K. Data is in arc minutes and is presented as produced by the computer recorder and the 7094 computer. The average adjusted mean slope error was read as 3.917 arc minutes.

Table 4-2. 9-1/2 FOOT MIRROR THICKNESS

Ref No.	Radius Inches	Ref Angle	Thickness Inches	Ref No.	Radius Inches	Ref Angle	Thickness Inches
1	50	90	*	33	35	210	0.036
2	50	75	*	34	35	180	0.036
3	50	60	*	35	35	150	0.037
4	50	45	0.039	36	35	120	0.037
5	50	30	0.039	37	20	90	0.036
6	50	15	0.040	38	20	30	0.035
7	50	0	0.039	39	20	330	0.035
8	50	345	0.040	40	20	270	0.035
9	50	330	0.039	41	20	210	0.034
10	50	315	0.039	42	20	150	0.035
11	50	300	0.040	43	8	90	**
12	50	285	0.038	44	8	30	**
13	50	270	**	45	8	330	**
14	50	255	0.038	46	8	270	**
15	50	240	0.037	47	8	210	**
16	50	225	0.037	48	8	150	**
17	50	210	0.039	49	45	330	0.036
18	50	195	0.039	50	40	330	0.037
19	50	180	0.039	51	30	330	0.036
20	50	165	0.037	52	25	330	0.036
21	50	150	0.038	53	16	330	**
22	50	135	0.037	54	12	330	**
23	50	120	*	55	8	180	**
24	50	105	*	56	12	180	0.033
25	35	90	*	57	16	180	0.035
26	35	60	0.038	58	20	180	0.035
27	35	30	0.037	59	25	180	0.036
28	35	0	0.039	60	30	180	0.036
29	35	330	0.036	61	35	180	0.036
30	35	300	0.037	62	40	180	0.036
31	35	270	0.036	63	45	180	0.036
32	35	240	*	64	50	180	0.038

* No reading

** Too rough for measurement on back surface

4.4 ALUMINUM COATING

It is important to the success of the vapor deposition process that the surface of the concentrator be absolutely clean, free of greases, or other volatile materials. Since a grease-like carrier is used in the french cotton polishing cloth used on the mirror surface, considerable care was exercised to ensure that a thorough cleaning did take place. The cleaning procedure consisted of washing the concentrator first with a cleaning detergent, a hot rinse, followed by washing with an additional detergent and another hot rinse. Two such cleanings were required before a no-water break surface resulted. This was immediately followed by a rinse with distilled water to remove any impurities left by the hot tap water. This rinse was in turn followed by blowing off the excess water with gaseous nitrogen. As soon as the surface was completely dry, it was spray-coated with a strippable lacquer to protect the surface during shipping and storage.

The aluminum and oxide coatings were successfully vacuum-deposited on the surface of the concentrator at Liberty Mirror, a division of Libbey-Owens-Ford Company. The work was performed in accordance with Specification No. 1051 (Appendix L). Tests for reflectivity, adhesion and abrasion resistance were conducted on a flat piece of electroformed nickel which was placed in the open center of the mirror during vapor deposition. This nickel was electroformed at the same time as the mirror and therefore was a true representation of the nickel concentrator surface.

Satisfactory results were obtained in each test. A general haze on the surface of the mirror persisted after application of the coating; however, specular reflectivity of the sample measured 88 percent which was well with contract requirements.

4.5 TORUS DESIGN AND ANALYSES

Since it had been decided that the nominal thickness of the solar concentrator produced under the contract would be 40 mils (versus 72 mils on JPL contract No. 950239 (Ref 2-1)), a detailed structural analysis of the torus supporting the mirror was performed in order to select the minimum section, consistent with manufacturing limitations, capable of fulfilling the mirror imposed strength and deflection requirements. The results of this analysis are found in Appendix M. In brief, a 40-mil thick 3-1/2 inch nickel torus could have been used.

Since contract plans and funding did not permit undertaking a new torus design and fabrication effort, the same design used for JPL mirror was chosen for the contract. A description is found in Reference 2-1. Figure 4-1 shows the detail.

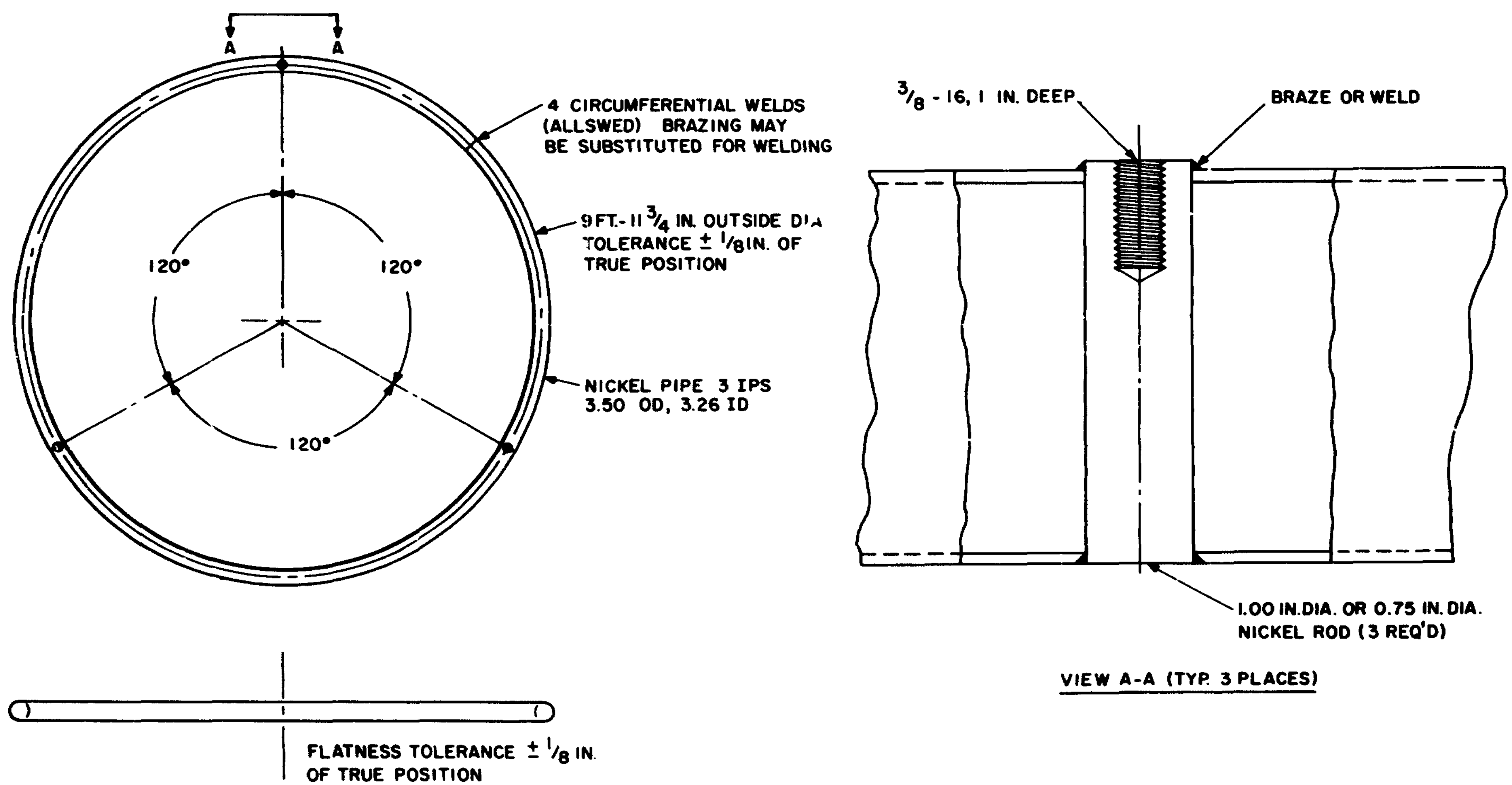


Figure 4-1. Mirror Support Torus

BLANK PAGE

SECTION 5
SUPPLEMENTAL INVESTIGATIONS

As noted in Section 1, Summary and Objectives, additional work was undertaken after the start of the contract to investigate a method of improving the surface of nickel masters and to attempt the separation of an electroformed mirror from a modified master using vacuum techniques.

A 30-inch "scrap" nickel master was "Kanigen" electroless nickel coated to eliminate the porosity of the surface and was machine and hand polished to return the surface to a specular condition. This modified master was then used for electroforming an aluminum mirror to demonstrate the improvements in the master. Separation was accomplished in a vacuum chamber, not without difficulty, however. Two such mirrors were produced since the quality of the first one was unacceptable. The second unit delivered to NASA Langley Research Center showed a much improved geometry over the previous concentrator fabricated from this master. All hangup due to surface porosity in the master was eliminated, indicating that the Kanigen treatment was successful.

5.1 KANIGEN COATING OF NICKEL MASTER

A 5-mil coating of Kanigen electroless nickel was applied to the 30-inch nickel master by Grunwald Plating Company, Chicago, Illinois. The coated master was heat treated at 375-425°F in order to increase adhesion of the coating. Hardness of the coating is shown in Figure 5-1. Several factors concerning Kanigen coating for aluminum electroforming were developed during this investigation.

a. Heat treatment of the Kanigen coating should be at 250°F rather than 375-425°F. At 250°F the coating remains amorphous or non crystaline, and is less likely to be attacked by caustic solutions.* The 8-10% phosphorous which is present in

*Private Communication, Mr. Kerfman, General American Transportation Corporation to D. E. Lee, 14 April, 1965.

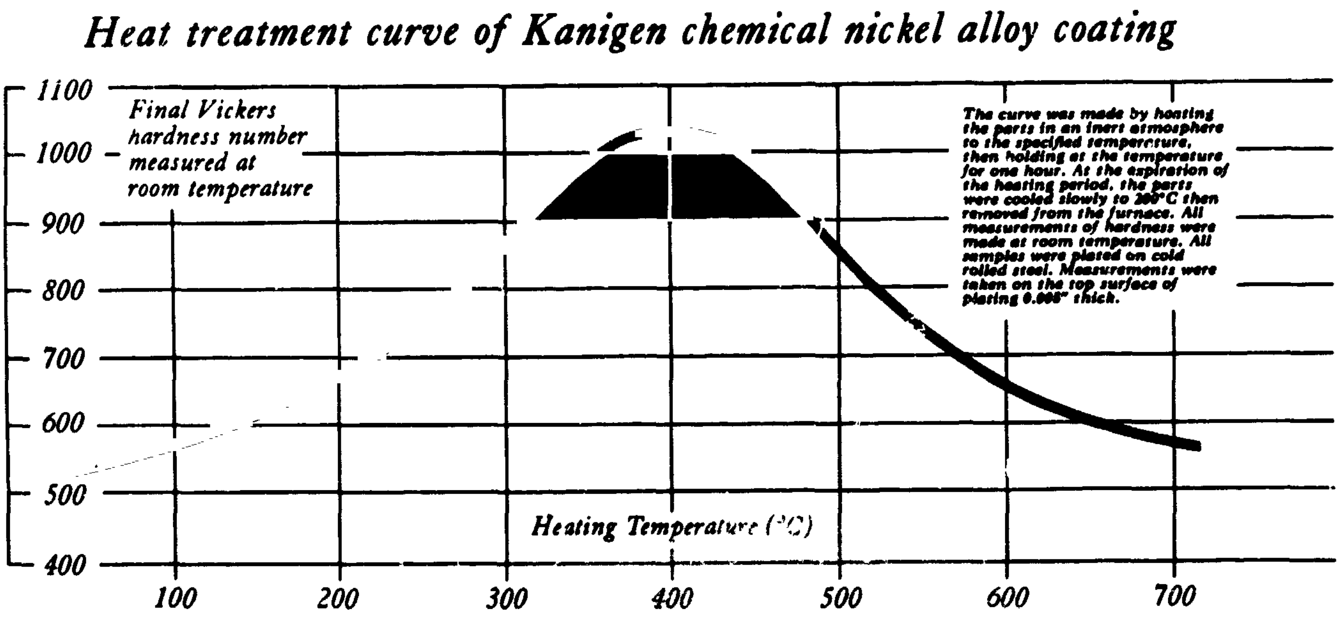


Figure 5-1. Heat Treatment Curve of Kanigen Chemical Nickel Alloy Coating

the super-cooled-liquid st ure of the coating forms tri-nickel phosphide (Ni_3P) crystals on heat treatment. (Tests made on a wash sample from run No. 1 aluminum mirror did not indicate the presence of any phosphorous on the mirror surface although the aluminum electroforming solution is caustic.)

b. Special precautions should be taken during the plating to prevent the formation of surface roughness due to settling of metalic particles on the surface of the master. Shielding, positioning or special fixturing can be used to eliminate this undesirable deposition on the surface of the master. These metallic particles were found to be present on approximately 20% of the surface area near one edge of the master and caused severe wear on the Burgandy pitch lap during polishing of the master. They were ultimately removed by local treatment of the surface with crocus cloth.

c. Any major work on the surface of the nickel master should be done prior to the application of the Kanigen coating to minimize the coating thickness required and to reduce the amount of final polishing of the hard coating.

5.2 POLISHING OF KANIGEN COATED NICKEL MASTER

Initial polishing was undertaken using a mechanical set up. The equipment consisted of the following:

a. An enclosure to exclude most of the external dust and dirt particles.

b. A four-foot diameter horizontal turntable with adjustable drive speed in the order of 5 to 50 rpm.

c. Groups of three polishing laps rigidly mounted to a triangular support structure with 1/16 inch to 1/8 inch crossed vee groves of 3/8 inch to 5/8 inch spacing on the pitch lap surface.

d. A polishing lap mounting surface capable of supporting a number of lap assemblies and movable in a radial direction relative to the horizontal turntable.

e. A polishing lap mounting surface drive assembly to drive the mounting surface in a radial direction relative to the horizontal turntable. The amplitude of the motion was 1/4 inch, the frequency was in the range of 10 to 20 cps.

f. Hand mixed polishing slurry of Linde "A" and "B" compound was applied before the polishing lap assembly on the surface of the nickel master.

g. A six-volt small filament bulb which produced a Schlieren type image of surface characteristics on a screen was used for the surface quality inspection.

h. Centering of the master on the table was accomplished without a theodolite since it was determined that exact centering was not required.

i. The master was directly clamped down to the turntable since it was determined that the exact alignment of the master with the axis of rotation was not required.

Polishing lap mounting surface drive system was a combination of springs, pulleys, weights etc., which established the approximate amplitude and frequency range.

Observations and conclusions obtained from the machine polishing process are as follows:

a. Continuous rotation of the table in one direction tends to produce "comet tails" from any local surface disturbance on the master.

b. Approximately equal speed of lap movement in a radial and circumferential direction is required to minimize or break up line patterns on the surface.

c. A random motion, or some specific motion pattern would be more desirable in producing good optical quality on the master surface.

d. An oscillating (cw-ccw) motion of the table with a very slow precision to cover the entire surface would be better than continuous rotation in either direction.

e. A large pitch lap with some flexibility in the backing would minimize the pattern effect produced by the several small laps. Individual elements (approximately 1/2 square inch) of the flexible lap would be rigid and would provide good polishing action.

Figures 5-2, 5-3, and 5-4 show Schlieren type photographs of the Kanigen coated and polished nickel master.

Figure 5-5 shows a similar photograph of the 30-inch nickel master delivered on contract NAS 1-3309 for comparison purposes. Major dark areas on Figures 5-2, 5-3, and 5-4 are caused by the granular metalic deposit which was embedded in the Kanigen coating. This deposit, when removed, by emery cloth, caused an uneven rate of metal removal in the local areas on the nickel master. The small circles visible on the smooth areas in Figure 5-2 are the result of slightly concave "dimples" in the (scrap) master, caused by the honeycomb condition which developed during electroforming. The sharpness of these "dimples" has been reduced slightly in Figures 5-3 and 5-4 by cloth polishing. The vertical pattern in Figure 5-3 is silver remaining from the faulty separation of the run No. 1 mirror. Additional lap polishing of the master would have removed this pattern from the master.

5.3 THIRTY-INCH DIAMETER MIRROR ELECTROFORMING RUN NO. 1

Electroforming of the aluminum concentrators was accomplished using the electroforming pilot cell described in Section 5.1.

Mirror No. 1 was electroformed on the Kanigen nickel-coated master which had been machine polished to conditions shown in Figure 5-2(worst area) as a Schlieren type photograph. A four-pound tension was applied at each of three points about one hour before time for insertion into the vacuum chamber. Separation occurred after five minutes of pumping at a pressure greater than the 1000 microns maximum reading on the gauge (Figure 5-6).

Examination of the mirror after separation showed the following:

a. Delamination of the aluminum electroform with a horizontal line pattern extending across the mirror master and the top ring assembly. Line pattern showed alternate nickel and silver/aluminum bands.

b. Corrosion on mirror surface, primarily on one edge of mirror.

c. No distortion or other indication of lock-in to pinholes in the nickel master.

d. Local distortion at two points on the ring assembly indicating lock-in to flaws in the machined surface of the ring.

Figure 5-2. Comet Tails and Line Pattern Produced by First Machine Polish of 30-Inch Nickel Master

Figure 5-3. Comet Tails and Line Pattern after Cloth Polish to Clean Up Master Following Run No. 1 Mirror

Figure 5-4. Portion of 30-Inch Nickel Master with Minimum Line Pattern

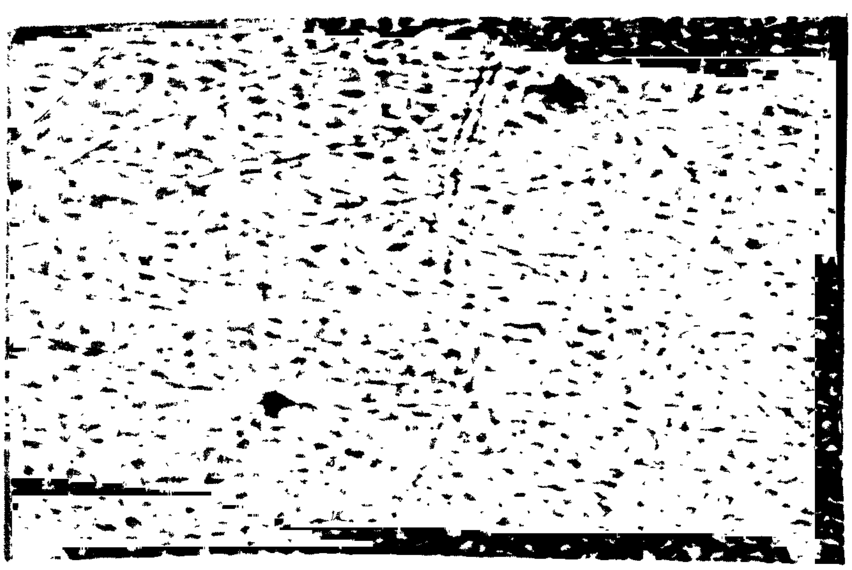


Figure 5-5. Typical Portion of Electroformed Nickel Master Delivered on NAS 1-3309

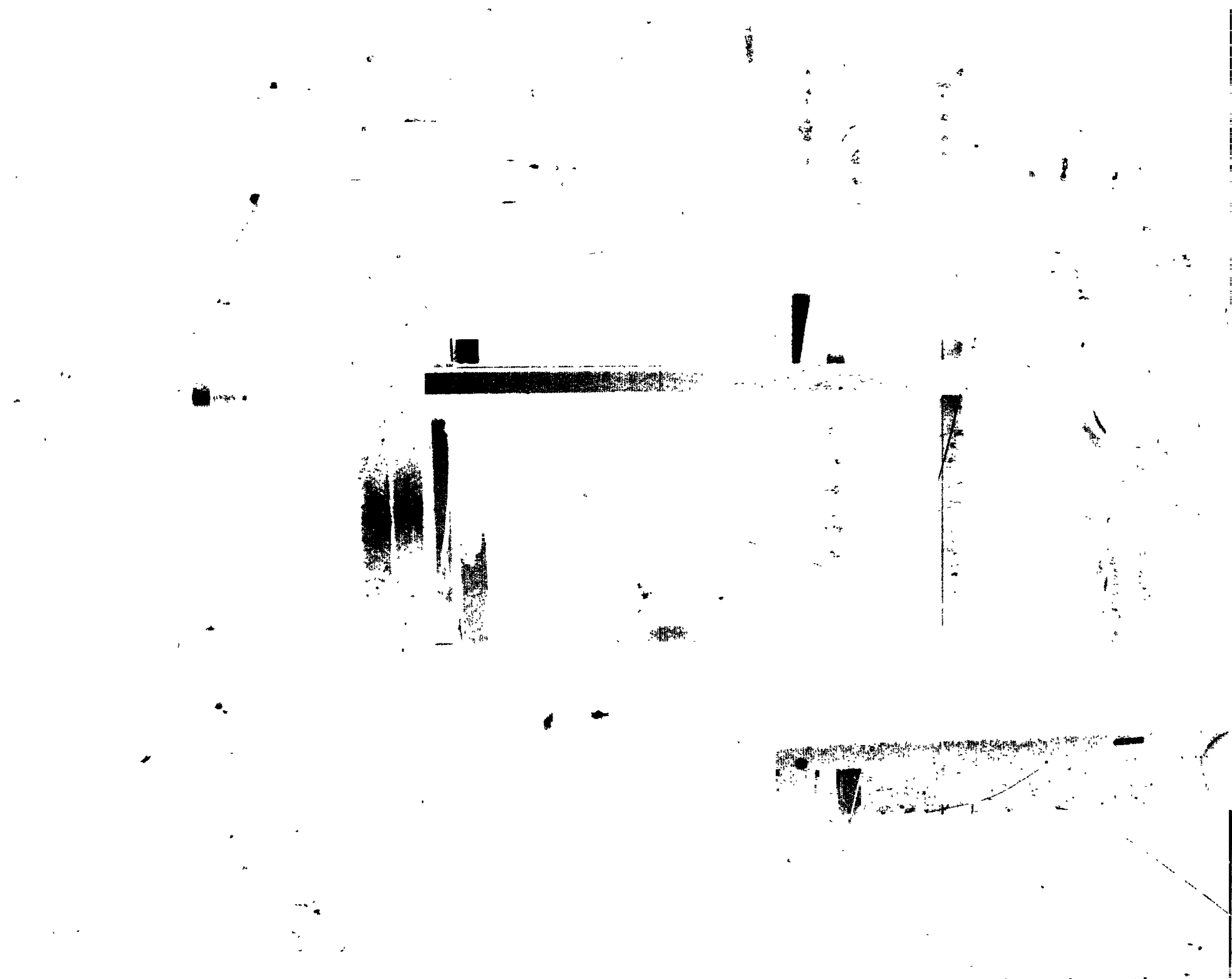


Figure 5-6. Electroformed Nickel Master and Vacuum Chamber

e. Continued fault lines along edge of mirror at intermittant points where the ring assembly did not provide adequate contact with the nickel master.

An investigation into the possible causes for the faults developed the following possibilities:

a. Heat treatment of the Kanigen coating at 375^{o}-$425^{o}F$ forms tri-nickel phosphide (Ni_3P) which is more soluble in caustic solutions than the phosphorous which is "in solution" in the coating that is not heat treated.

b. Kanigen plating solution may have remained in pores of the nickel master to contaminate the aluminum electroforming bath.

c. Failure to maintain the nickel master cathodic while placing it in the tank may have caused the silver layer to be damaged.

d. Slow immersion of the cathode assembly may have weakened the silver layer.

e. An unintentional current interruption within the first ten minutes in the bath may have caused a lamination in the aluminum near the face of the mirror.

Emmision spectrographs of the distilled water rinse and dry components taken from the mirror surface did not detect any phosphorous in the residue. Duplication of the delamination was demonstrated in the laboratory, however, by causing a momentary current interruption during the first ten minutes of aluminum deposition. Placing the laboratory sample in the bath (non cathodic) without a current interruption resulted in a sound aluminum electroformed sample. Thus, it was determined that the surface condition of the 30 inch aluminum mirror was caused by delamination of the aluminum as the result of a momentary current interruption in the first few minutes after electroforming was started. All data to date has shown that similar interruptions after one hour or more do not cause delamination.

A conclusion was reached, based on the line structure of the failure pattern, that rapid immersion of the cathode into the bath without momentary pauses would be less likely to weaken the silver layer. Therefore, arrangements were made to motorize the hoist mechanism to provide a continuous, fast entry into the electroforming baths prior to making the next mirror.

5.4 ELECTROFORMING RUN NO. 2

Mirror No. 2 was electroformed to fulfill contractual requirements of delivery of a 30-inch aluminum mirror to demonstrate the use of the Kanigen nickel coating to eliminate porosity or poor surface quality in the nickel master. It was also important to verify the accuracy of the failure analysis following the Run No. 1 separation failure. The master surface was hand cleaned and polished using a 600 mesh silicon carbide and an aluminum abrasive, sizes 1 micron and 0.3 micron.

The primary cause for the separation failure on the No. 1 mirror had been determined to be the momentary current interruption within a few minutes after start of the electroforming cycle. However, the slow, manual insertion of the cathode assembly into the bath was felt to be a possible contributor to the mirror corrosion and, therefore, a motorized drive unit was added to the hoist by the vendor. Three dummy runs of the hoist assembly were made with the nickel master on the cathode assembly in the glove box to verify the newly modified hoist drive operation. In spite of these verification runs, the drive motor failed after the nickel master was lowered approximately one third of the distance into the solution. The drive motor was disconnected and the mirror was lowered the remaining distance into the tank by hand operation of the hoist. The remainder of the electroforming proceeded without difficulty.

Separation was attempted under vacuum conditions, initially with no spring tension and then with four pounds tension at each of three pickup points. Examination of the mirror periphery showed local hangup of the electroformed guide ring to the bolted top ring assembly. This was freed mechanically by gently working the aluminum loose, but sticking appeared to be occurring at the guide ring joint. The bolted ring assembly was loosened and raised slightly to assist in breaking the edge evenly around the mirror. As soon as this ring was free the mirror separated from the master due to the spring tension on each of the three lift points. There appeared to be no sticking or lock-in of the mirror to the master, indicating that the Kanigen process was completely effective in this case in correcting the porosity on the electroformed nickel master.

The mirror was washed to remove any traces of plating solution and cleaned with french cotton prior to being delivered to NASA Langley Research Center.

APPENDIX A

SPINCAST MOLD

FIRST OPTICAL INSPECTION

OPTICAL INSPECTION OF 9.5 FT. SPIN CAST MASTER

*ALL STD. DEVIATIONS * BY 5.5 ARCSEC/DIVISION

TELESCOPE	AVERAGE X READING	STANDARD DEVIATION	AVERAGE Y READING	STANDARD DEVIATION	AVERAGE SLOPE ERROR
1	50.89	36.275	52.58	33.955	44.185
2	54.54	27.442	52.76	30.943	36.159
3	55.90	28.939	51.38	31.654	39.069
4	53.04	27.874	54.74	30.384	37.620
5	56.56	30.038	54.49	29.953	39.770
6	55.61	31.403	55.79	30.369	41.489
7	56.06	29.484	51.22	31.065	40.560
8	61.14	33.330	50.96	30.086	42.922

TELESCOPES 1-8

AVERAGE X READING 55.47
STANDARD DEVIATION 30.537

AVERAGE Y READING 52.99
STANDARD DEVIATION 31.008

X VS Y
STANDARD DEVIATION 43.520

Figure A-1. Spincast Mold #1 Optical Inspection

RAW MEASURED SLOPE ERROR

ANGULAR POSITION (DEGREES)	TELESCOPE 1	TELESCOPE 2	TELESCOPE 3	TELESCOPE 4	TELESCOPE 5	TELESCOPE 6	TELESCOPE 7	TELESCOPE 8
0	27.750	27.750	35.537	20.011	35.537	40.405	11.100	22.200
5	43.347	31.396	5.550	29.888	27.750	11.100	5.550	40.022
10	62.051	20.011	15.698	32.362	27.750	27.750	12.410	35.101
15	47.419	28.300	17.551	37.231	28.300	22.200	5.550	33.300
20	35.101	39.244	28.300	39.244	27.750	28.300	12.410	33.759
25	22.200	23.547	35.537	22.200	16.650	12.410	27.750	47.743
30	62.051	0.	11.100	23.547	16.650	16.650	11.100	42.268
35	83.987	7.849	12.410	28.300	0.	11.100	17.551	47.419
40	67.519	0.	5.550	32.362	11.100	16.650	11.100	44.400
45	39.244	5.550	7.849	15.698	0.	0.	22.200	57.141
50	0.	5.550	22.200	7.849	12.410	5.550	28.300	67.746
55	33.300	40.405	44.746	23.547	27.750	22.883	44.400	78.880
60	42.268	27.750	47.743	20.011	15.698	5.550	27.750	66.600
65	55.500	50.257	56.599	28.300	37.231	42.268	45.766	75.488
70	59.775	44.746	52.359	16.650	39.244	39.244	55.500	86.694
75	44.746	67.061	93.035	72.995	62.051	47.093	91.869	115.416
80	44.746	57.944	77.103	49.641	60.032	43.347	67.746	114.281
85	56.599	67.746	78.489	43.347	64.724	59.775	64.724	109.040
90	77.303	71.075	71.075	28.300	67.061	55.777	74.461	114.416
95	87.753	75.488	83.250	62.051	87.753	68.650	86.871	119.551
100	39.244	87.753	100.054	52.359	89.663	78.489	89.491	117.602
105	77.303	87.753	94.838	45.766	78.469	83.250	72.150	117.733
110	35.101	67.519	84.899	50.257	66.831	77.700	74.046	105.536
115	64.561	77.700	83.435	66.831	80.800	89.491	83.250	111.139
120	61.050	66.600	77.898	72.150	94.350	83.250	93.035	52.359
125	60.032	72.150	78.489	61.050	83.250	94.513	81.945	115.807
130	47.419	68.650	77.700	61.050	79.464	79.464	67.519	57.944
135	102.036	70.203	78.489	59.775	86.159	77.303	66.630	111.000
140	57.944	74.471	70.203	86.831	82.507	84.535	77.700	111.554
145	72.303	59.775	66.600	59.775	80.809	82.507	78.489	111.139
150	71.075	43.347	67.519	102.337	86.159	77.303	66.600	122.100
155	40.022	35.537	62.051	57.141	77.303	81.94[illegible]	61.050	116.550
160	35.537	39.244	67.746	58.997	72.150	81.945	70.203	111.000
165	44.746	63.280	67.746	66.831	74.461	77.103	75.488	111.139
170	51.168	49.641	44.400	43.347	67.061	62.051	66.600	94.513
175	45.766	39.244	47.419	47.419	74.461	66.831	55.777	100.515
180	44.400	52.359	43.347	57.944	71.075	71.075	52.359	59.775
185	24.820	47.743	44.746	59.775	70.640	74.668	64.724	87.753
190	42.268	54.942	58.997	58.997	67.746	78.489	82.507	91.869
195	49.641	40.022	40.405	35.537	60.032	74.668	56.599	91.533
200	35.537	31.396	45.766	37.231	64.724	74.668	49.641	94.838
205	27.750	35.537	44.746	42.268	71.075	71.075	58.997	101.884
210	27.750	39.244	43.347	62.051	78.489	77.103	78.489	100.054
215	51.168	40.022	47.419	54.942	67.746	74.668	67.746	77.303
220	29.888	54.661	56.599	54.942	71.075	71.075	57.141	81.945
225	31.396	40.405	68.650	58.997	70.640	77.103	58.997	63.280
230	35.537	104.275	72.363	67.746	74.668	84.717	71.075	82.507
235	39.244	72.363	82.507	77.103	83.250	92.370	63.280	54.942
240	75.488	67.746	66.831	67.746	86.694	81.945	62.791	47.743
245	61.050	67.746	58.997	59.775	64.724	67.746	52.652	62.051
250	56.599	62.051	55.500	62.051	67.746	72.150	47.743	62.051
255	56.599	59.775	60.032	63.280	72.150	75.488	52.359	51.168
260	105.536	59.775	57.944	74.046	77.103	72.150	54.942	43.347
265	62.051	40.405	39.244	57.944	64.724	59.775	39.244	58.997
270	74.461	38.850	39.244	66.600	56.599	67.519	43.347	55.500
275	75.488	44.746	54.942	61.302	68.650	72.363	42.268	62.791
280	42.268	62.051	67.746	67.519	68.650	68.650	49.641	54.942
285	12.410	61.302	63.280	72.150	62.051	66.600	44.746	43.347
290	55.500	44.746	29.888	51.168	52.652	55.500	22.883	29.888
295	42.268	27.750	24.820	51.168	44.746	55.500	27.750	39.244
300	29.888	40.405	32.362	56.599	44.400	55.500	38.850	47.743
305	12.410	28.300	29.888	40.405	50.257	49.950	39.244	47.743
310	20.011	39.244	24.820	40.405	45.766	56.599	32.362	39.244
315	44.746	28.300	5.550	28.300	39.244	51.168	22.200	35.537
320	40.022	24.820	16.650	38.850	44.746	50.257	27.750	31.396
325	22.200	20.011	16.650	39.244	38.850	50.257	28.300	24.820
330	11.100	11.100	22.200	44.400	32.362	44.400	44.400	35.537
335	11.100	0.	12.410	27.750	28.300	33.300	0.	44.746
340	24.820	24.820	16.650	5.550	20.011	40.405	20.011	40.405
345	40.405	29.888	11.100	40.022	33.759	40.405	17.551	32.362
350	45.766	35.537	20.011	35.101	35.101	33.759	22.200	35.537
355	42.268	40.022	22.200	38.850	33.759	38.850	22.883	16.650

UNIT 26, TAPE SERIAL NO. 00001, FILE NO. 002, REEL NO. 001
RECORDS PROCESSED 00072, PERMANENT RTT RECORDS 00000, NOISE RECORDS IGNORED 00000

MEAN	47.255	45.373	48.181	48.100	55.944	57.449	48.913	70.121
STD.DEV.	116.085	124.813	141.004	102.875	134.925	135.136	135.980	174.006

TELESCOPES 1-8 (ALL READINGS)
MEAN SLOPE ERROR 52.673
STD. DEVIATION 140.394
MEDIAN SLOPE ERROR 52.359

Figure A-2. Raw Measured Slope Error

ADJUSTED SLOPE ERROR

ANGULAR POSITION (DEGREES)	TELESCOPE 1	TELESCOPE 2	TELESCOPE 3	TELESCOPE 4	TELESCOPE 5	TELESCOPE 6	TELESCOPE 7	TELESCOPE 8
0	32.328	32.328	13.811	19.242	6.176	29.420	25.409	18.484
5	64.612	9.885	32.289	42.917	32.328	30.835	37.563	38.907
10	86.564	19.242	41.805	48.298	32.328	32.328	45.334	27.852
15	74.742	27.186	35.892	49.873	27.186	30.855	39.542	16.856
20	63.679	33.316	37.566	42.232	32.328	27.186	22.186	22.341
25	55.100	57.562	69.855	55.100	30.342	42.888	53.731	55.505
30	51.557	34.583	44.641	46.992	30.342	30.342	41.081	34.316
35	116.919	42.173	46.987	59.132	34.583	44.641	48.925	36.095
40	100.620	34.583	39.542	58.092	30.835	30.342	41.081	21.749
45	73.083	37.563	42.173	41.805	34.583	34.583	49.251	66.595
50	34.583	37.563	49.251	37.553	25.393	32.289	50.804	60.885
55	58.396	69.221	65.840	57.562	53.731	52.851	68.125	73.288
60	72.680	53.731	55.505	53.128	33.723	29.833	53.731	39.875
65	78.219	71.013	74.618	57.050	51.739	57.110	63.958	68.268
70	72.553	56.039	61.050	45.009	44.420	44.470	61.066	80.697
75	55.039	77.688	105.426	90.807	72.141	49.982	100.206	106.266
80	65.840	73.383	83.628	61.536	66.610	49.962	72.595	100.180
85	74.618	72.595	76.358	49.962	55.878	46.238	55.878	87.222
90	88.782	65.979	65.979	22.296	53.939	33.516	61.[illegible]78	92.044
95	78.588	68.288	75.781	50.984	69.034	49.192	72.917	101.124
100	44.420	69.634	89.425	46.520	72.724	54.861	77.221	97.877
105	60.946	69.034	76.856	31.058	54.861	55.450	57.281	92.396
110	27.852	45.625	62.486	29.578	42.486	50.181	53.415	78.305
115	49.477	50.181	57.355	37.903	60.768	58.716	55.450	83.643
120	34.905	39.875	52.290	44.981	66.124	55.450	73.374	46.520
125	25.760	44.981	54.861	34.905	55.450	67.731	69.441	94.843
130	14.058	36.258	50.181	34.905	47.358	47.358	45.625	41.691
135	67.767	36.689	47.676	25.775	53.204	43.271	39.875	82.348
140	25.158	39.922	76.689	34.024	48.654	50.218	50.181	85.280
145	37.925	25.775	39.875	25.775	47.689	48.654	54.861	83.643
150	37.498	11.541	36.672	69.784	53.204	43.271	39.875	93.247
155	6.338	6.176	31.196	22.559	43.271	47.363	34.905	87.791
160	6.176	11.453	33.589	26.324	37.935	47.363	36.689	82.348
165	10.189	2[illegible].661	33.589	36.197	39.922	42.544	42.182	81.411
170	22.451	15.135	21.749	11.541	32.672	27.520	39.875	64.954
175	33.814	11.453	14.056	30.994	39.922	34.024	27.476	69.775
180	41.155	27.926	11.541	41.244	37.498	41.367	17.946	25.775
185	20.042	22.406	10.189	39.748	38.692	43.567	30.199	54.071
190	8.508	23.826	26.324	29.078	33.589	46.331	48.654	57.398
195	28.973	6.338	10.128	13.811	25.760	41.779	25.751	58.726
200	13.811	9.885	15.094	21.600	30.199	41.779	15.135	60.798
205	14.795	6.176	10.189	26.130	37.498	41.367	29.078	67.305
210	16.796	11.453	16.905	38.992	46.331	50.724	46.331	65.673
215	20.363	6.338	14.058	23.826	33.589	43.567	33.589	43.271
220	22.242	20.394	25.751	23.826	37.498	41.367	22.559	47.363
225	52.840	10.128	36.258	29.078	38.692	50.724	29.078	34.424
230	53.713	65.787	37.925	39.825	43.567	57.307	41.367	49.564
235	33.316	45.262	49.564	50.724	53.712	64.174	34.424	23.826
240	46.625	39.825	34.024	39.825	53.182	56.203	31.157	14.030
245	53.823	39.825	26.324	39.748	39.018	39.825	19.608	27.520
250	56.842	38.972	27.962	38.992	39.825	50.073	14.030	27.520
255	56.842	39.748	33.486	46.516	50.073	56.149	27.926	16.747
260	52.249	39.748	41.244	57.218	50.724	50.073	23.826	11.541
265	48.441	29.420	11.453	41.244	39.018	39.748	11.453	26.324
270	80.937	37.629	11.453	58.491	43.404	53.580	16.905	27.962
275	55.528	45.402	23.826	50.901	51.846	60.836	26.130	31.157
280	51.596	60.776	39.825	53.580	51.846	51.846	28.973	23.826
285	36.310	57.136	46.516	63.301	48.441	58.491	23.698	11.541
290	49.338	37.253	22.242	53.198	36.056	49.338	25.418	6.075
295	51.596	32.328	20.042	53.198	37.253	49.338	32.328	11.453
300	42.917	47.040	17.661	56.842	41.155	49.338	37.629	22.406
305	36.310	37.586	22.242	47.040	41.560	45.091	33.316	22.406
310	19.242	33.316	20.042	47.040	33.814	43.404	17.661	11.453
315	45.492	37.586	29.833	37.586	33.316	53.198	30.855	6.176
320	55.134	41.819	30.342	37.629	37.253	48.998	32.3[illegible]8	9.885
325	55.100	47.312	30.342	42.232	37.629	48.998	37.586	20.042
330	54.641	30.835	30.855	41.155	17.661	41.155	41.155	13.811
335	25.409	34.583	25.393	32.328	27.186	34.637	34.583	17.878
340	41.619	9.822	21.514	39.542	19.242	29.420	19.242	10.128
345	69.410	6.075	25.409	55.134	29.895	47.040	35.892	2.592
350	74.544	6.176	19.242	44.682	25.482	39.589	30.[illegible]	13.811
355	69.192	18.584	30.855	37.629	29.895	37.624	25.418	21.514

UNIT 26, TAPE SERIAL NO. 00001, FILE NO. 003, REEL NO. 001
RECORDS PROCESSED 00002, PERMANENT RTT RECORDS 00000, NOISE RECORDS IGNORED 00000

	1	2	3	4	5	6	7	8
MEAN	45.606	36.465	38.370	42.018	41.462	45.151	40.207	47.[illegible]98
STD.DEV.	139.661	109.676	117.285	76.242	70.870	51.765	96.682	168.383

TELESCOPES 1-8 (ALL READINGS)
MEAN SLOPE ERROR 42.584
STD. DEVIATION 261.567
MEDIAN SLOPE ERROR 39.875

Figure A-3. Adjusted Slope Error

GENERAL ELECTRIC
MISSILE AND SPACE DIVISION
PHILADELPHIA

PROGRAM INFORMATION REQUEST / RELEASE

PIR NO.	*CLASS. LTR.	OPERATION	PROGRAM	SEQUENCE NO.	REV.
	U	— 4A26 —		— 038	

*USE "C" FOR CLASSIFIED AND "U" FOR UNCLASSIFIED

FROM	TO
N. Shebby, Programmer Room U2605 Data Processing VFSTC	D. Lee Room M2614 VFSTC

DATE SENT	DATE INFO. REQUIRED	PROJECT AND REQ. NO.	REFERENCE DIR. NO.
4/5/66			

SUBJECT

OPTICAL INSPECTION FORTRAN IV PROGRAM

INFORMATION [redacted]/RELEASED

I. Purpose

This program computes the following results utilizing Azimuth readings from eight telescopes.

A. Standard deviation for each telescope for

X (radial) slope error

Y (circumferential) slope error

X and Y combined readings of all telescopes

B. Raw Measured Slope Errors

Calculated slope errors without any adjustment for light source position error.

C. Adjusted Slope Error

Calculated slope error with adjustments of all telescope readings based on the overall average X or Y deviation.

II. Input

This program requires 3 types of parameter card input.

✓ RETENTION REQUIREMENTS

COPIES FOR	MASTERS FOR
☐ 1 MO.	☐ 3 MOS.
☐ 3 MOS.	☐ 6 MOS.
☐ 6 MOS.	☐ 12 MOS.
☐ MOS.	☐ MOS.
☐	☐ DO NOT DESTROY

A-6

FORM 1020 H REV. (9-65)

II. Input (cont.)

Card 1 Title Information

Columns 1-72 will contain the BCD characters required as "title" for the printout.

Example: OPTICAL INSPECTION OF 9.5 SPIN CAST MASTER

Card 2 Control Card

This program utilizes the Fortran IV namelist facility for this parameter card.

Card Columns
2-7 $INPUT

Card Columns 9→72

Field 1 NCD = I,
where I is the number of data cards following, or number of degree positions of input.

Field 2 NDEG = I,
where I is the delta degrees between slope error readings.

Field 3 YMAX = X.,
where X. =
1) The maximum value of raw, adjusted and combined slope errors.
This value will be utilized as the maximum Y axis value for plotting scales.
2) If X. = 0. this program will compute the maximum value of all slope errors.
The computed value will be utilized as the maximum Y axis value for plotting scales.

Field 4 DELTAY = X.,
where X. =
the delta value of Y to draw grid lines for plotting.
If YMAX = 0., this field is not necessary. This program will compute the correct delta.

II. Input (cont.)

Field 5 IEND = 1 $
where I = 1 if another set of parameter cards or optical inpsection readings are following.

I = 0 Call Exit after these computations.

Example:
CC2
$INPUT NCD = 72, NDEG = 5, YMAX = 15., DELTAY = 1., IEND = 0$

72 data cards are following in steps of 5 degrees. The plots will be scaled from 0. to 15., with 15 lines on the grid. Each separation will have a delta value of 1.

This is the only optical inspection test to be run at this time.

Card 3's Data Cards

There will be NCD data cards required following CARD 2. Each card will contain a degree position, increasing in steps of NDEG.

Format of Data Cards
Card Columns

	5-8	Azimuth reading in degrees (Right justified in columns)
Telescope 1	*9-12	X (radial) reading
	*13-16	Y (circumferential) reading
Telescope 2	*17-20	X (radial) reading
	*21-24	Y (circumferential) reading
Telescope 3	*25-28 *29-32	Same as Telescope 1
Telescope 4	*33-36 *37-40	Same as Telescope 1
Telescope 5	*41-44 *45-48	Same as Telescope 1

*NOTE: * denotes that these fields require decimal points.

II. Input (cont.)

Telescope 6	*49-52 *53-56	Same as Telescope 1
Telescope 7	*57-60 *61-64	Same as Telescope 1
Telescope 8	*65-68 *69-72	Same as Telescope 1

See page 8 for examples of Data Input Card.

III. Output

This program generates two types of output

A. Printout

A printout of the results is generated on the system output tape. This printout will also precede the plots on the copy-flo scroll output. An example of the copy flo scroll output is shown in this section.

The following results will be available on this printout.

1. For each telescope
   Average X reading and stand..rd deviation
   Average Y reading and standard deviation
   Average slope error

2. All Telescopes combined
   Average X reading and standard deviation
   Average Y reading and standard deviation

*NOTE: *denotes that these fields require decimal points.

III. Output (cont.)

A. Printout (cont.)

3. X (radial) vs. Y (circumferential) standard deviation

4. For each Angular Position of each telescope
Adjusted Slope Error
Raw Slope Error

5. For each telescope
Average Adjusted Slope Error
Standard deviation of adjusted slope error
Average Raw Slope Error
Standard deviation of raw slope error

6. All telescopes combined

Average raw slope error
Standard deviation
Median slope error

Average adjusted slope error
Standard deviation
Median slope error

B. Plots

This program will generate a tape which will be utilized by the Stromberg Carlson High Speed Microfilm Recorder (SC 4020). This recorder will generate plots of Combined, raw and adjusted slope errors versus azimuth positions.

An example of the plots generated is available in this section.

The annotation specifies clearly which results are plotted.

IV. Method

The following results are computed in this program utilizing the following equations.

Average X (radial) per telescope

$$\bar{X}_K = \Sigma \frac{Yn}{N}$$

n = 1 to number of azimuth positions
K = 1 to 8 telescopes
N = Total azimuth positions

Average Y (circumferential) per telescope

$$\bar{Y}_K = \Sigma \frac{Yn}{N} = \text{Same as X radial}$$

Standard Deviations

X (radial) per telescope

$$\sqrt{\Sigma \frac{(Xn - \bar{X}_K)^2}{N - 1}}$$

Y (circumferential) per telescope

$$\sqrt{\Sigma \frac{(Yn - \bar{Y}_K)^2}{N - 1}}$$

IV. Method (cont.)

Combined Slope Error per azimuth position

$$\sqrt{(X_N - \bar{X}_K)^2 + (Y_n - \bar{Y}_K)^2}$$

Combined Slope Error per telescope

$$\sqrt{\frac{(Xn - \bar{X}_K)^2 + (Yn - \bar{Y}_K)^2}{n}}$$

n = number of azimuth positions

Mean and Standard Deviations for X (radial) and Y (circumferential) are computed for all telescopes combined, as well as individual telescopes. The Combined Slope Error is also available for all telescopes.

The average X (radial) and Y (circumferential) are computed for each telescope and all 8 telescopes combined. This mean value is utilized in the following equation:

Adjusted slope error

$$ASERR_n = \sqrt{(X_n - \bar{X})^2 + (Y_n - \bar{Y})^2}$$

n = 1 to number of azimuth readings

Raw slope error is computed using the value 50., or slope error without any adjustment for light source position error.

$$RSERR_n = \sqrt{(X_n - 50.)^2 + (Y_n - 50.)^2}$$

n = 1 to number of azimuth readings

An adjusted and raw slope error is also computed for each telescope, as well as all telescopes combined.

The median slope error for raw and adjusted is computed utilizing the $RSERR_n$ and $ASERR_n$ computations for combined telescopes.

Example of Input Cards

Card Cols.	5-8	9-12	13-16	17-20	21-24	25-28	29-32	33-36	37-40	41-44	45-58	49-52	53-56	47-60	61-64	65-68	69-72
		Telescope 1		Telescope 2		Telexcope 3		Telescope 4		Telescope 5		Telescope 6		Telexcope 7		Telescope 8	
		X	Y	X	Y	X	Y	X	Y	X	YX	X	Y	X	Y	X	Y
Card																	
1	0	48.	50.	47.	50.	52.	51.	51.	48.	52.	57.	54.	56.	62.	60.	61.	60.
2	5	44.	55.	43.	56.	49.	48.	49.	52.	53.	56.	55.	57.	61.	62.	63.	61.
3	10	48.	53.	44.	54.	61.	52.	60.	54.	52.	56.	60.	55.	60.	59.	61.	62
4	15	42.	52.	45.	53.	49.	47.	71.	56.	51.	55.	49.	58.	59.	41.	59.	58.
5	20	44.	56.	48.	52.	54.	56.	46.	55.	53.	54.	61.	51.	58.	60.	55.	54.
6	25	46.	52.	49.	50.	62.	50.	53.	54.	54.	53.	54.	50.	52.	63.	53.	52.
	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
72	355	48.	50.	46.	49.	50.	61.	58.	55.	51.	50.	54.	56.	62.	60.	61.	60.

APPENDIX B

EPOXY TEST PROGRAM PLAN

GENERAL ELECTRIC
MISSILE AND SPACE DIVISION
PHILADELPHIA

OGRAM INFORMATION REQUEST / RELEASE

NO. 4419-062

FROM G. A. Yen, Proj. Mgr.
Bus. Anal. & Proj. Oper.
Rm. U2450, Ext. 3112

TO DISTRIBUTION

DATE SENT | DATE INFO. REQUIRED | PROJECT AND REQ. NO. | REFERENCE DIR. NO.

SUBJECT
EPOXY TEST PROCEDURES

INFORMATION REQUESTED / RELEASED

OBJECTIVE

Formulate a stable epoxy which is not subject to attack by cleaning sensitizing chemicals and which will not contaminate an electroform (nickel sulfumate) bath. The program conducted must provide controls in such a manner as to:

(a) Assure positive identification of samples tested.
(b) Assure complete control of processes as regards formulation, materials and temperature
(c) Assure that the results can be used to make a positive recommendation to the customer concerning continuation or termination of his program.

GENERAL PROGRAM

The basic approach will consist of hand-mixing resins and hardeners to provide a large number of samples. These samples will vary from each other in such characteristics as:

1. Hardener to resin ratio
2. Cure temperature
3. Hardener ratios
4. Elimination of wetting agent

The resulting samples will be tested for resistance to chemical attack such as:

Distilled water
Cleaning solution
Sensitizing solution
Silvering solution
Electroforming baths

DISTRIBUTION

PAGE NO. 1 OF

CONT. ON 2

FORM 1020 H REV. (12-62)

Selected samples which successfully survive the chemical test will be placed in an electroforming solution and plated with nickel, (5-mils thick). The nickel will be analyzed for ductility, brightness and hardness.

The formulation which produces the epoxy to give the best nickel and chemical stability will then be mixed by the epoxy mixing equipment located at "D" Street. Samples will be drawn and tested for the same properties indicated above.

A report of these activities along with recommendations for future development will be forwarded to the customer.

SCHEDULE

PERSONNEL & RESPONSIBILITIES

PROCEDURES

The various procedures are detailed in the attachments. They consist of the following:

1. Hand mixing procedure (Attachment B)

    (a) Materials
    (b) Ratios
    (c) Equipment
    (d) Sample identification (not available to RSD)
    (e) Ambient cure
    (f) Oven cure
    (g) Controls
    (h) Responsibilities

2. <u>Chemical Tests</u> (Attachment C)

(a) Tests
(b) Controls
(c) Responsibilities

3. <u>Bath Contamination Tests</u> (Attachment D)

(a) Tests
(b) Controls
(c) Responsibilities

4. <u>Machine Mixing Procedures</u> (Attachment E)

(a) Materials
(b) Ratios
(c) Equipment
(d) Samples

ATTACHMENT B

HAND MIXING PROCEDURE

(a) Materials

The materials to be used in making the test epoxies are identified as follows:

* "Resins"

* "Hardeners or Catalysts"

* Others

* GE Proprietary Information

Vendor certification and other control data will be obtained for the "Resins" and Hardeners".

(b) Ratios

The hardener elements will be added on a parts per hundred of resin and the resulting ratios will be varied from stochiometric quantities of PHR up to PHR.

The relationship between the hardeners and the resins will be varied from parts to parts and parts to parts.

The will be removed in one set of samples and the Wetting Agent in another.

(c) Equipment

The prime mechanical equipment to be used includes the homo-mixer for mixing the formulations and an oven for curing the samples.

(d) Sample Identification

In order to be sure of the formulation used in the various samples, a system for identification has been established. This is shown in Attachment (B_1). It is not available to RSD (supporting GE function) so that the results of their testing cannot be influenced by the fore-knowledge of formulation used. There are four groups of samples to be taken.

Group I - Six samples each of five formulations and at two different ambient temperatures. In a six sample batch, two samples will be held as reference, two will be chemically tested and two will be chemically and bath tested. Accurate logs will be maintained for positive record of sample handling.

Groups II, III and IV will have 3 samples only since their potential for success is less than Group I.

The identification markings will be etched onto the bottom of the pie plates used to collect the sample mixes.

(e) <u>Ambient Cure</u>

Ambient temperatures are important to the successful curing of the formulations. For this reason, two temperature ranges have been established for Group I samples. These are indicated in Attachment B. Maintenance of these temperatures will be required from time of pour until ambient cure is complete (48 hours). All samples will be covered and sealed with polyethylene sheet during ambient cure.

(f) <u>Oven Cure</u>

Immediately following ambient cure of the samples, they will be subjected to an oven cure of 120°F for a period of 10 hours. Temperature rise from ambient to 120°F should not exceed 1°/minute and temperature drop should not exceed this limit. Samples will not be covered during this cure cycle.

(g) <u>Controls</u>

Each step of the hand mixing process shall be done in the presence of two people each serving as a check on the other. Any deviation from the established procedures will be duly recorded in the log book with reasons for the deviation. It is essential that whatever is done in the hand mixing process can be duplicated in the machine mixing process. The steps outlined herein must be strictly adhered to.

(h) <u>Responsibilities</u>

The prime responsibility for the hand mixing process described above is assigned to R. Fuse. He will be assisted by G. Yeo and D. Lee as required.

EPOXY TEST PLAN NUMBERING SYSTEM

NAS 1-4105 REQ. 829

	I					II			III			IV		
Hardener PHR	9	11	13	15	17	9	13	17	9	13	17	9	13	17
Sample Sequence	L	K	B	A	C	M	D	E	N	G	F	O	J	H
T (72°-73°)	1-6	1-6	1-6	1-6	1-6	1-3	1-3	1-3	1-3	1-3	1-3	1-3	1-3	1-3
L (77°-78°)	1-6	1-6	1-6	1-6	1-6									
Formulation	13 4	13 4	13 4	13 4	13 4	14 3	14 3	14 3	17 PhR DEAPA			NO SF-1034		
Proposer	Foster					Howe			Fuse			Fuse		

EXAMPLE: TL3

T = temperature cure range 72°-73°F

L = PAR 9

3 = sample #3 of six for this particular mix.

ATTACHMENT B_1

ATTACHMENT C

CHEMICAL TESTS

(a) Tests

The objective of these tests is to determine the chemical resistivity of the various samples submitted. Each sample shall separately be subjected to the following treatment·

1. Distilled Water - 1 hour at 75°F
2. Cleaning Solution -
   - 10g $Na_2 CO_3$, 10g NaH_2PO_4, 2-3 ml Triton X-100 } 1 hour, 1 liter at 75°F
3. Sensitizing Solution
   - 5g $SnCl_2$, 5ml HCL } 1 liter ½ hour at 75°F
4. Silvering Solution 1 hour 55°F
5. Nickel Sulfamate 1 hour 120°F

Evidence of discoloration, etching, pitting, or other surface corrosion will be noted and recorded by sample number. The samples shall be rated as excellent, fair or failed.

(b) Controls

The testing should be done in the presence of two people and a log book or record shall be maintained of all results by sample number. Since it is desired to minimize the amount of testing required both from a cost and time standpoint, the results of the tests should be communicated to D. Lee or G. Yeo as soon as they are available. In general, as soon as an excellent sample is identified, it will be used to run the bath test described further in this plan. Disposition of the balance of the samples will be determined at that time.

(c) Responsibilities

This part of the program will be under the direct control of F. Schmidt assisted by I. Hess. The solutions, time and temperatures set forth by this PIR are those previously used to test epoxies prepared for electroforming. Deviation, if required, will be made at Dr. Schmidt's descretion and will be so noted with reasons in the log book.

Attachment D

BATH CONTAMINATION TESTS

(a) Tests

The objective of these tests is to determine the stability of the epoxy in an electroform bath as regards it's ability to produce good nickel i.e., will not contaminate the bath.

Bart Mfg. Co. will perform the tests under the direction of F. Schmidt. A commercially pure electroform bath in a small (approximately 1' x 1' x 1') tank will be used for the tests.

The bath will be tested for "purity" by electroforming nickel (approximately 5 mils) against a pre-selected metal plate. This nickel will be examined for hardness, ductility and brightness and assuming it to be good nickel will be used as the reference for further electroformed nickel. An epoxy sample in the pie plate will then be immersed in the bath (following cleaning, sensitizing and silvering) and a 5 mil nickel deposit will be electroformed. This nickel will be compared to the reference. Another sample and pie plate will be immersed (after preparation) in the bath and allowed to "soak" for one hour. The surface will be examined for degradation.

If degraded, another sample will be immersed and nickel electroformed against the surface. This nickel will be compared with the reference sample. Failure of any sample nickel to equal the reference nickel indicates failure of the epoxy.

(b) Controls

Temperature of the bath will be 120°F for each test.

Bath stress will be determined before and after each test. Upper limits will be 3000-4000 psi.

Epoxy samples and pie plates will be brought up to at least 100F before immersing in the bath.

The samples will be cleaned and sensitized in accordance with pre-set standards and not altered to meet special conditions. Silvering will be done at less than 55°F.

Strict accountability for the samples tested will be maintained and recorded.

(c) Responsibility

The overall responsibility for this test effort lies with F. Schmidt.

ATTACHMENT E

MACHINE MIXING PROCEDURE

(a) Materials

The same materials listed in Attachment B will be used. They will be shipped from VFSTC to "D" Street for this part of the program.

(b) Ratios

The ratio of hardener to resin will be that ratio which best satisfied the tests run on the hand mixed epoxies. In any event, only one epoxy mix will be made in the machine and in quantities large enough to provide at least 20 pie plate samples and one complete spin casting. This is estimated to be approximately 22 gallons.

(c) Equipment

The Mitchell Metering and Mixing Machine located at "D" Street is the prime equipment to be used for the final epoxy mix. The available vacuum pressure 55 gallon capacity tanks will be used for storage of the resins and initial mixing. A 20 gallon capacity tank will be used for the catalyst storage and mixing.

Operation of the equipment will be handled by R. Dalzell and R. Fuse.

(d) Samples

The samples drawn from this mix will be to one formulation only. A minimum of 20 pie plate samples will be drawn and all will be ambient and elevated temperature cured.exactly as indicated in Attachment B. All but two samples will be sent to RSD (Schmidt) where two or three will be chemically tested (Attachment C). Assuming the samples successfully passed this test, additional samples will be tested for electroforming stability per Attachment D. The controls which apply to all preceding attachments also apply here.

Responsibility for each of the above steps is spelled out in the appropriate attachment.

APPENDIX C

CLEANING OF SPINCAST MOLD AND COVER

GENERAL ELECTRIC
MISSILE AND SPACE DIVISION
PHILADELPHIA

OGRAM INFORMATION REQUEST / RELEASE

NO. PIR 4622-104

FROM: W. L. Jolitz, Engineer, Process & Methods Engineering

TO: D. Lee

DATE SENT	DATE INFO. REQUIRED	PROJECT AND REQ. NO.	REFERENCE DIR. NO.
8/26/65			

SUBJECT

Cleaning of Spincast Mold and Cover.

INFORMATION REQUESTED / RELEASED

A. Introduction: The following confirms our discussions and agreements on 8/24/65 as to a satisfactory method for cleaning the spincast surfaces prior to priming and after the removal of all residues (epoxy and RTV) from the previous run. The final operation in that procedure should be disk sanding or sandblasting.

B. Cleaning Procedure Mold:

1. Applicable area - area to which spincasting epoxy or RTV sealer is to be applied.

2. Procedure.

   a. Flood area with water and observe water film formation. This is to be used as a guide to the amount of contamination of the surface.
   b. Prepare sufficient solution of Clepo 86P in warm water 100-120°F at a concentration of ½ - 1# per gallon.
   c. Continuously mop all applicable surfaces with solution "b" for a minimum of 30 minutes. Close drain in mold and use at least 25 gallons of solution.
   d. Drain solution and flush rinse surfaces with warm water.
   e. Close drain and fill mold with water - allow water to remain in mold for 1 to 2 hours.
   f. Drain mold and rinse (flush) with water. Observe water film formation, if surface not too contaminated proceed with next step.
   g. Preapre sufficient quantity of solution composed as follows:

      1 gallon Turco W.O.#1
      3 gallons warm water (100-120°F)

      Mop and scrub surface with this solution for 30 minutes.

   h. Flush rinse surfaces thoroughly.
   i. Close drain hole on mold and fill mold to brim. Mop surface throughout soak. Soak for 30 minutes minimum.
   j. Empty mold, flush and mop surfaces to remove smut during removal of water.
   k. flush surface and observe water film formation. If water breaks occur, re-operate paragraph g thru 1.

DISTRIBUTION

G. Yeo
F. E. Spinelli

PAGE NO. 1 OF

CONT. ON -2-

1. Dry mold 1-2 hours at room temperature or preferably 30 minutes at 150°F. Mold should be covered during this period to prevent air-born contamination from settling on surface and in such a manner ventilation is sufficient for drying.

C. <u>Cleaning of Polyester Cover:</u> (Inside surface)

1. Wipe oily deposit off using Toluene or Genesolv; or with Clepo 86P solution used in B-2-b. The first method is preferred.

2. Disk sand all polyester surfaces.

3. Remove sanding dust with clean compressed nitrogen or clean cheesecloth (bleached and unstarched).

4. Mask all window areas with paper - do not touch surface with ungloved hands.

5. Keep surface protected from air-born contamination.

APPENDIX D

BOND OF THE PRIMER AND RESIN TO ALUMINUM MOLD

BLANK PAGE

GENERAL ELECTRIC
MISSILE AND SPACE DIVISION
PHILADELPHIA

PROGRAM INFORMATION REQUEST / RELEASE

NO. 4494-006

FROM: A. T. Tweedie, SMR&D

TO: D. Lee/G. Yeo
Langley Spincast Project

DATE SENT	DATE INFO. REQUIRED	PROJECT AND REQ. NO.	REFERENCE DIR. NO.
Sept. 7, 1965			

SUBJECT

BONDING OF THE PRIMER AND RESIN TO THE ALUMINUM MOLD

INFORMATION REQUESTED / RELEASED

SUMMARY & CONCLUSIONS

In order to check the method of priming the aluminum spincast mold to assure good adherence of the spincast resin several tests have been made. Before the mold was primed several aluminum treatments and primers were tested. This work indicated that the same treatment and primer as used before should be used. It is reported in Table I. During priming of the mold, samples of the materials treated in the same fashion as the mold were made up for shear strength tests. The results are shown in Table II. In each case although there was considerable scatter in the data, the results indicate that a sound bond between the primer and mold (the point of failure in the previous casting) should be present. If the primer surface is kept clean, a good bond between it and the resin mold should result without any further treatment.

RESULTS

A. TESTS OF SURFACE TREATMENTS AND PRIMERS

Two aluminum surface treatments and two resins were tested as primer coats. The surface treatments were: 1. wash with 86P alkaline cleaning agent, followed by etching with proprietary etching compound; 2. etch with Hughson Chemical Co.EXB paste etching compound. The primers tested were: 1. Ciba, XK571 cured with General Mills, Pentamid and 2. Shell 815 cured with TETA (triethylene tetramine). The results are shown in Table I.

B. LAP SHEAR TESTS OF MOLD PRIMER

The mold was treated with 86P and TURCO W.O.1 then the XK571 primer was applied. At the same time, aluminum lap shear samples were made in the same fashion as controls. The results of the tests of these lap shears are given in Table II.

These tests on the control samples indicate that a good bond was accomplished.

A. T. Tweedie
A. T. Tweedie, Manager
Chemical Materials Development

DISTRIBUTION
R. H. Fuse

PAGE NO. 1 OF 3

CONT. ON 2

TABLE I

Experiment	90 hr Air Cure	80 hr Air Cure & 10 hr 120°F	Type of Failure
	LAP SHEAR RESULTS PSI (Avg.)		
1. XK571 & Pentamide 86P - 180S	1100	1300	mostly cohesive
2. 815/TETA 86P-180S	700-1100	700-1100	adhesive
3. 815/TETA ExB	500	600	adhesive

TABLE II

LAP SHEAR TESTS OF PRIMER
APPLIED TO MOLD

			Shear Strength (psi) Average
BATCH 1	1	1840	
	2	2090	
	3	2100	1880
	4	1760	
	5	1610	
BATCH 2	6	1410	
	7	2050	
	8	2310	1940
	9	2000	
	10	1950	

APPENDIX E

PRIMING SURFACE OF SPINCAST MOLD

GENERAL ELECTRIC
MISSILE AND SPACE DIVISION
PHILADELPHIA

PROGRAM INFORMATION REQUEST / RELEASE

NO. PIR 4622-103

FROM: W. L. Jolitz, Engineer
Process and Methods Engineering

TO: D. Lee

DATE SENT: 9/2/65

DATE INFO. REQUIRED:

PROJECT AND REQ. NO.:

REFERENCE DIR. NO.:

SUBJECT: Instructions for Priming Surfaces of Spincast Mold.

INFORMATION REQUESTED / RELEASED

1. Applicable Areas:

   A. Aluminum surfaces of mold to which spincasting epoxy will be poured.
   B. Polyester surface of mold cover which will be subjected to fumes from curing spincast epoxy.

2. Cleanliness Requirements:

   A. Surface shall be free of oils, silicones, dust and material foreign to the system. Surface shall support a water film without droplet formation for a minimum of 1 minute. The surface must be dry at time of primer application.
   B. Surface shall have been cleaned per cleaning instruction. (PIR-4622-104).
   C. If more than 12 hours have elapsed since cleaning or surface has remained unprotected from contamination settling out of the air for more than 4 hours, the surface shall be re-tested for cleanliness as follows:

      1. Flood surface whith water and observe for water droplet formation.
      2. If surface supports water film, flush surface with isoproply alcohol (reagent grade 95-99%) and dry.
      3. If surface does not support water film, re-close surface with Turco W. O. #1 cleaning step of the cleaning instruction until a satisfactory surface has been obtained and dry surface.

3. Quality Control Tests:

   A. Prepare five (5) 1" lapshear specimens with each batch of primer material.

      1. Lapshear specimens should be cleaned, sanded, cleaned and pass a water break test.
      2. Coat both mating surfaces of lapshear specimens.
      3. Air cure lapshear specimens for 1 hour before mating.
      4. Mate specimens with 1/2" overlap.
      5. Oven cure specimens concurrently with mold.
      6. Determine shear strength of bond.

DISTRIBUTION:

F. E. Spinelli

G. Yeo

B. Prepare Hockey Pack sample of each primer batch with material that does not contain toluene and cure for 1 hour at 150°F. Determine Shore D hardness.

C. Apply primer to a 12" x 12" clean panel in the same manner as used on mold and cover surfaces. Measure dry film thickness of sample panel.

4. Primer Preparation Instructions:

A. Primer formulation:

Araldite #571KX-75%	100 grams
Pentamide #815	49.0 grams
Cabosil	1.0 grams
Toluene	As Required-grams
	(Approx. 100 - 150 grams)

B. Primer mixing:

1. Weigh out the desired amount of 571KX and add the required amount of cabosil.
2. Disperse the cabosil thoroughly.
3. Add the required amount of Pentamide #815 and thoroughly mix.
4. Add the required amount of Toluene to reduce to 25-35 seconds zahn #2 viscosity.
5. Homongenize solution for 2-5 minutes on Homomixer.

5. Primer Application:

A. Place prepared primer in pressure pot of spray gun and adjust fluid pressure to approximately 8 psi. Adjust atomizing air to 35-50#/in^2 and adjust gun control to obtain a satisfactory spray pattern.

B. Apply .005 - .015 inch of primer to dry film. Apply primer with overlaping wet passes and cross spray surface to obtain a uniform thickness.

6. Primer Cure:

A. Air dry surface for 1 to 2 hours, followed by an Oven Cure for 16 - 20 hours at 150 ± 10°F.

7. Finishing:

A. Protect primed surfaces from air born contamination, greases and oils, dust and do not touch surface with ungloved hands.

APPENDIX F
EPOXY TEST SAMPLES

BLANK PAGE

GENERAL ELECTRIC
MISSILE AND SPACE DIVISION
PHILADELPHIA

PROGRAM INFORMATION REQUEST / RELEASE

NO. 4413-104

FROM	TO
D. E. Lee, Engineer Rm. M2614	G. L. Yeo, Prog. Mgr. Rm. U2450, Ext. 5112

DATE SENT	DATE INFO. REQUIRED	PROJECT AND REQ. NO.	REFERENCE DIR. NO.
9/10/65			

SUBJECT

EPOXY TEST SAMPLES, LANGLEY 9½ FOOT MIRROR

INFORMATION ~~REQUESTED~~/ RELEASED

Test samples will be prepared before and during each of the three pours to verify ability of the epoxy to withstand chemical attack of the cleaning silvering and electroforming solution. Both the resin and the catalyst tanks will be drained and cleaned after each pour to insure that fresh material is used on all pours. Samples will be identified by test series, ambient cure temperature range and sample number. A summary of the samples as currently planned is as follows:

Test Sample Designation	Quantity	Pour Date	Test Date	Ambient Cure Temp.	Description of Sample
AM 1-4	4	9/9	9/13	72°F	Batch #1
AL 1-4	4	9/9	9/13	67°F	Batch #1
BM 1-4	4	9/13	9/17	72°F	Pour #1
BH 1-4	4	9/13	9/17	77°F	Pour #1
CM 1-4	4	9/16	9/20	72°F	Batch #2
CL 1-4	4	9/16	9/20	67°F	Batch #2
DM 1-4	4	9/20	9/24	72°F	Pour #2
DH 1-4	4	9/20	9/24	77°F	Pour #2
EM 1-4	4	9/23	9/27	72°F	Batch #3
EL 1-4	4	9/23	9/27	67°F	Batch #3
FM 1-4	36	9/27	10/1	72°F	Pour #3
FH 1-4	4	9/27	10/1	77°F	Pour #3

DISTRIBUTION

F. S. Schmidt R. J. Fuse R. Delzell

PAGE NO. 1 OF 2

CONT. ON 2

Samples H & L series are being made to provide additional data on how critical is the ambient cure temperature.

All samples will be cured at 120°F for a minimum of 10 hours after an ambient temperature cure for 72 hours. Dr. Schmidt will require 2 samples of each series for chemical compatibility tests, one sample of each will be available for the customer (if customer desires it), and one of each will be held as a record at the Spincast Laboratory. Additional samples are being made for the final pour to permit sufficient tests for electroforming. Dr. Schmidt has requested 25 samples and an additional 10 samples will be held in reserve in the laboratory.

SAMPLE TEST RESULTS

Batch #1 (AM 1-4 & AL 1-4)

Samples were bagged and sealed in polyethylene during entire cure process. The surfaces, without chemical exposure, appeared to be slightly alligatored although localized certain-positions. Determined that this was caused by the breakage of air bubbles prior to setting of the epoxy. The samples were attacked by the cleaning and sensitizing solutions showing etching and pitting. This attack was more pronounced on the AM samples than the AL.

Following a discussion of these results, it was decided to make up additional samples of this material when conducting Pour #1. It was felt that inadequate mixing of the resin and catalyst was a likely explanation. (Since Pours #1 and #2 would not "see" the electroform bath, no real risk was involved in going ahead with these pours.)

The additional samples were:

- MHH - Hand mixed from the mix head
- MH - Same as AM 1-4
- THM - Hand-mixed from resin & catalyst tank
- PHM - Hand mixed from pumps

All samples were significantly better than the AM1-4 series but no correlation between samples was observed.

Pour #1 (BM 1-4 & BH 1-4)

Two changes in the preparation of these samples were made over the "A" series of samples. Surface quality is affected by the shape and distance of the cover above the epoxy. To simulate the mold cover, therefore, each poured sample was covered with aluminum foil stretched flat across the top of the plate. Also, the B series and all subsequent test samples were poured through the tubing and the mold pouring funnel. It is to be noted that improvement in all subsequent surfaces as regards to surface physical quality was evident.

Chemical test results showed that the BH sample was probably acceptable for electroforming despite some minor attack by the cleaning solution. The BM sample has less resistance but possibly could undergo successful plating.

Batch #2 (CM 1-4 & CL 1-4)

CL tested very good and was literally free from any chemical attack indicating a stable sample. CM, on the other hand, did have some small pitting in cleaning and sensitizing solutions. It rated with BM described above.

Pour #2 (DM 1-4 & DH 1-4)

Both of these samples were attacked by the cleaning and sensitizing solutions and were not considered acceptable for electroforming.

Batch #3 (EM 1-4 & EL 1-4)

Because of the concern for what might be inadequate mixing within the mixing head, a line mixing device was fabricated and installed in the pumping system just after the shear head mixer. Basically, it consisted of a series of random punched discs separated by 1 inch rings and all placed in a 2-inch pipe. This was capped at both ends and the inlet attached to the outlet of the mixing head with the outlet going directly to the pour funnel.

The results of the chemical tests on these samples indicated a fairly good epoxy. In addition, a sample was sent to Bart Mfg. Co. for electroforming nickel. The result was clear, bright ductile metal. However, the surface treatment (cleaning, sensitizing and silvering) procedure was not done over as long a period as our test at GE. While this reduced the assurance of a really good epoxy somewhat, it was not considered to be a deterrent to pouring the final coat.

Pour #3 (FM 1-4 & FH 1-4)

One further change was made for these samples. The atmosphere within the large (9-1/2 foot) mold was nitrogen purged before each pour. All of the previous samples were sealed and cured in an air atmosphere. Therefore, to more approximately duplicate the conditions "seen" by the mold epoxy surface, each of the Pour #3 samples were purged with N_2 prior to covering and sealing with aluminum foil and the polyethylene bags were also filled with N_2 before sealing.

The results of the listing of samples from this pour were comparable to that found in Batch No. 3 (EMI-4 and EL 1-4). Degradation of the surface did not begin to show until after a half hour exposure to the sensitizing soulution. Since this step could be accomplished in much less time than that, it was reasonable to conclude that the epoxy was relatively stable and would give good results.

APPENDIX G

SPINCAST MOLD

SECOND OPTICAL INSPECTION

OPTICAL INSPECTION OF 9.5 FOOT 2ND EPOXY MASTER

*ALL STD. DEVIATIONS * BY .0925 ARCMIN/DIVISION

TELESCOPE	AVERAGE X READING	STANDARD DEVIATION	AVERAGE Y READING	STANDARD DEVIATION	AVERAGE SLOPE ERROR
1	50.07	0.364	56.19	0.251	0.375
2	57.83	0.287	53.19	0.268	0.355
3	53.47	0.199	53.50	0.257	0.295
4	56.25	0.184	40.58	0.213	0.248
5	50.54	0.150	48.94	0.187	0.206
6	47.13	0.206	54.46	0.284	0.285
7	45.36	0.190	49.92	0.212	0.229
8	53.06	0.182	47.60	0.260	0.288

TELESCOPES 1-8

AVERAGE X READING	51.71
STANDARD DEVIATION	0.228
AVERAGE Y READING	50.55
STANDARD DEVIATION	0.242
X VS Y	
STANDARD DEVIATION	0.333

Spincast Mold No. 2 Optical Inspection

RAW MEASURED SLOPE ERROR

ANGULAR POSITION (DEGREES)	TELESCOPE 1	TELESCOPE 2	TELESCOPE 3	TELESCOPE 4	TELESCOPE 5	TELESCOPE 6	TELESCOPE 7	TELESCOPE 8
0	0.911	0.873	0.827	0.853	0.277	1.234	0.293	0.093
5	1.083	1.185	0.704	0.853	0.185	0.704	0.462	0.131
10	1.208	1.185	0.746	0.667	0.000	0.746	0.585	0.277
[illegible]	1.324	1.185	0.832	0.539	0.131	0.827	0.746	0.131
20	1.217	1.034	0.925	0.523	0.293	1.034	0.853	0.093
25	0.740	0.414	0.462	0.796	0.293	0.654	0.462	0.093
30	0.853	0.523	0.472	0.911	0.093	0.654	0.555	0.381
35	1.079	0.654	0.472	0.838	0.000	0.654	0.832	0.093
40	1.034	0.654	0.462	0.838	0.093	1.055	0.930	0.000
45	0.621	0.498	0.472	0.796	0.093	0.983	0.746	0.185
50	0.648	0.207	0.370	0.911	0 093	0.853	0.555	0.293
55	0.873	0.523	0.370	0.943	0.277	0.952	0.832	0.293
60	0.983	0.722	0.555	0.878	0.277	0.785	0.838	0.093
65	0.746	0.916	0.555	0.878	0.185	0.853	0.911	0.131
70	0.746	0.621	0.654	0.873	0.370	0.873	0.563	0.093
75	0.555	0.207	0.093	1.203	0.131	0.592	0.621	0.293
80	0.370	0.277	0.093	1.170	0.381	0.472	0.621	0.472
85	0.277	0.462	0.185	1.324	0.277	0.414	0.555	0.462
90	0.000	0.462	0.277	1.375	0.462	0.293	0.472	0.654
95	0.462	0.462	[illegible]	1.540	0.673	0.093	0.498	0.827
100	0.293	0.966	0.498	1.446	0.667	0.131	0.472	0.796
105	0.293	1.203	0.462	[illegible]	0.472	0.093	0.414	0.462
110	0.370	1.298	0.648		0.462	0.293	0.185	0.648
115	0.414	0.943	0.585	[illegible]	0.462	0.462	0.093	0.592
120	0.667	0.648	0.370	1.506	0.414	0.185	0.370	0.873
125	0.539	0.925	0.472	1.334	0.462	0.000	0.498	0.983
130	0.462	0.930	0.498	1.118	0.334	0.207	0.392	0.785
135	0.462	0.943	0.498	1.079	0.293	0.462	0.370	0.796
140	0.796	0.911	0.523	0.983	0.093	0.563	0.277	0.722
145	0.796	0.563	0.414	1.244	0.131	0.293	0.131	0.654
150	0.555	0.746	0.498	1.079	0.207	0.381	0.462	0.785
155	0.498	0.832	0.498	1.129	0.131	0.392	0.472	0.667
160	0.462	0.763	0.462	1.079	0.131	0.472	0.462	0.498
165	0.722	0.621	0.539	1.114	0.131	0.539	0.370	0.654
170	0.592	0.555	0.381	1.079	0.277	0.207	0.462	0.592
175	0.462	0.648	0.370	1.285	0.277	0.207	0.293	0.592
180	0.472	0.654	0.414	1.159	0.277	0.462	0.472	0.539
185	0.370	0.673	0.414	1.159	0.185	0.414	0 462	0.462
190	0.592	0.472	0.293	1.185	0.293	0.392	0.185	0.381
195	0.592	0.555	0.370	1.285	0.381	0.262	0.334	0.592
200	0.462	0.563	0.472	1.159	0.293	0.334	0.414	0.654
205	0.277	0.654	0.472	1.241	0.277	0.293	0.462	0.472
210	0.277	0.740	0.462	1.206	0.207	0.539	0.462	0.370
215	0.563	0.555	0.472	1.258	0.334	0.293	0.185	0.462
220	0.185	1.022	0.462	1.463	0.392	0.293	0.334	0.585
225	0.523	1.203	0.555	1.334	0.392	0.370	0.462	0.392
230	0.667	1.217	0.827	1.114	0.185	0.472	0.472	0.185
235	0.654	1.206	0.746	1.177	0.277	0.648	0.414	0.262
240	0.785	0.827	0.654	1.244	0.277	0.370	0.381	0.207
245	0.740	1.034	0.654	1.001	0.293	0.293	0.293	0.472
250	0.746	1.118	0.722	0.952	0.131	0.472	0.370	0.381
255	0.838	1.129	0.592	1.034	0.000	0.472	0.370	0.293
260	0.853	0.853	0.621	0.983	0.000	0.621	0.462	0.472
265	0.704	0.585	0.523	0.983	0.000	0.498	0.370	0.185
270	0.722	0.838	0.472	1.079	0.000	0.722	0.462	0.462
275	0.983	0.746	0.498	1.079	0.093	0.654	0.370	0.370
280	0.592	0.925	0.592	1.055	0.000	0.746	0.462	0.381
285	0.523	0.796	0.827	1.001	0.000	0.592	0.381	0.370
290	0.722	0.853	0.262	0.983	0.000	0.667	0.277	0.462

295	0.555	1.034	0.462	1.001	0.093	0.654	0.381	0.523
300	0.654	1.083	0.592	0.925	0.093	0.667	0.563	0.381
305	0.472	0.996	0.592	0.925	0.131	0.621	0.472	0.370
310	1.047	0.796	0.592	1.185	0.093	0.585	0.472	0.277
315	0.911	0.827	0.462	1.047	0.000	0.621	0.555	0.381
320	0.832	0.952	0.667	0.925	0.000	0.704	0.673	0.370
325	0.838	0.983	0.746	0.853	0.000	0.704	0.673	0.462
330	0.648	0.925	0.704	0.853	0.000	0.673	0.654	0.207
335	0.853	0.667	0.796	1.055	0.131	0.563	0.334	0.414
340	0.654	1.258	0.592	0.796	0.093	0.704	0.462	0.381
345	0.996	1.494	0.667	0.796	0.207	0.952	0.704	0.472
350	1.022	1.572	0.704	0.722	0.093	0.790	0.654	0.539
355	1.022	1.129	0.796	0.722	0.185	0.673	0.621	0.293
MEAN	0.673	0.826	0.533	1.059	0.207	0.547	0.482	0.426
STD.DEV.	0.262	0.288	0.169	0.223	0.161	0.252	0.178	0.218

TELESCOPES 1-8 (ALL READINGS)

MEAN SLOPE ERROR	0.594
STD. DEVIATION	0.329
MEDIAN SLOPE ERROR	0.555

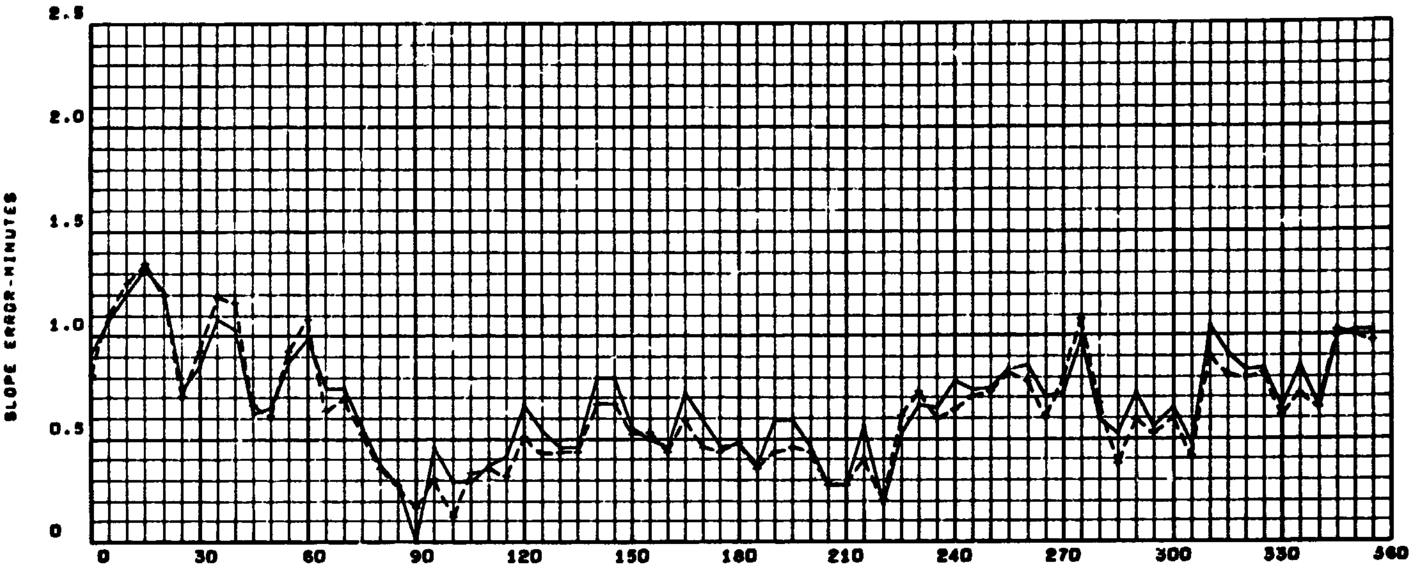
ADJUSTED SLOPE ERROR

ANGULAR POSITION (DEGREES)	TELESCOPE 1	TELESCOPE 2	TELESCOPE 3	TELESCOPE 4	TELESCOPE 5	TELESCOPE 6	TELESCOPE 7	TELESCOPE 8
0	0.810	0.753	0.721	0.778	0.277	1.327	0.438	0.214
5	1.102	1.031	0.609	0.803	0.208	0.739	0.623	0.158
10	1.259	1.031	0.692	0.642	0.166	0.797	0.726	0.129
15	1.355	1.050	0.798	0.527	0.254	0.869	0.867	0.078
20	1.202	0.926	0.889	0.471	0.338	1.072	1.008	0.164
25	0.707	0.320	0.441	0.762	0.438	0.745	0.623	0.083
30	0.930	0.383	0.482	0.908	0.256	0.745	0.715	0.426
35	1.195	0.512	0.482	0.886	0.166	0.745	0.992	0.083
40	1.159	0.512	0.540	0.886	0.256	1.157	1.084	0.166
45	0.667	0.413	0.482	0.762	0.256	1.079	0.899	0.284
50	0.617	0.150	0.356	0.908	0.256	0.951	0.715	0.335
55	0.928	0.383	0.356	0.976	0.439	1.073	0.992	0.335
60	1.079	0.572	0.529	0.891	0.439	0.874	0.992	0.083
65	0.633	0.772	0.529	0.891	0.347	0.951	1.041	0.078
70	0.692	0.518	0.600	0.847	0.531	0.928	0.715	0.083
75	0.529	0.049	0.083	1.200	0.289	0 698	0.785	0.335
80	0.356	0.129	0.083	1.180	0.490	0.622	0.785	0.517
85	0.277	0.308	0.057	1.314	0.365	0.545	0.715	0.437
90	0.166	0.308	0.129	1.380	0.537	0.438	0.637	0.701
95	0.308	0.308	0.255	1.505	0.699	0.256	0.618	0.819
100	0.126	0.834	0.385	1.432	0.642	0.078	0.571	0.762
105	0.338	1.045	0.308	1.382	0.517	0.164	0.543	0.537
110	0.356	1.137	0.492	1.382	0.390	0.236	0.347	0.492
115	0.320	0.778	0.419	1.298	0.390	0.441	0.256	0.519
120	0.509	0.492	0.218	1.444	0.422	0.208	0.450	0.847
125	0.429	0.768	0.307	1.298	0.437	0.166	0.618	0.930
130	0.441	0.768	0.332	1.111	0.329	0.285	0.546	0.724
135	0.441	0.778	0.332	1.053	0.186	0.441	0.531	0.709
140	0.670	0.746	0.383	0.930	0.083	0.563	0.439	0.678
145	0.670	0.399	0.251	1.186	0.158	0.338	0.289	0.597
150	0.529	0.583	0.332	1.053	0.146	0.406	0.622	0.724
155	0.536	0.676	0.332	1.091	0.158	0.491	0.637	0.578
160	0.441	0.597	0.310	1.053	0.158	0.482	0.623	0.385
165	0.589	0.457	0.429	1.057	0.158	0.600	0.531	0.597
170	0.463	0.400	0.216	1.053	0.365	0.346	0.622	0.519
175	0.441	0.492	0.218	1.260	0.365	0.346	0.459	0.519
180	0.482	0.491	0.251	1.139	0.365	0.54[illegible]	0.637	0.447
185	0.356	0.507	0.251	1.139	0.284	0.469	0.623	0.390
190	0.441	0.307	0.126	1.136	0.335	0.491	0.347	0.426
195	0.463	0.400	0.218	1.260	0.426	0.369	0.496	0.555
200	0.441	0.399	0.307	1.139	0.335	0.456	0.579	0.597
205	0.277	0.491	0.307	1.227	0.365	0.438	0.623	0.336
210	0.277	0.584	0.308	1.175	0.245	0.600	0.623	0.218
215	0.399	0.400	0.307	1.216	0.329	0.338	0.347	0.437
220	0.208	0.871	0.308	1.423	0.349	0.338	0.496	0.606
225	0.617	1.045	0.400	1.298	0.349	0.356	0.623	0.349
230	0.730	1.053	0.663	1.057	0.057	0.482	0.622	0.057
235	0.600	1.046	0.584	1.111	0.129	0.617	0.545	0.237
240	0.641	0.663	0.512	1.169	0.129	0.356	0.548	0.245
245	0.707	0.870	0.512	0.968	0.186	0.338	0.459	0.517
250	0.734	0.953	0.589	0.934	0.158	0.482	0.531	0.426
255	0.821	0.971	0.463	1.022	0.166	0.482	0.531	0.335
260	0.762	0.702	0.518	0.930	0.166	0.667	0.623	0.517
265	0.609	0.419	0.383	0.930	0.166	0.536	0.531	0.057
270	0.800	0.675	0.307	1.053	0.166	0.800	0.623	0.390
275	1.079	0.583	0.332	1.053	0.083	0.745	0.531	0.218
280	0.670	0.770	0.463	1.010	0.166	0.797	0.575	0.216
285	0.383	0.639	0.721	0.906	0.166	0.670	0.530	0.218
290	0.589	0.687	0.137	0.930	0.166	0.730	0.439	0.390

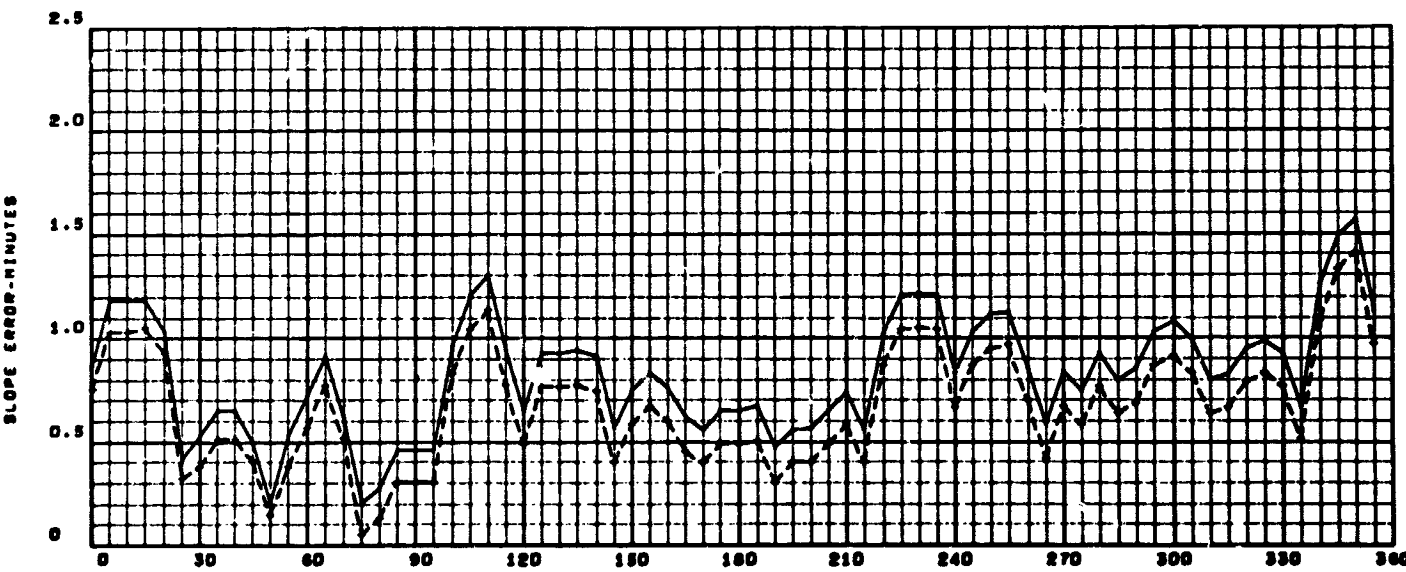
295	0.529	0.869	0.310	0.968	0.083	0.745	0.533	0.471
300	0.600	0.916	0.463	0.885	0.083	0.730	0.715	0.255
305	0.417	0.830	0.441	0.885	0.158	0.667	0.622	0.218
310	0.902	0.639	0.441	1.101	0.214	0.610	0.622	0.129
315	0.810	0.663	0.310	0.982	0.166	0.667	0.715	0.255
320	0.798	0.790	0.547	0.885	0.166	0.739	0.817	0.218
325	0.821	0.833	0.633	0.803	0.166	0.739	0.817	0.310
330	0.617	0.770	0.609	0.803	0.166	0.689	0.745	0.049
335	0.716	0.509	0.670	0.970	0.078	0.563	0.456	0.317
340	0.647	1.092	0.463	0.762	0.164	0.739	0.623	0.255
345	1.022	1.328	0.547	0.762	0.150	0.998	0.837	0.307
350	0.999	1.409	0.609	0.678	0.164	0.816	0.745	0.429
355	0.969	0.971	0.670	0.649	0.208	0.689	0.667	0.236
MEAN	0.642	0.674	0.417	1.027	0.266	0.607	0.631	0.379
STD.DEV.	0.278	0.282	0.178	0.223	0.140	0.254	0.175	0.215

TELESCOPES 1-8 (ALL READINGS)

MEAN SLOPE ERROR	0.580
STD. DEVIATION	0.659
MEDIAN SLOPE ERROR	0.534

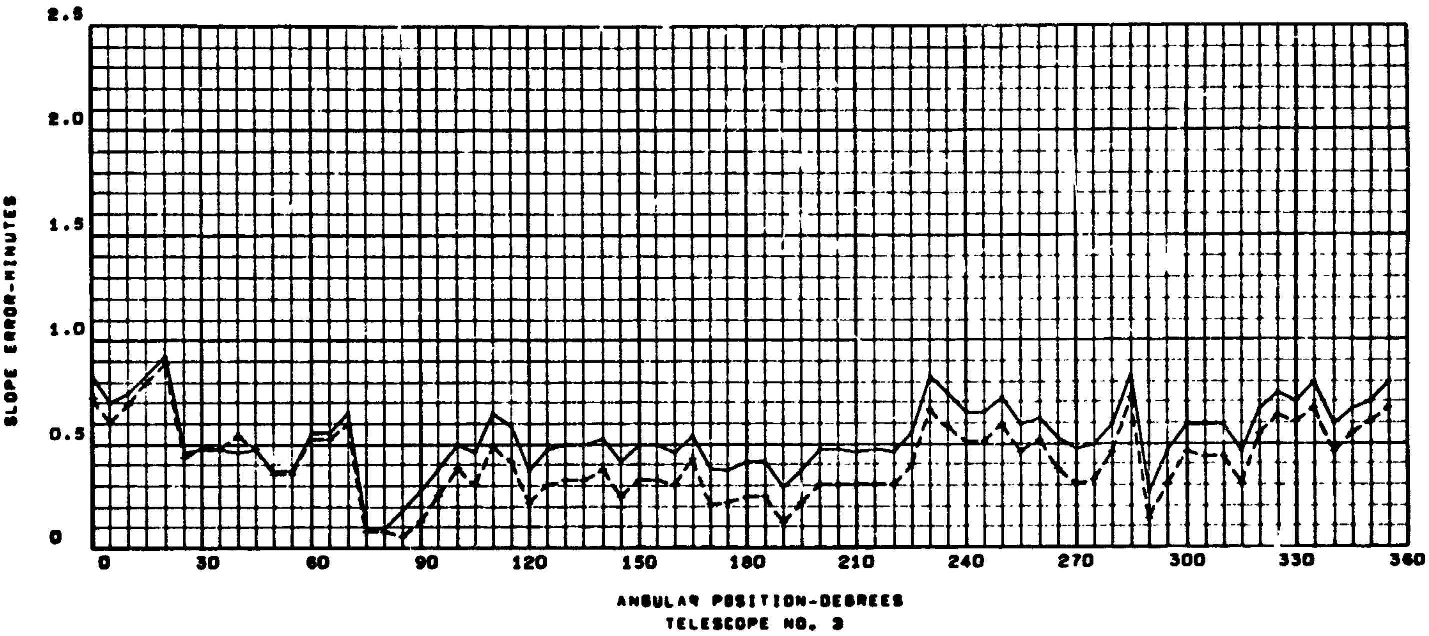


ANGULAR POSITION-DEGREES
TELESCOPE NO. 1

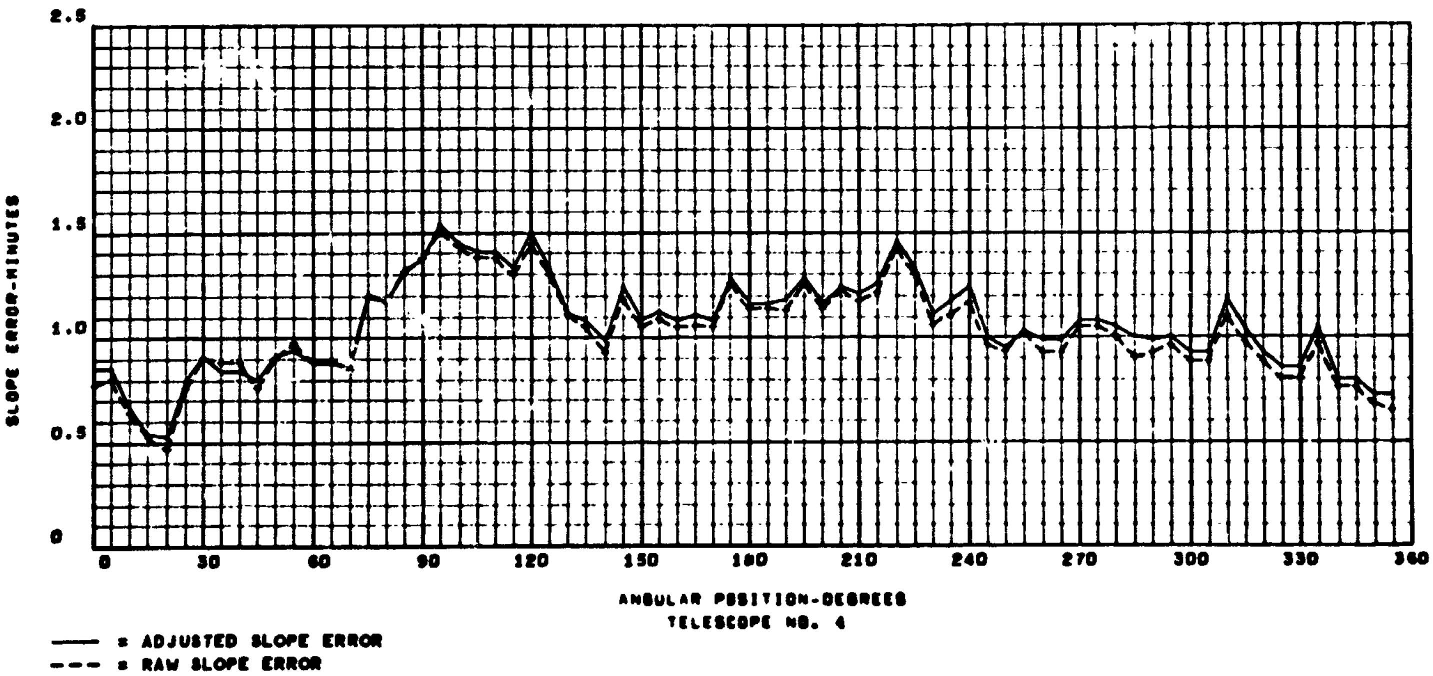


ANGULAR POSITION-DEGREES
TELESCOPE NO. 2

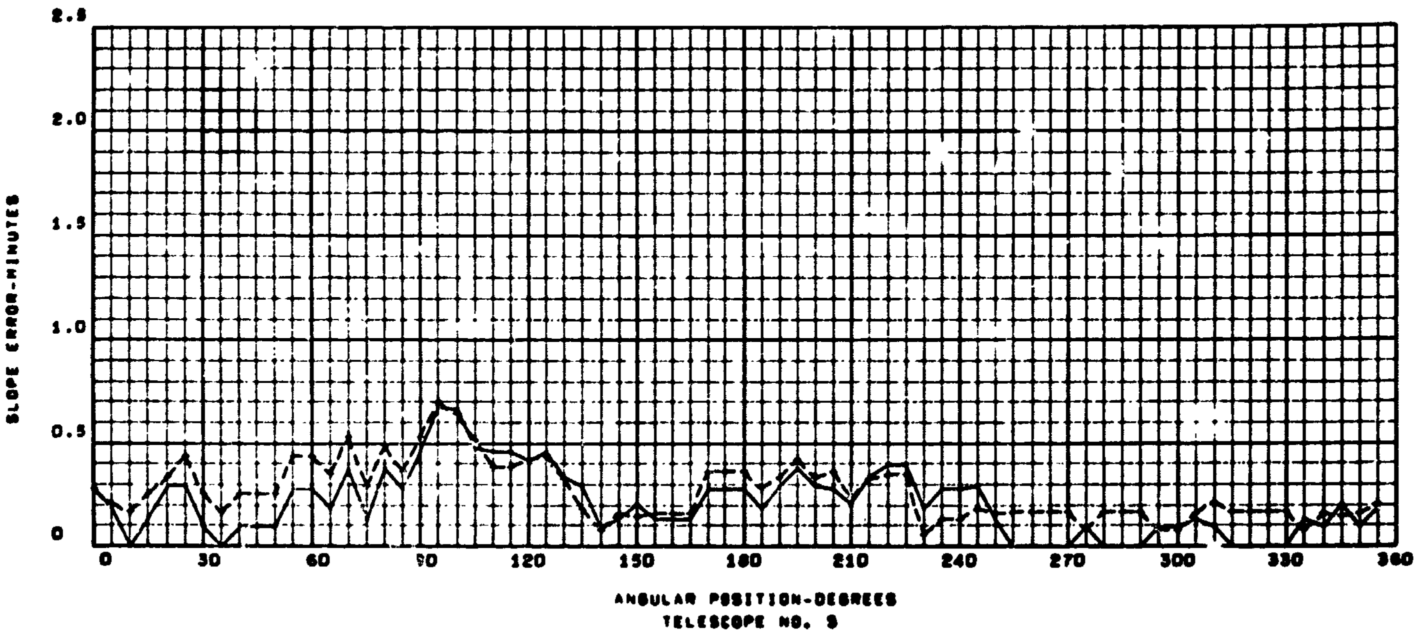
——— = ADJUSTED SLOPE ERROR
– – – = RAW SLOPE ERROR

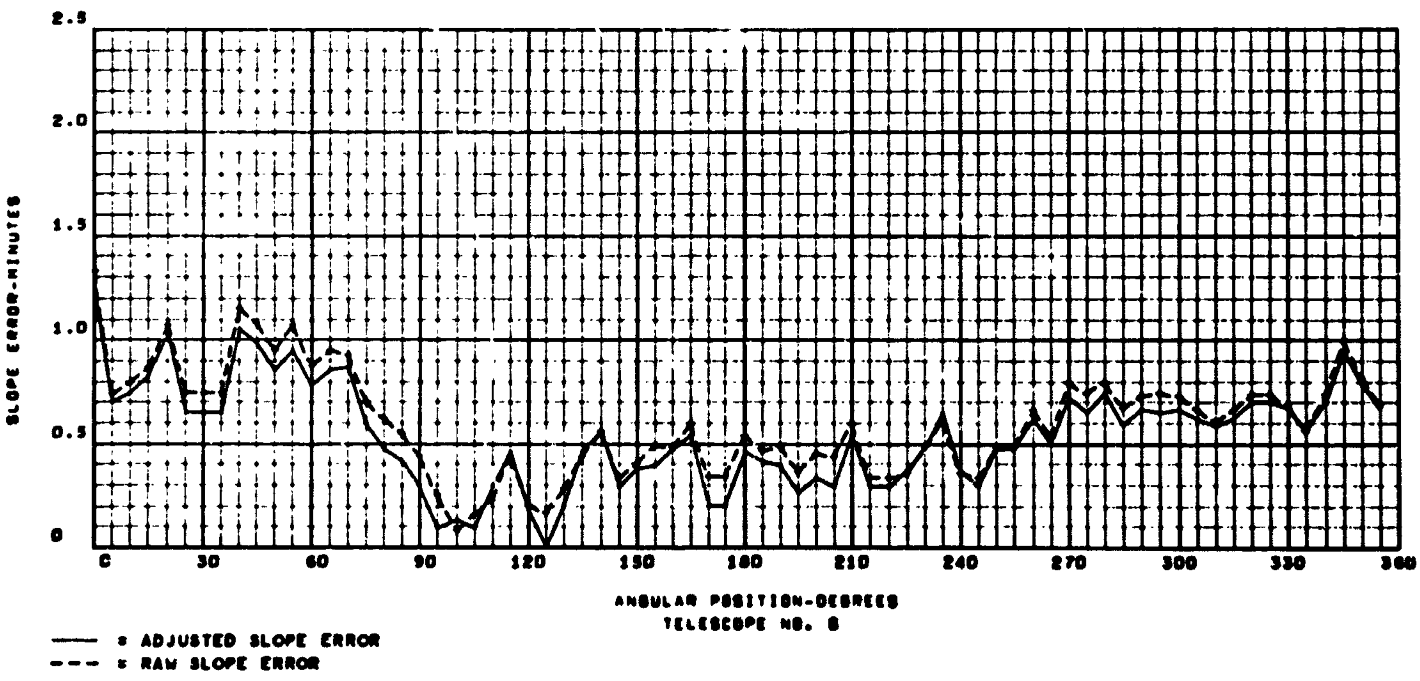


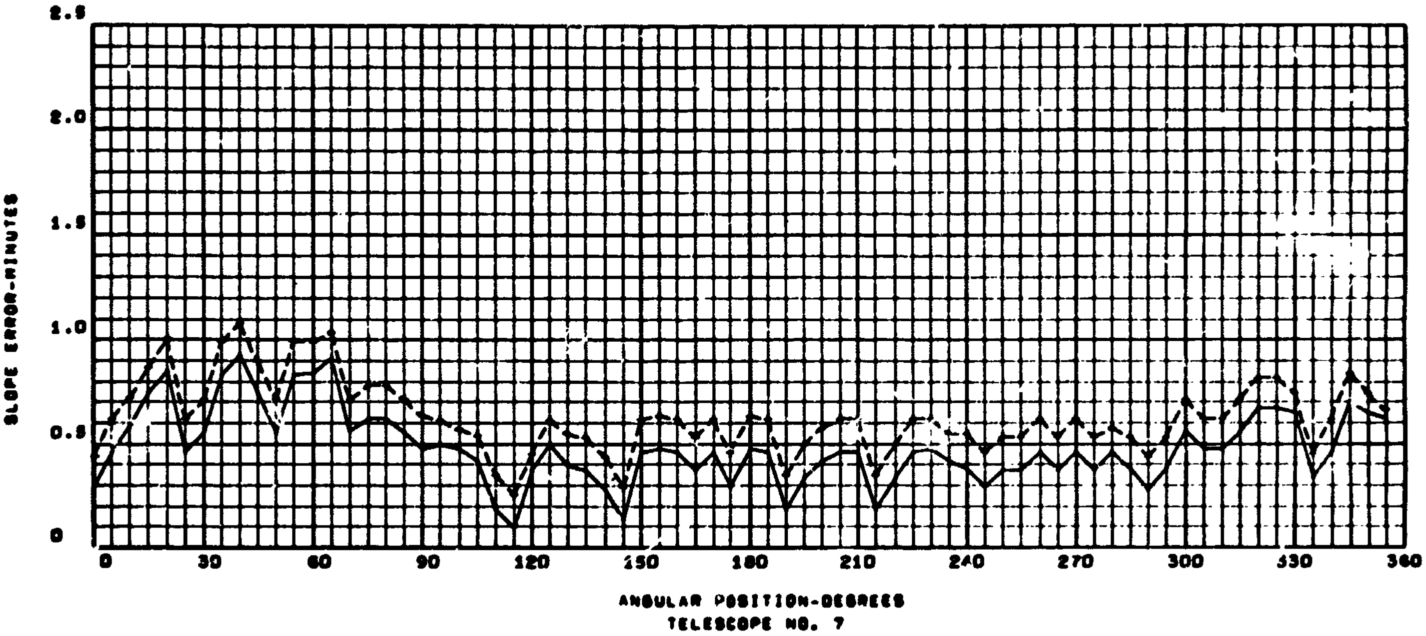
SLOPE ERROR-MINUTES
2.5
2.0
1.5
1.0
0.5
0
0
30
60
90
120
150
180
210
240
270
300
330
360
ANGULAR POSITION-DEGREES
TELESCOPE NO. 3

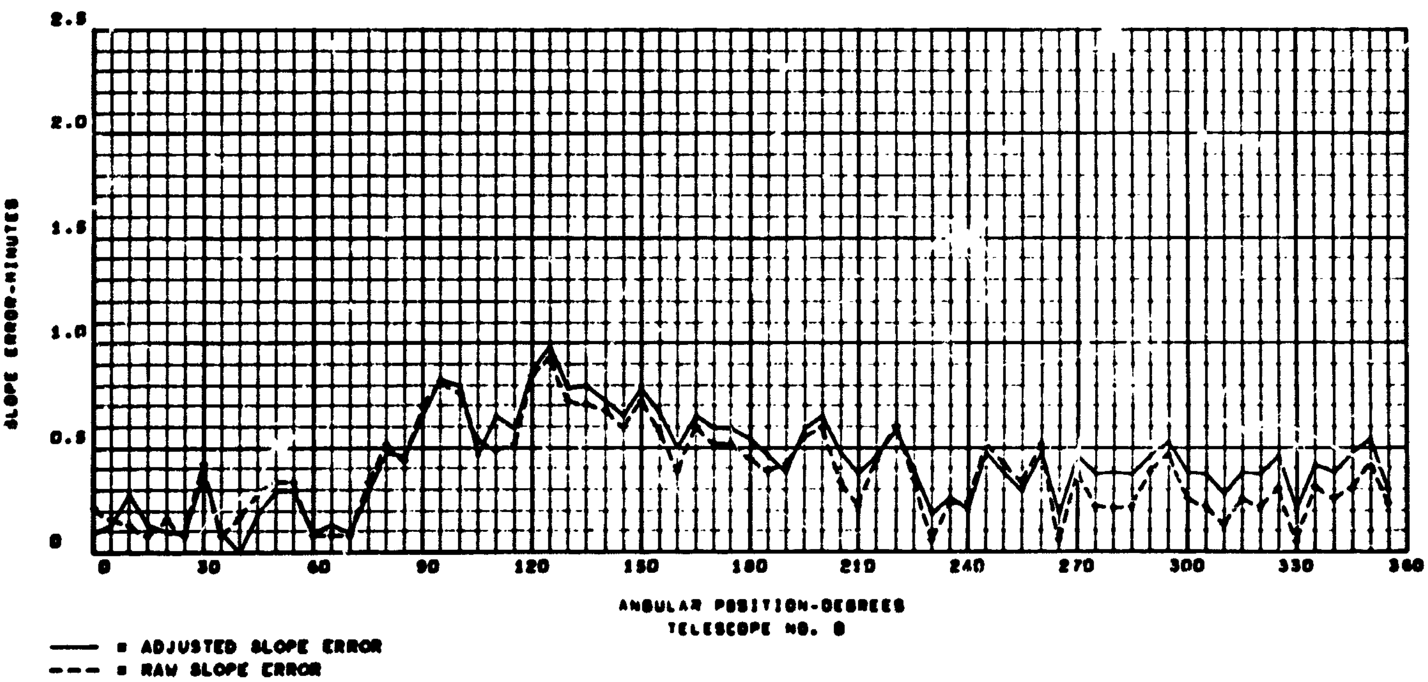


SLOPE ERROR-MINUTES
2.5
2.0
1.5
1.0
0.5
0
0
30
60
90
120
150
180
210
240
270
300
330
360
ANGULAR POSITION-DEGREES
TELESCOPE NO. 4
——— = ADJUSTED SLOPE ERROR
– – – = RAW SLOPE ERROR


2.5
2.0
1.5
1.0
0.5
0
SLOPE ERROR-MINUTES
0
30
60
90
120
150
180
210
240
270
300
330
360
ANGULAR POSITION-DEGREES
TELESCOPE NO. 5


2.5
2.0
1.5
1.0
0.5
0
SLOPE ERROR-MINUTES
0
30
60
90
120
150
180
210
240
270
300
330
360
ANGULAR POSITION-DEGREES
TELESCOPE NO. 6
—— = ADJUSTED SLOPE ERROR
--- = RAW SLOPE ERROR


2.5
2.0
1.5
1.0
0.5
0
SLOPE ERROR-MINUTES
0
30
60
90
120
150
180
210
240
270
300
330
360
ANGULAR POSITION-DEGREES
TELESCOPE NO. 7


2.5
2.0
1.5
1.0
0.5
0
SLOPE ERROR-MINUTES
0
30
60
90
120
150
180
210
240
270
300
330
360
ANGULAR POSITION-DEGREES
TELESCOPE NO. 8
——— = ADJUSTED SLOPE ERROR
– – – = RAW SLOPE ERROR

APPENDIX H

NICKEL MASTER

FIRST OPTICAL INSPECTION

OPTICAL INSPECTION - NICKEL MASTER FOR 9.5 FT. LANGLEY MIRROR

*ALL STD. DEVIATIONS * BY .0925 ARCMIN/DIVISION

TELESCOPE	AVERAGE X READING	STANDARD DEVIATION	AVERAGE Y READING	STANDARD DEVIATION	AVERAGE SLOPE ERROR
1	50.93	3.403	42.33	2.949	4.097
2	63.69	2.406	55.44	2.703	3.275
3	53.24	2.221	47.97	2.600	3.132
4	51.88	1.955	51.38	2.216	2.567
5	71.10	2.288	56.61	2.369	2.939
6	40.67	1.830	47.40	2.081	2.437
7	47.86	1.651	36.26	1.723	2.101
8	66.96	1.428	43.78	1.837	2.153

TELESCOPES 1-8

AVERAGE X READING 55.79
STANDARD DEVIATION 2.208

AVERAGE Y READING 47.65
STANDARD DEVIATION 2.330

X VS Y
STANDARD DEVIATION 3.210

RAW MEASURED SLOPE ERROR

ANGULAR POSITION (DEGREES)	TELESCOPE 1	TELESCOPE 2	TELESCOPE 3	TELESCOPE 4	TELESCOPE 5	TELESCOPE 6	TELESCOPE 7	TELESCOPE 8
0	5.394	5.491	5.003	4.478	5.923	2.618	0.853	2.818
5	5.233	5.762	4.916	4.406	6.222	3.302	0.414	2.909
10	3.814	6.222	4.762	3.999	5.394	3.058	[illegible]	4.264
15	3.729	5.646	4.625	4.669	5.780	3.559	1.668	4.625
20	3.912	4.981	4.775	4.521	4.981	3.302	1.668	3.294
25	4.163	4.535	4.155	4.468	4.756	3.701	1.962	1.962
30	3.545	4.626	4.648	3.705	4.441	4.057	1.836	1.517
35	3.612	4.483	4.259	3.814	3.982	3.669	2.683	2.358
40	3.612	4.108	3.797	2.983	4.129	3.270	2.358	1.907
45	4.252	4.264	3.705	3.231	4.363	4.003	1.767	1.034
50	4.738	4.372	4.070	3.833	3.955	4.422	2.068	0.392
55	5.569	7.733	4.829	4.601	4.354	4.304	2.592	0.462
60	5.233	4.717	4.746	3.830	3.130	4.300	2.868	0.853
65	5.646	4.626	3.270	3.404	3.206	4.264	2.684	1.114
70	6.012	4.516	3.733	3.569	3.441	4.188	2.921	1.668
75	6.291	5.080	4.106	3.779	3.109	4.464	3.686	1.591
80	6.541	4.535	4.172	4.188	3.231	4.717	4.387	1.445
85	7.400	4.440	3.977	4.684	3.392	4.829	4.057	1.412
90	7.458	4.829	4.902	4.810	2.905	4.807	4.146	1.668
95	8.273	5.809	5.533	5.003	2.819	4.697	4.655	1.388
100	7.224	5.421	5.646	3.830	3.281	4.738	4.644	0.925
105	6.012	4.717	5.171	5.003	3.723	5.239	5.273	2.775
110	6.938	4.699	4.577	4.264	3.792	4.916	4.429	3.270
115	5.721	3.952	4.648	3.847	4.079	4.762	4.422	3.054
120	4.981	3.729	4.070	3.779	3.773	4.268	4.670	2.973
125	4.264	3.612	3.710	3.109	3.483	4.725	4.684	3.075
130	3.705	4.062	3.195	3.422	3.362	4.300	4.179	3.141
135	3.259	2.750	3.464	2.925	3.441	3.190	3.797	3.179
140	1.859	1.668	3.294	2.989	3.990	3.559	3.903	3.270
145	2.605	2.235	3.411	2.750	4.268	3.087	4.004	3.454
150	2.989	2.068	3.157	2.491	4.595	3.270	2.986	3.236
155	4.445	2.850	2.697	2.951	3.873	2.777	3.030	2.838
160	3.729	3.080	2.938	3.612	4.717	2.127	3.316	2.750
165	3.863	3.103	2.890	3.183	4.717	2.407	4.057	2.989
170	3.924	3.705	2.136	2.491	4.684	1.688	3.723	3.441
175	4.163	4.555	1.531	1.415	3.995	1.118	3.103	3.663
180	6.541	5.103	1.125	1.125	4.164	1.285	2.499	2.961
185	7.529	3.270	1.129	0.930	4.629	1.315	3.080	2.697
190	7.180	2.572	1.581	0.414	4.626	1.572	3.294	2.540
195	6.491	1.125	2.689	0.185	4.163	1.079	3.335	2.421
200	4.898	1.597	3.622	1.295	3.052	0.785	2.629	2.616
205	4.125	1.334	2.290	0.916	3.889	0.563	2.340	2.489
210	4.906	2.313	1.993	0.131	4.684	0.832	2.400	2.313
215	5.003	2.504	1.852	0.654	4.779	1.125	2.697	2.364
220	1.907	2.068	1.540	1.506	4.137	1.591	2.369	2.940
225	2.925	3.321	2.253	1.308	3.352	1.668	1.244	2.412
230	1.400	3.270	2.268	3.108	4.366	1.463	1.436	1.931
235	2.157	3.663	2.905	3.441	4.608	1.185	1.581	2.313
240	2.961	4.089	2.489	3.270	4.223	1.388	1.375	2.961
245	3.270	3.891	2.054	1.185	2.206	0.462	1.034	2.961
250	2.313	3.522	1.757	1.745	2.079	1.185	0.207	2.498
255	3.103	2.504	1.110	1.388	2.552	1.366	0.000	3.924
260	2.590	2.313	0.746	1.203	1.925	1.859	0.930	4.648
265	2.590	1.636	0.722	0.740	1.873	1.206	1.244	2.159
270	2.813	0.827	1.324	0.925	0.555	1.170	1.655	2.890
275	2.961	0.878	1.871	1.483	0.722	1.415	0.763	2.980
280	1.738	0.654	1.668	0.966	1.942	1.034	0.790	2.777
285	2.235	0.654	1.767	0.704	1.852	1.034	1.203	2.631
290	1.597	0.654	1.463	0.648	2.113	0.621	1.324	3.087

295	1.668	1.668	2.526	1.203	1.388	0.873	1.366	3.599
300	3.367	1.668	1.144	0.722	1.206	0.381	0.414	4.074
305	3.270	1.445	1.945	0.555	2.320	0.185	1.234	3.811
310	3.101	1.925	2.239	0.832	2.869	0.763	1.017	2.526
315	2.872	2.565	2.167	0.966	3.054	0.790	1.298	2.830
320	2.127	3.824	2.570	0.878	2.498	0.334	1.298	2.830
325	4.483	3.236	3.091	1.777	3.612	0.853	0.943	2.925
330	4.207	3.729	3.684	2.111	4.164	1.022	1.079	2.663
335	4.025	3.863	3.684	2.371	4.629	1.388	1.170	2.956
340	4.268	4.684	4.244	2.313	4.717	1.757	1.244	3.545
345	4.057	4.684	4.501	1.907	3.803	1.144	0.654	4.137
350	4.319	4.717	4.167	2.565	5.053	2.616	1.570	4.478
355	4.264	5.315	4.600	4.057	5.301	2.489	1.492	3.554
MEAN	4.222	3.529	3.156	2.572	3.672	2.465	2.343	2.697
STD.DEV.	1.649	1.534	1.311	1.440	1.188	1.528	1.344	0.933

TELESCOPES 1-8 (ALL READINGS)

MEAN SLOPE ERROR	3.082
STD. DEVIATION	1.512
MEDIAN SLOPE ERROR	3.103

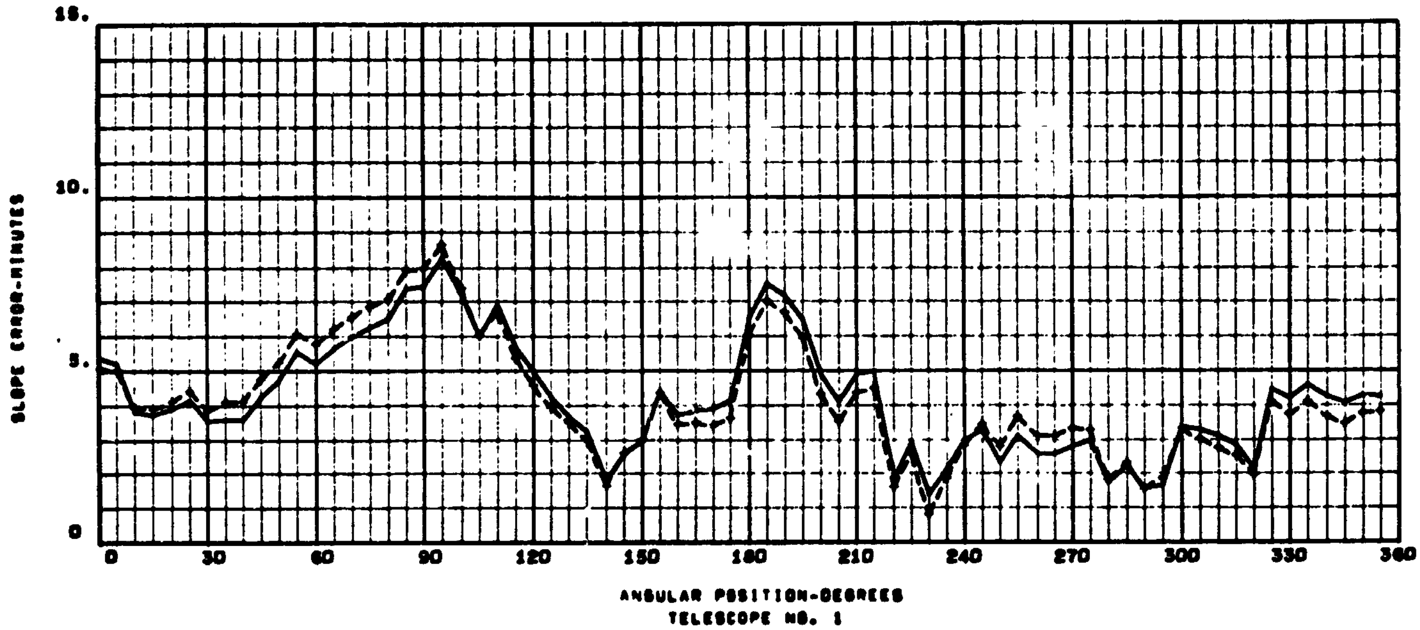
ADJUSTED SLOPE ERROR

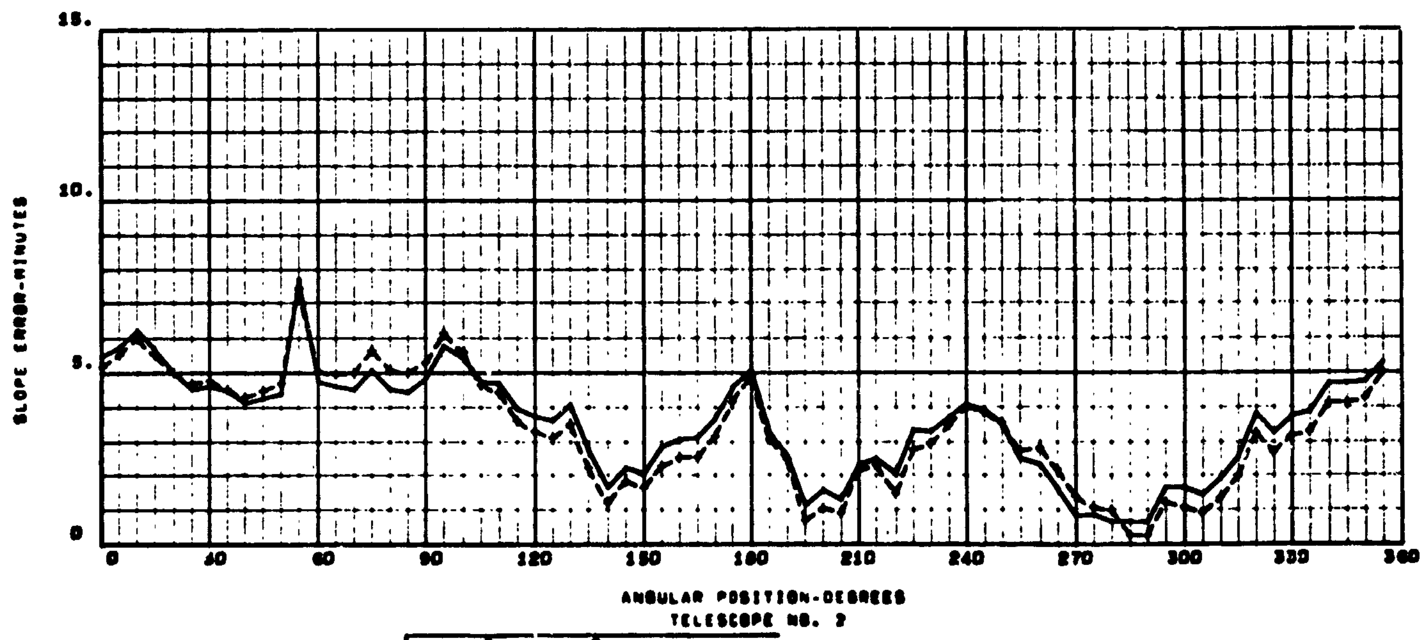
ANGULAR POSITION (DEGREES)	TELESCOPE 1	TELESCOPE 2	TELESCOPE 3	TELESCOPE 4	TELESCOPE 5	TELESCOPE 6	TELESCOPE 7	TELESCOPE 8
0	5.067	5.179	4.702	4.223	5.663	2.582	0.500	2.448
5	5.036	5.538	4.685	4.158	5.992	3.457	0.684	2.603
10	3.937	5.992	4.727	3.607	5.335	3.289	1.514	4.117
15	3.918	5.545	4.512	4.588	5.631	3.733	1.985	4.512
20	4.103	5.018	4.715	4.471	5.018	3.457	1.985	3.183
25	4.413	4.674	4.248	4.455	4.877	3.968	2.308	1.817
30	3.864	4.766	4.843	3.933	4.679	4.493	2.366	1.473
35	4.131	4.523	4.486	4.181	4.210	4.159	3.227	2.531
40	4.131	4.288	4.025	3.304	4.234	3.810	2.889	2.296
45	4.787	4.480	3.933	3.596	4.411	4.556	2.317	1.517
50	5.250	4.673	4.321	4.241	4.108	4.982	2.645	0.952
55	6.093	7.450	5.210	5.071	4.705	4.879	3.141	0.868
60	5.770	5.058	5.231	4.336	3.625	4.877	3.410	1.274
65	6.210	4.970	3.810	3.935	3.741	4.835	3.220	1.675
70	6.591	5.012	4.282	4.141	4.004	4.747	3.420	2.049
75	6.867	5.648	4.684	4.357	3.682	4.982	4.148	1.962
80	7.103	5.105	4.724	4.747	3.803	5.209	4.799	1.712
85	7.939	4.980	4.518	5.187	3.889	5.292	4.476	1.612
90	7.967	5.292	5.263	5.237	3.412	5.182	4.457	1.871
95	8.666	6.124	5.720	5.349	3.056	5.056	4.944	1.287
100	7.421	5.594	5.802	4.018	3.325	5.046	4.891	0.887
105	6.045	4.643	5.248	5.150	3.812	5.515	5.459	2.613
110	6.741	4.417	4.532	4.207	3.615	5.135	4.532	3.181
115	5.400	3.585	4.519	3.577	3.861	4.866	4.396	2.904
120	4.599	3.294	3.889	3.406	3.488	4.384	4.563	2.755
125	3.964	3.114	3.492	2.733	3.207	4.769	4.588	2.711
130	3.500	3.490	2.822	3.249	3.113	4.306	4.048	2.842
135	3.024	2.217	3.000	2.587	2.965	3.189	3.592	2.928
140	1.670	1.233	2.807	2.621	3.461	3.473	3.671	3.021
145	2.612	1.859	2.910	2.404	3.696	3.005	3.761	3.093
150	3.041	1.678	2.711	2.131	4.049	3.181	2.765	2.796
155	4.381	2.292	2.330	2.505	3.328	2.633	2.745	2.495
160	3.483	2.542	2.521	3.114	4.143	1.984	2.935	2.404
165	3.529	2.527	2.395	2.624	4.150	2.232	3.661	2.621
170	3.399	3.165	1.560	1.913	4.123	1.470	3.311	2.965
175	3.633	4.175	1.214	0.854	3.445	0.803	2.696	3.138
180	6.048	4.922	1.511	0.575	3.629	0.899	2.013	2.473
185	7.050	3.092	1.698	0.498	4.109	0.853	2.576	2.262
190	6.728	2.480	2.159	0.435	4.091	1.188	2.807	2.091
195	5.944	0.701	3.243	0.753	3.633	0.708	2.875	1.910
200	4.333	1.039	3.905	1.843	2.526	0.338	2.140	2.096
205	3.548	0.916	2.584	1.259	3.374	0.127	1.764	1.955
210	4.383	2.162	2.072	0.640	4.200	0.368	1.825	1.760
215	4.536	2.307	1.691	0.684	4.329	0.701	2.127	1.794
220	1.634	1.493	0.977	1.412	3.780	1.562	1.622	2.362
225	2.587	2.752	1.675	1.207	3.118	1.652	0.767	1.870
230	0.853	2.940	1.817	2.850	4.094	1.607	0.865	1.357
235	1.868	3.479	2.657	3.176	4.354	1.712	1.003	1.841
240	2.851	3.973	2.356	3.092	3.884	1.935	0.890	2.473
245	3.456	3.870	1.997	1.034	1.935	1.022	0.873	2.413
250	2.824	3.559	2.046	2.239	2.170	1.746	0.629	1.974
255	3.679	2.738	1.432	1.692	2.402	1.941	0.578	3.738
260	3.133	2.824	1.145	1.518	1.685	2.419	0.835	4.097
265	3.133	2.187	1.285	1.097	1.613	1.743	0.767	1.634
270	3.320	1.404	1.771	1.477	0.218	1.653	1.795	2.280
275	3.283	1.081	2.436	2.039	0.776	1.924	0.890	2.434
280	1.861	1.028	2.049	1.462	1.424	1.553	0.966	2.243
285	2.332	0.256	2.045	1.185	1.351	1.481	1.339	2.060
290	1.580	0.256	1.686	1.203	1.756	0.880	1.350	2.329

295	1.871	1.233	2.608	1.664	1.197	1.299	1.539	3.241
300	3.355	1.107	1.207	1.054	0.735	0.914	0.737	3.557
305	3.021	0.911	1.568	0.633	1.822	0.537	1.277	3.310
310	2.770	1.368	1.760	0.815	2.335	0.629	0.963	1.949
315	2.566	1.968	1.680	0.753	2.520	0.213	1.247	2.266
320	1.984	3.256	2.142	0.667	1.974	0.356	1.247	2.369
325	4.103	2.666	2.544	1.303	3.042	0.299	0.790	2.653
330	3.746	3.157	3.110	1.539	3.640	0.573	0.515	2.270
335	4.140	3.280	3.110	1.793	4.109	0.879	0.594	2.557
340	3.806	4.123	3.666	1.738	4.246	1.241	0.728	3.105
345	3.480	4.123	3.939	1.337	3.384	0.758	0.168	3.780
350	3.756	4.246	3.649	2.218	4.669	2.450	1.447	4.223
355	3.803	4.993	4.155	3.682	4.960	2.356	1.222	3.310
MEAN	4.188	3.362	3.136	2.594	3.458	2.584	2.306	2.435
STD.DEV.	1.715	1.644	1.333	1.470	1.205	1.702	1.405	0.782

TELESCOPES 1-8 (ALL READINGS)

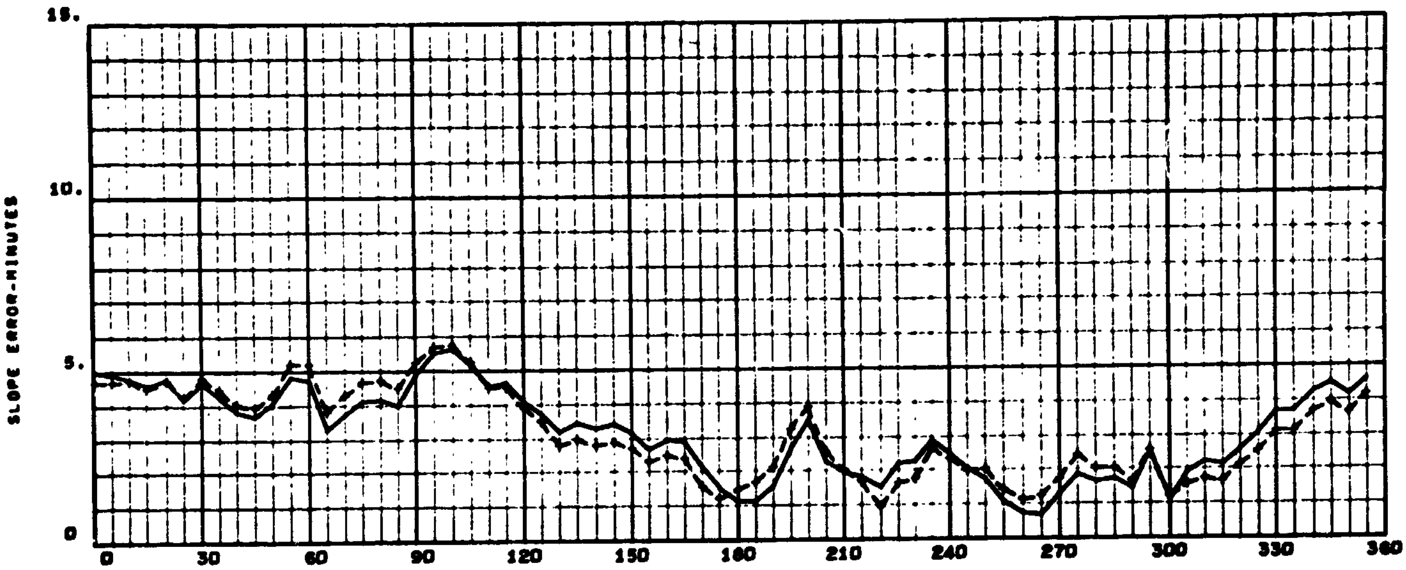
MEAN SLOPE ERROR	3.008 *
STD. DEVIATION	3.386
MEDIAN SLOPE ERROR	2.952



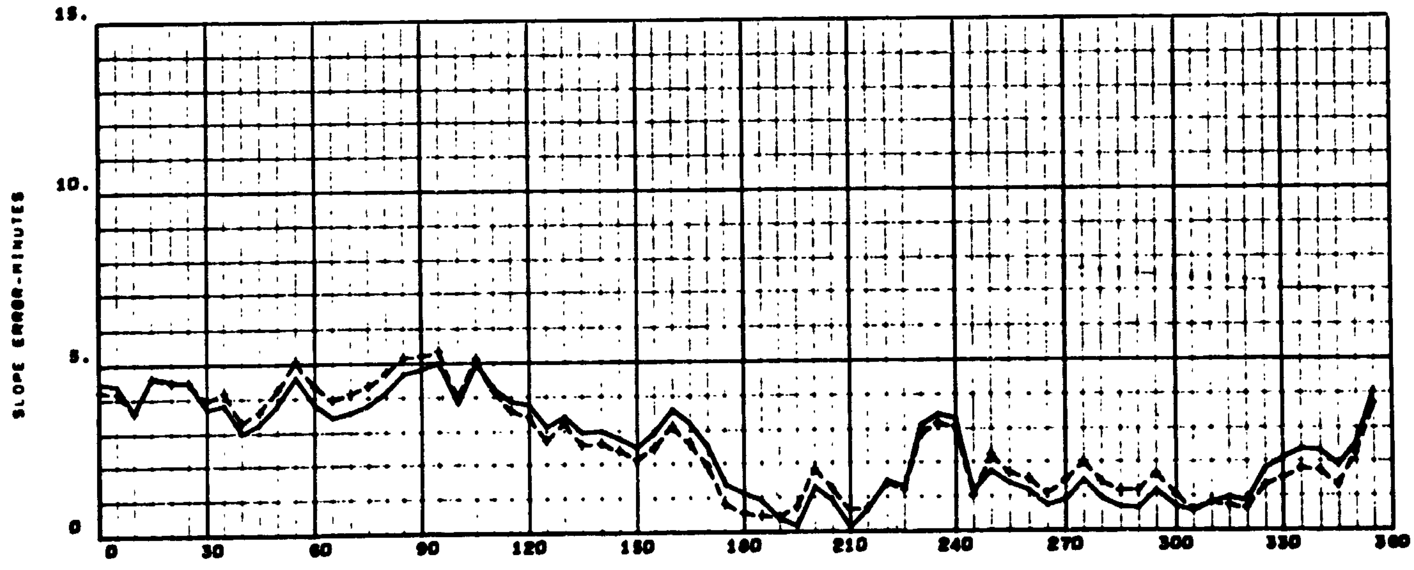


——— = ADJUSTED SLOPE ERROR $\sqrt{(X-\bar{X})^2 + (Y-\bar{Y})^2}$

- - - = RAW SLOPE ERROR $\sqrt{(X-80.)^2 + (Y-80.)^2}$



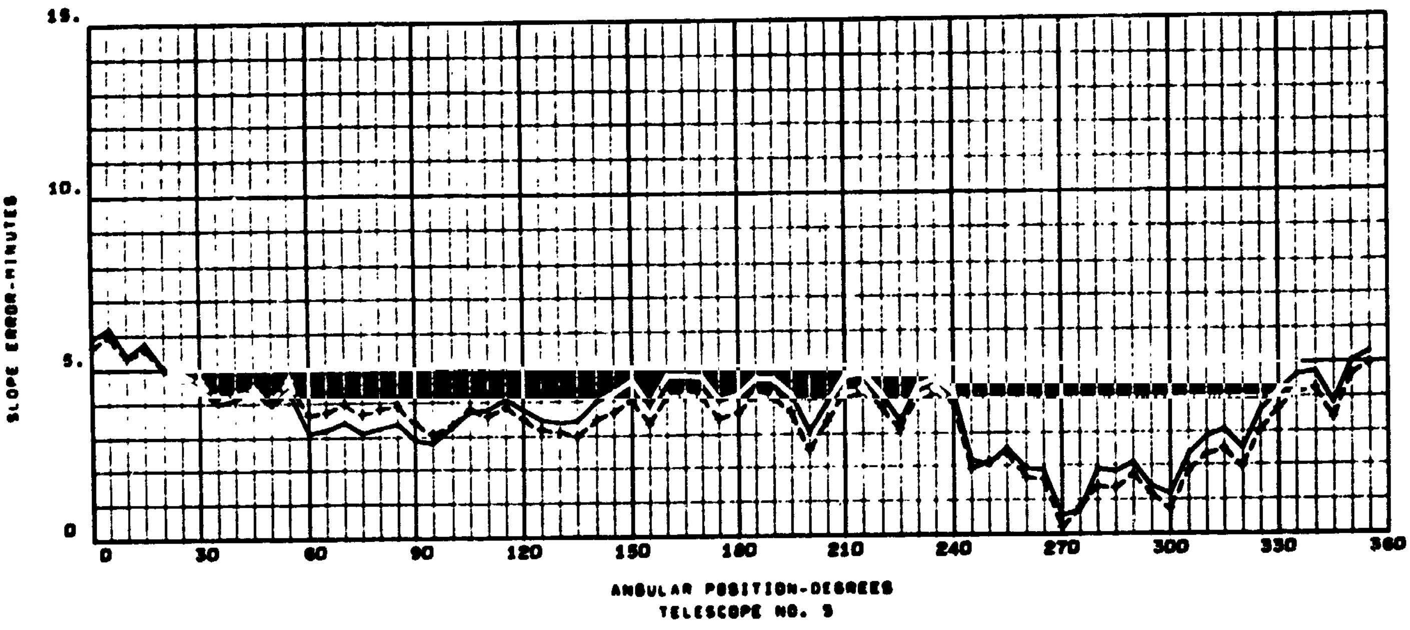
ANGULAR POSITION-DEGREES
TELESCOPE NO. 3

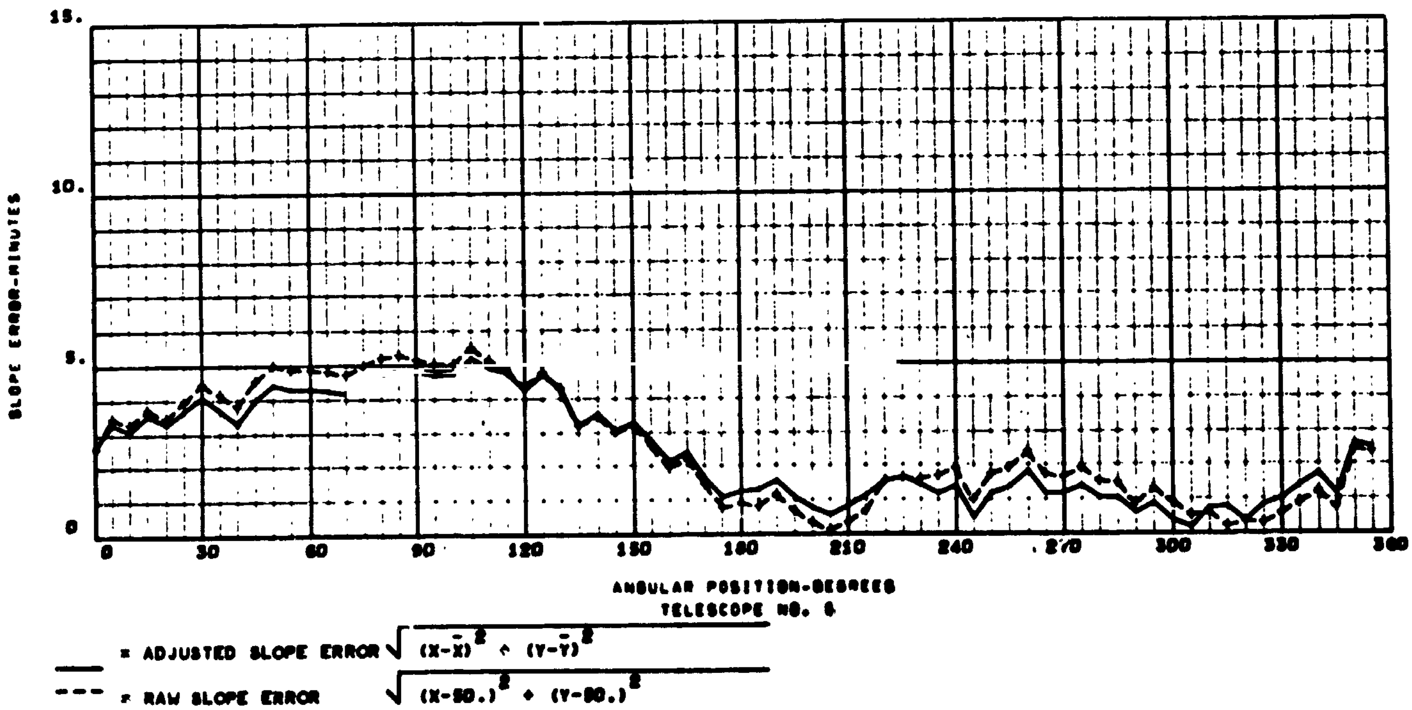


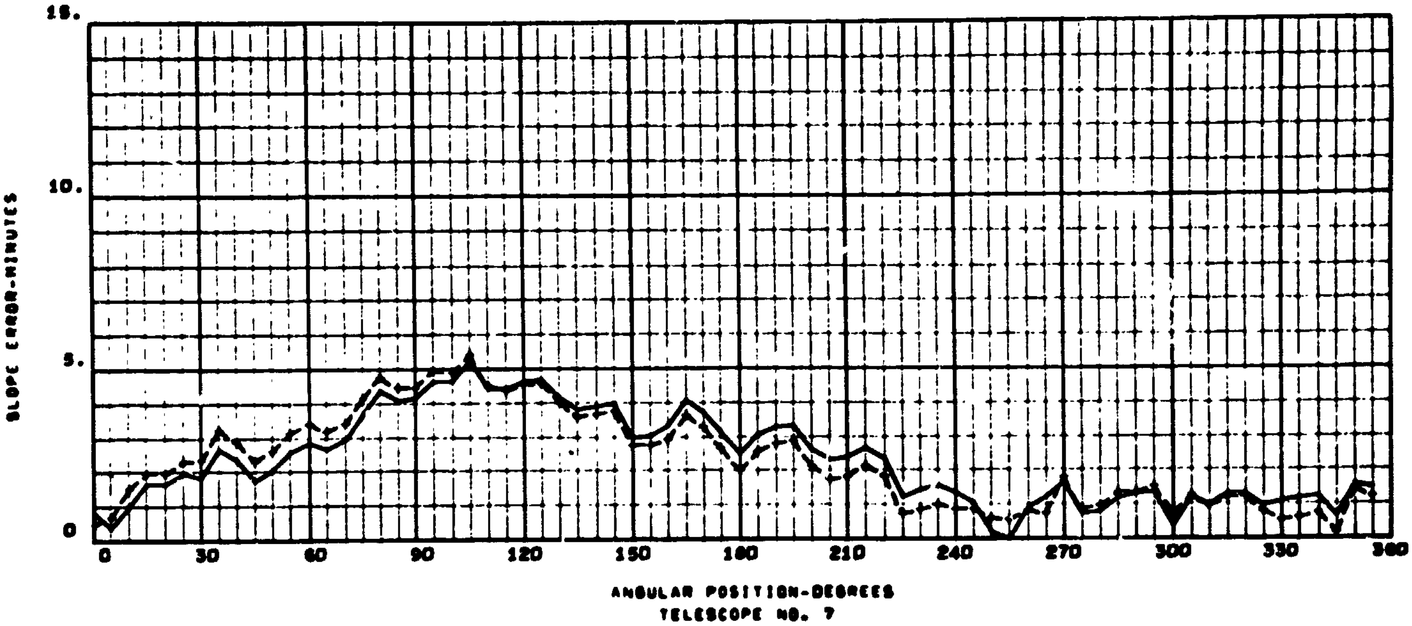
ANGULAR POSITION-DEGREES
TELESCOPE NO. 4

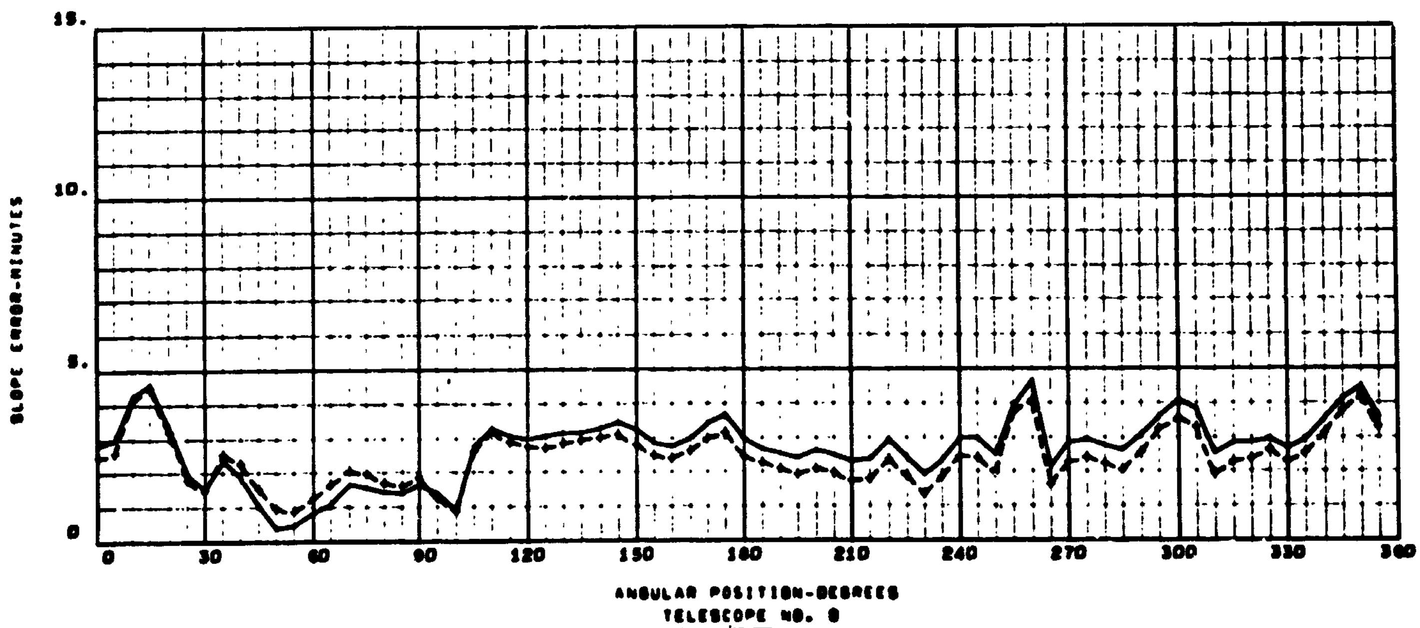
——— = ADJUSTED SLOPE ERROR $\sqrt{(X-\bar{X})^2 + (Y-\bar{Y})^2}$

- - - = RAW SLOPE ERROR $\sqrt{(X-80.)^2 + (Y-80.)^2}$


SLOPE ERROR-MINUTES
15.
10.
5.
0
0 30 60 90 120 150 180 210 240 270 300 330 360
ANGULAR POSITION-DEGREES
TELESCOPE NO. 5


SLOPE ERROR-MINUTES
15.
10.
5.
0
0 30 60 90 120 150 180 210 240 270 300 330 360
ANGULAR POSITION-DEGREES
TELESCOPE NO. 6
= ADJUSTED SLOPE ERROR √ (X-X̄)² + (Y-Ȳ)²
= RAW SLOPE ERROR √ (X-50.)² + (Y-50.)²





——— = ADJUSTED SLOPE ERROR $\sqrt{(X-\bar{X})^2 + (Y-\bar{Y})^2}$

\- - - = RAW SLOPE ERROR $\sqrt{(X-50.)^2 + (Y-50.)^2}$

APPENDIX I

NICKEL MASTER

SECOND OPTICAL INSPECTION

2ND OPTICAL INSPECTION 9 1/2 FOOT NICKEL MASTER 6/14/66

*ALL STD. DEVIATIONS * BY .0925 ARCMIN/DIVISION

TELESCOPE	AVERAGE X READING	STANDARD DEVIATION	AVERAGE Y READING	STANDARD DEVIATION	AVERAGE SLOPE ERROR
1	59.46	3.499	49.03	3.0[illegible]5	4.184
2	65.49	2.596	42.21	2.865	3.445
3	56.64	2.410	44.18	2.595	3.230
4	49.71	2.286	46.82	2.155	2.759
5	57.49	2.235	37.28	2.239	2.801
6	50.72	1.714	47.43	1.880	2.245
7	46.03	1.397	43.81	1.555	1.849
8	47.32	1.419	44.64	1.778	2.112

TELESCOPES 1-8

AVERAGE X READING	54.11
STANDARD DEVIATION	2.273
AVERAGE Y READING	44.42
STANDARD DEVIATION	2.307
X VS Y	
AVERAGE	98.53
STANDARD DEVIATION	3.239

RAW MEASURED SLOPE ERROR

ANGULAR POSITION (DEGREES)	TELESCOPE 1	TELESCOPE 2	TELESCOPE 3	TELESCOPE 4	TELESCOPE 5	TELESCOPE 6	TELESCOPE 7	TELESCOPE 8
0	6.670	4.981	4.981	4.981	4.829	3.157	2.029	2.167
5	5.923	4.555	4.555	4.924	4.640	3.072	1.668	2.001
10	4.137	5.795	4.579	3.342	2.616	3.034	1.887	3.103
15	4.207	4.884	4.625	5.057	3.491	3.796	2.491	3.891
20	4.062	4.625	5.103	4.916	3.464	3.924	2.697	2.872
25	4.681	3.972	4.625	4.916	3.487	4.223	2.401	1.907
30	3.437	3.649	4.725	3.891	3.259	3.637	2.146	1.388
35	3.145	4.264	4.213	3.700	2.329	3.157	3.101	2.540
40	4.074	4.089	3.689	3.058	2.989	3.239	2.996	3.079
45	4.824	4.471	3.599	3.422	3.075	3.814	2.421	2.616
50	5.553	4.648	4.535	4.319	3.285	3.891	2.054	2.068
55	6.132	5.108	5.108	4.882	4.109	3.979	2.313	1.824
60	6.012	5.550	4.981	3.903	3.733	3.612	2.702	2.75[illegible]
65	6.670	4.363	4.264	3.904	3.186	3.270	2.258	2.777
70	6.541	4.916	4.264	4.074	3.814	3.294	2.491	2.449
75	6.670	4.762	4.363	3.824	3.773	2.830	3.179	2.556
80	6.376	4.648	4.264	4.717	4.213	3.454	3.701	2.220
85	7.400	5.171	4.188	5.091	4.717	2.868	3.239	2.313
90	7.400	5.850	4.125	4.885	3.904	2.577	2.813	2.449
95	7.903	6.541	4.916	5.461	3.944	2.491	3.353	1.907
100	7.224	6.291	5.162	4.464	4.655	2.777	3.522	1.675
105	6.670	5.627	5.171	5.365	5.129	3.889	4.981	2.428
110	6.475	6.030	5.721	4.633	5.096	3.472	3.079	3.352
115	5.588	5.660	4.684	3.270	4.810	3.157	3.002	3.150
120	4.521	4.981	3.700	3.101	4.125	3.183	3.186	3.183
125	3.422	4.762	3.729	2.694	4.067	3.353	3.236	1.980
130	3.249	3.873	2.961	3.101	4.095	3.491	2.697	3.103
135	2.463	3.335	3.335	2.616	3.618	1.668	2.313	2.777
140	1.526	2.313	3.472	2.136	3.411	2.540	2.358	2.903
145	0.943	2.358	3.183	1.997	3.276	1.786	2.605	3.190
150	1.388	1.757	2.938	1.931	3.939	2.631	2.340	3.270
155	3.108	2.491	2.358	2.228	3.545	2.199	2.428	3.130
160	2.663	3.522	2.872	2.850	3.920	1.871	1.942	3.109
165	2.813	3.335	2.818	2.068	3.367	2.504	2.421	3.062
170	3.472	3.236	2.109	1.308	3.411	1.760	2.513	2.491
175	3.889	3.237	1.241	1.217	2.577	1.665	2.222	2.407
180	6.734	2.224	0.740	1.375	3.186	1.770	1.492	2.376
185	7.414	1.308	1.871	1.375	3.270	1.960	1.960	2.491
190	7.414	1.144	2.268	1.375	3.904	2.087	2.340	2.313
195	6.876	2.746	3.729	2.029	3.157	1.960	2.558	2.020
200	6.622	4.579	3.612	2.444	2.925	1.755	1.526	2.054
205	6.012	3.979	2.925	2.650	3.183	1.334	1.129	1.668
210	4.884	4.191	2.781	1.728	3.756	1.388	1.375	1.767
215	3.472	3.779	3.075	0.853	3.396	1.668	1.962	1.298
220	2.235	3.034	2.552	0.996	2.731	1.388	2.097	1.110
225	3.183	4.030	2.818	0.952	1.668	1.206	1.203	1.298
230	2.590	2.983	2.405	2.789	2.313	1.570	0.925	0.827
235	3.516	3.062	3.612	3.051	2.781	0.262	1.244	2.428
240	3.612	3.183	2.629	2.491	1.859	0.627	1.308	2.540
245	3.367	2.616	1.907	1.445	1.706	1.017	1.572	2.496
250	2.087	2.489	1.445	0.836	0.763	0.131	0.539	0.370
255	2.489	1.185	0.911	0.746	1.001	0.093	0.000	0.555
260	1.824	0.414	0.796	0.381	1.258	1.034	0.925	1.324
265	1.206	0.621	0.3[illegible]	0.131	1.409	0.207	0.853	2.035
270	1.850	0.925	1.591	1.551	2.251	0.943	1.779	1.492
275	1.622	0.673	1.114	2.020	1.942	0.763	1.114	1.185
280	0.996	1.483	1.591	1.721	2.048	0.763	0.966	0.873
285	1.659	1.728	1.755	1.618	2.268	0.763	1.170	1.185
290	1.144	2.068	1.728	1.570	1.907	1.494	1.203	1.324
295	1.203	3.103	3.278	2.093	1.[illegible]62	1.083	1.388	1.852
300	3.239	3.434	2.251	1.905	2.605	1.150	0.462	2.037
305	3.635	3.569	2.577	1.945	2.649	1.591	1.144	3.145
310	4.916	3.982	3.108	1.850	3.612	2.313	0.966	2.358
315	3.924	4.595	3.183	1.960	3.472	2.387	1.203	1.618
320	2.540	5.923	3.273	1.931	3.145	1.668	1.110	1.583
325	4.579	4.864	4.146	2.540	4.312	2.491	0.790	1.591
330	4.762	5.003	4.550	2.961	4.259	2.401	1.334	1.492
335	5.588	5.053	4.633	3.560	4.303	2.605	1.288	1.668
340	4.577	6.171	4.511	3.195	4.445	3.065	1.448	1.639
345	3.614	6.734	4.535	2.428	3.335	2.237	1.129	2.890
350	5.087	5.550	4.440	3.939	3.977	3.101	1.668	3.270
355	5.413	5.627	4.717	4.264	3.821	3.278	1.572	2.499

UNIT 26, TAPE SERIAL NO. 00001, FILE NO. 002, REEL NO. 001
RECORDS PROCESSED 00002, PERMANENT RTT RECORDS 00000, NOISE RECORDS IGNORED 00000

MEAN	4.281	3.857	3.372	2.419	3.283	2.300	1.993	2.205
STD.DEV.	1.942	1.570	1.300	1.380	0.986	1.084	0.900	0.746

TELESCOPES 1-8 (ALL READINGS)
MEAN SLOPE ERROR 3.014
STD. DEVIATION 1.498
MEDIAN SLOPE ERROR 2.914

ADJUSTED SLOPE ERROR

ANGULAR POSITION (DEGREES)	TELESCOPE 1	TELESCOPE 2	TELESCOPE 3	TELESCOPE 4	TELESCOPE 5	TELESCOPE 6	TELESCOPE 7	TELESCOPE 8
0	6.671	4.860	4.860	4.860	4.652	3.171	1.995	2.402
5	5.983	4.462	4.462	4.873	4.540	3.777	1.758	2.072
10	4.465	5.744	4.717	3.531	2.785	3.270	2.366	3.442
15	4.470	4.936	4.675	5.136	3.501	3.964	2.880	4.295
20	4.357	4.849	5.254	5.011	3.727	4.070	3.080	3.310
25	4.976	4.291	4.849	5.011	3.863	4.529	2.841	2.367
30	3.797	.945	5.081	4.204	3.753	4.124	2.724	1.941
35	3.680	4.358	4.605	4.233	2.830	3.662	3.713	3.129
40	4.590	4.310	4.231	3.574	3.371	3.764	3.576	3.719
45	5.378	4.816	3.938	3.957	3.461	4.413	2.994	3.251
50	6.092	5.141	4.986	4.900	3.757	4.503	[illegible]	2.655
55	6.717	5.604	5.666	5.515	4.747	4.619	2.932	2.426
60	6.636	6.078	5.604	4.541	4.363	4.252	3.323	3.381
65	7.310	5.002	4.765	4.544	3.764	3.905	2.872	3.373
70	7.175	5.544	4.890	4.698	4.376	3.915	3.054	2.952
75	7.276	5.351	4.964	4.426	4.269	3.332	3.658	2.878
80	7.415	5.100	4.765	5.208	4.689	3.926	4.125	2.650
85	7.797	5.483	4.646	5.477	5.021	3.288	3.068	2.741
90	7.797	6.078	4.353	5.115	4.192	2.815	3.155	2.785
95	8.101	6.476	4.819	5.610	3.963	2.788	3.541	2.230
100	7.214	6.127	5.008	4.536	4.558	2.918	3.721	2.162
105	6.480	5.281	4.913	5.322	5.007	4.061	5.180	2.468
110	5.971	5.497	5.335	4.374	4.759	3.599	3.184	3.254
115	4.963	5.087	4.259	2.723	4.513	2.979	2.848	3.066
120	3.884	4.364	3.207	2.504	3.805	3.045	2.942	3.045
125	2.818	4.127	3.185	2.105	3.722	3.092	3.047	1.903
130	2.724	3.253	2.322	2.771	3.762	3.308	2.520	2.868
135	1.823	2.695	2.695	2.074	3.093	1.569	1.990	2.587
140	2.132	1.725	2.835	1.623	2.837	2.153	1.984	2.629
145	0.453	1.799	2.542	1.657	2.685	1.541	2.176	2.986
150	1.350	1.298	2.306	1.629	3.380	2.239	2.039	2.849
155	2.983	1.678	1.799	1.715	3.000	1.863	2.117	2.978
160	2.373	2.902	2.288	2.275	3.313	1.487	1.476	2.917
165	2.261	2.695	2.199	1.441	2.727	2.061	1.892	2.812
170	2.835	2.657	1.469	0.682	2.773	1.274	1.984	2.150
175	3.575	2.984	0.731	0.889	1.966	1.210	1.768	1.911
180	6.538	2.405	1.233	1.147	2.558	1.246	0.984	2.025
185	7.088	1.153	2.242	1.398	2.639	1.361	1.361	2.220
190	7.088	3.768	2.600	1.398	3.263	1.521	1.742	1.990
195	6.354	2.107	3.855	2.054	2.519	1.361	1.989	1.706
200	6.069	3.946	3.515	2.600	2.324	1.162	0.964	1.655
205	5.473	3.338	2.609	2.456	2.542	0.695	0.561	1.242
210	4.335	3.574	2.268	1.425	3.144	0.796	0.758	1.364
215	2.835	3.164	2.462	0.372	2.825	1.088	1.332	0.911
220	1.614	2.394	1.924	0.564	2.170	1.132	1.460	0.705
225	2.542	3.443	2.287	0.327	1.353	1.023	0.785	0.830
230	2.270	2.728	2.090	2.523	2.000	1.782	0.362	0.783
235	3.563	3.003	3.706	2.870	2.496	0.900	0.610	2.117
240	3.816	3.238	2.738	2.517	1.507	1.129	0.803	2.153
245	3.793	2.785	2.040	1.715	1.068	0.629	1.123	2.018
250	2.686	2.692	1.715	1.356	0.297	0.673	0.875	0.407
255	3.127	1.485	0.995	1.356	0.454	0.699	0.641	1.136
260	2.476	1.026	1.166	0.931	0.618	1.306	0.558	0.946
265	1.818	0.965	0.961	0.770	0.799	0.577	0.372	1.566
270	2.289	0.558	1.520	1.861	1.862	0.697	1.608	0.858
275	2.057	0.580	1.549	2.323	1.476	0.008	1.164	0.589
280	0.409	1.074	1.520	1.837	1.452	0.297	0.774	0.364
285	1.449	1.152	1.481	1.795	1.706	0.297	0.957	0.589
290	0.603	1.441	1.425	1.604	1.357	0.889	1.031	0.824
295	1.031	2.474	2.935	2.095	1.430	0.502	1.523	1.591
300	2.762	2.803	1.704	1.739	2.077	0.531	0.787	2.168
305	3.048	2.932	1.966	1.503	2.025	0.951	0.866	2.813
310	4.278	3.345	2.468	1.387	2.973	1.072	0.422	1.799
315	3.293	3.975	2.542	1.361	2.835	1.789	0.785	1.056
320	1.901	5.307	2.637	1.346	2.513	1.088	0.705	1.238
325	3.946	4.273	3.531	1.901	3.671	1.976	0.432	1.707
330	4.188	4.406	3.991	2.348	3.660	1.937	0.764	1.554
335	5.039	4.509	4.076	3.016	3.751	2.130	0.824	1.758
340	4.113	5.700	4.027	2.670	3.989	2.083	0.925	1.543
345	3.343	6.243	4.081	1.946	2.828	2.004	1.285	2.997
350	4.736	5.196	4.393	3.693	3.634	2.955	1.758	3.426
355	5.269	5.367	4.483	4.048	3.550	3.118	1.610	2.732

UNIT 26. TAPE SERIAL NO. 00001, FILE NO. 003, REEL NO. 001
RECORDS PROCESSED 00002, PERMANENT RTT RECORDS 00005, NOISE RECORDS IGNORED 00000

MEAN	4.190	3.641	3.245	2.764	3.012	2.213	1.907	2.166
STD.DEV.	2.049	1.633	1.384	1.531	1.163	1.292	1.119	0.904

TELESCOPES 1-8 (ALL READINGS)
MEAN SLOPE ERROR 2.893 *
STD. DEVIATION 3.305
MEDIAN SLOPE ERROR 2.731

UNIT 09. TAPE SERIAL NO. 00000, FILE NO. 001, REEL NO. 001
RECORDS PROCESSED 00189, PERMANENT RTT RECORDS 00000, NOISE RECORDS IGNORED 00000

CALL APLOTV

CALL LINEV

CALL APLOTV

CALL LINEV

CALL APLOTV

CALL LINEV

CALL APLOTV

CALL LINEV

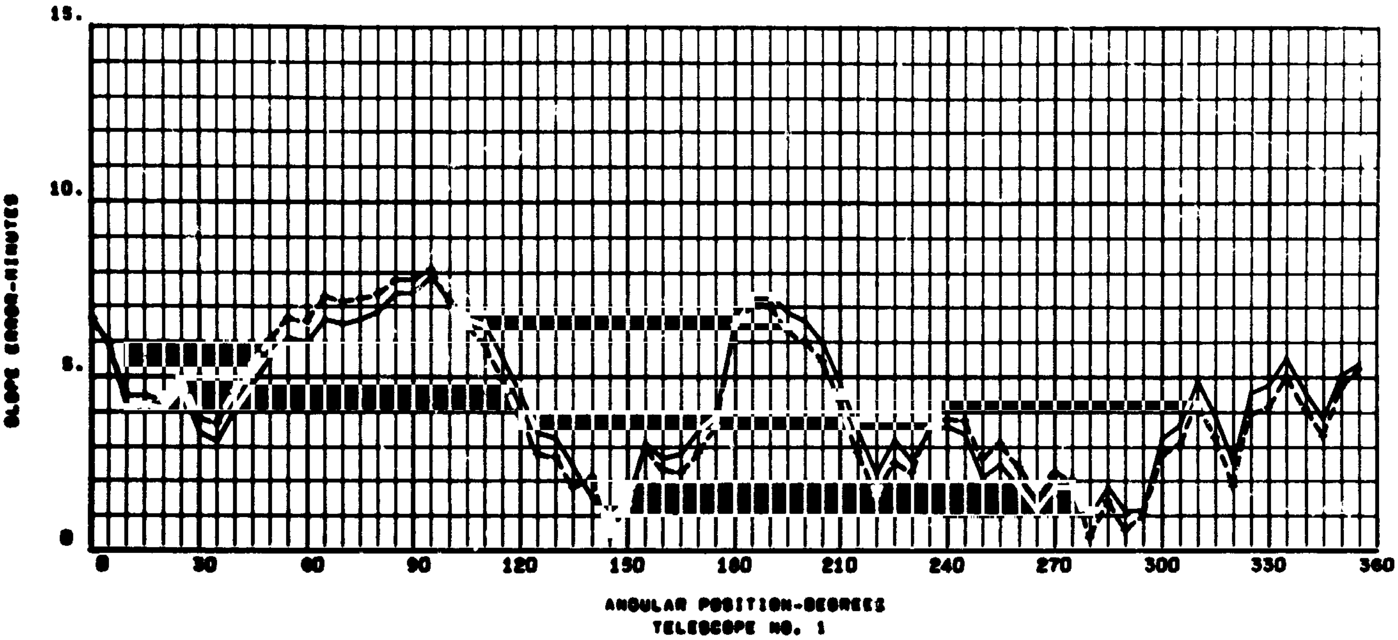
CALL APLOTV

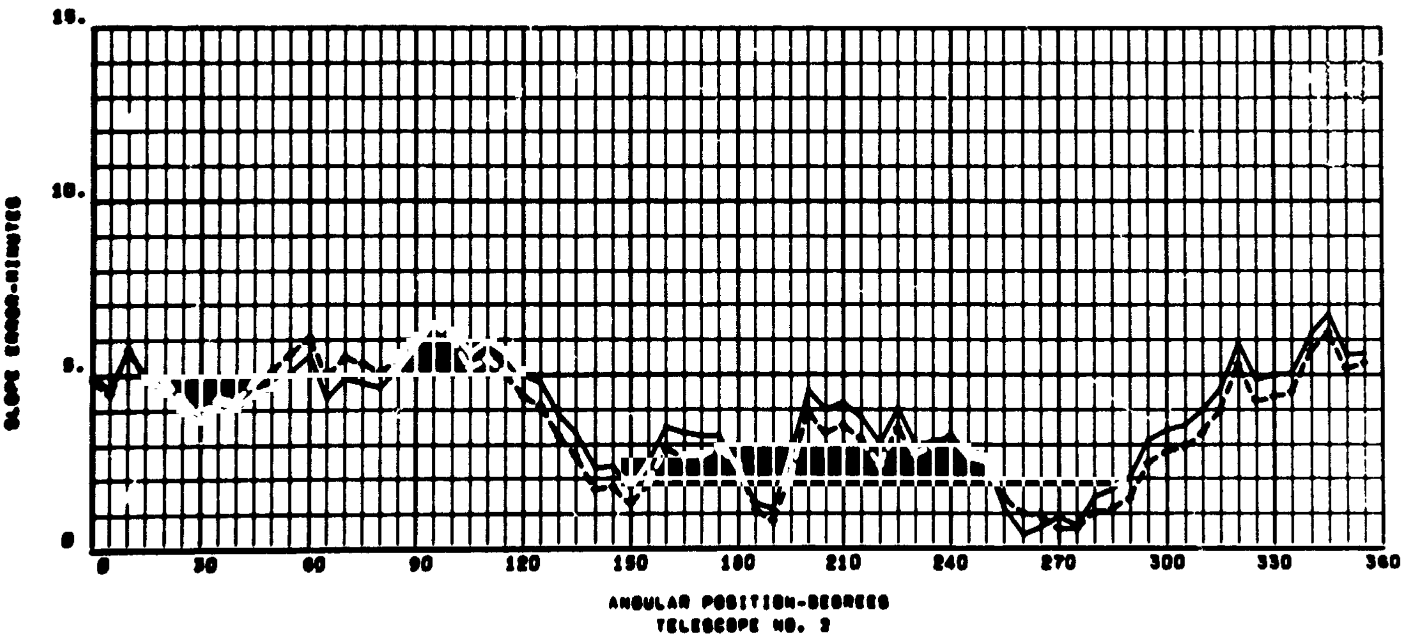
CALL LINEV

CALL APLOTV

[illegible]

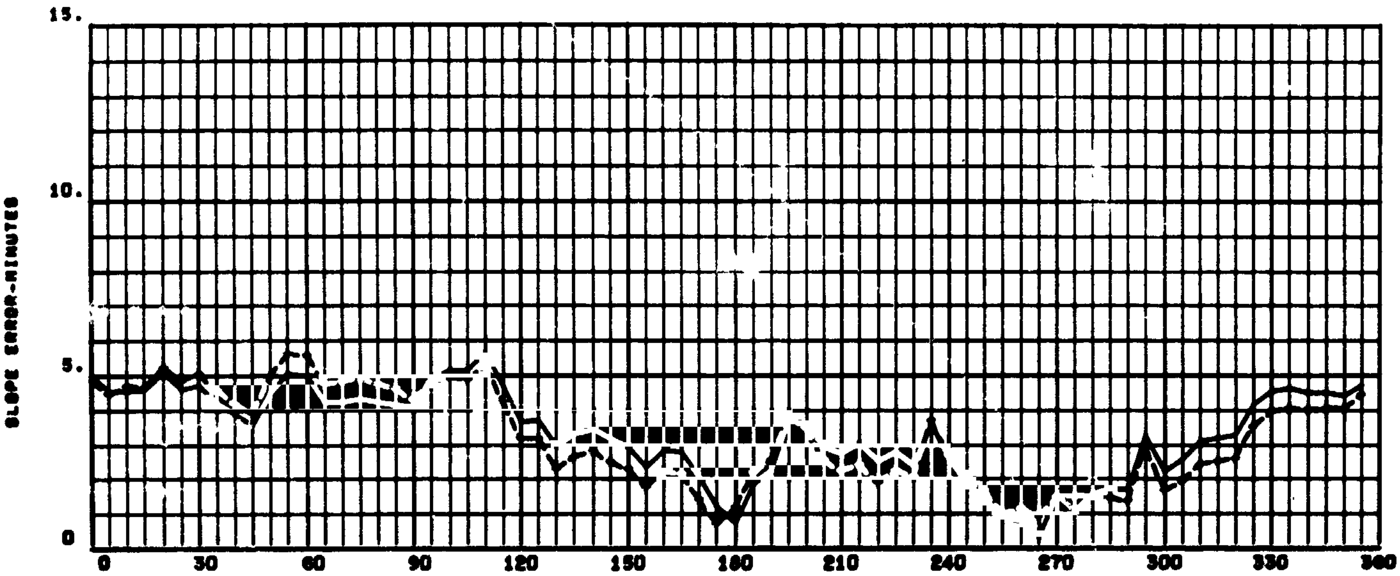
BLANK PAGE



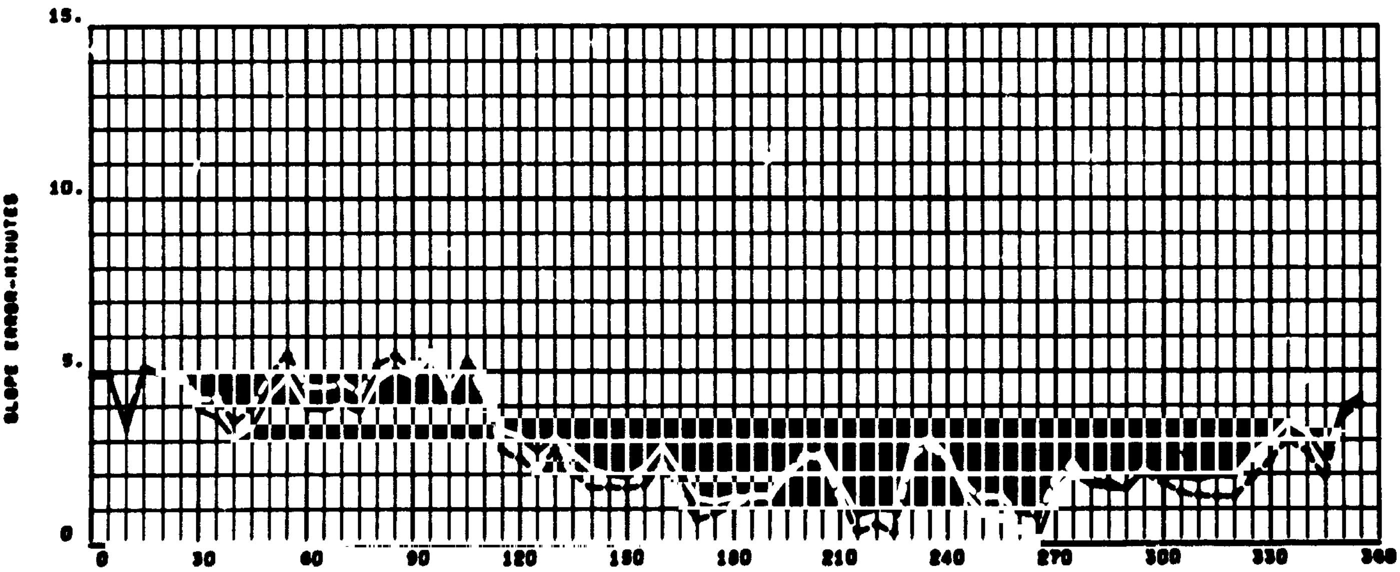


$$\text{— = ADJUSTED SLOPE ERROR } \sqrt{(X-\bar{X})^2 + (Y-\bar{Y})^2}$$

$$\text{--- = RAW SLOPE ERROR } \sqrt{(X-50.)^2 + (Y-50.)^2}$$



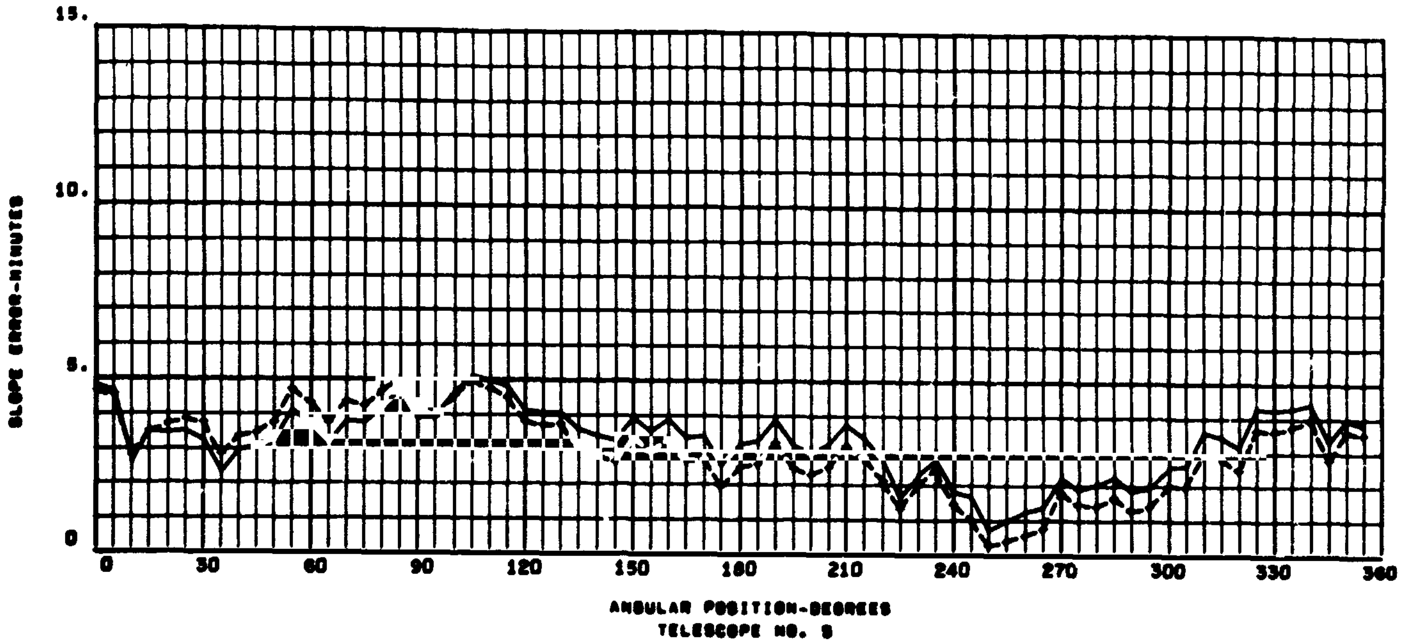
ANGULAR POSITION-DEGREES
TELESCOPE NO. 3

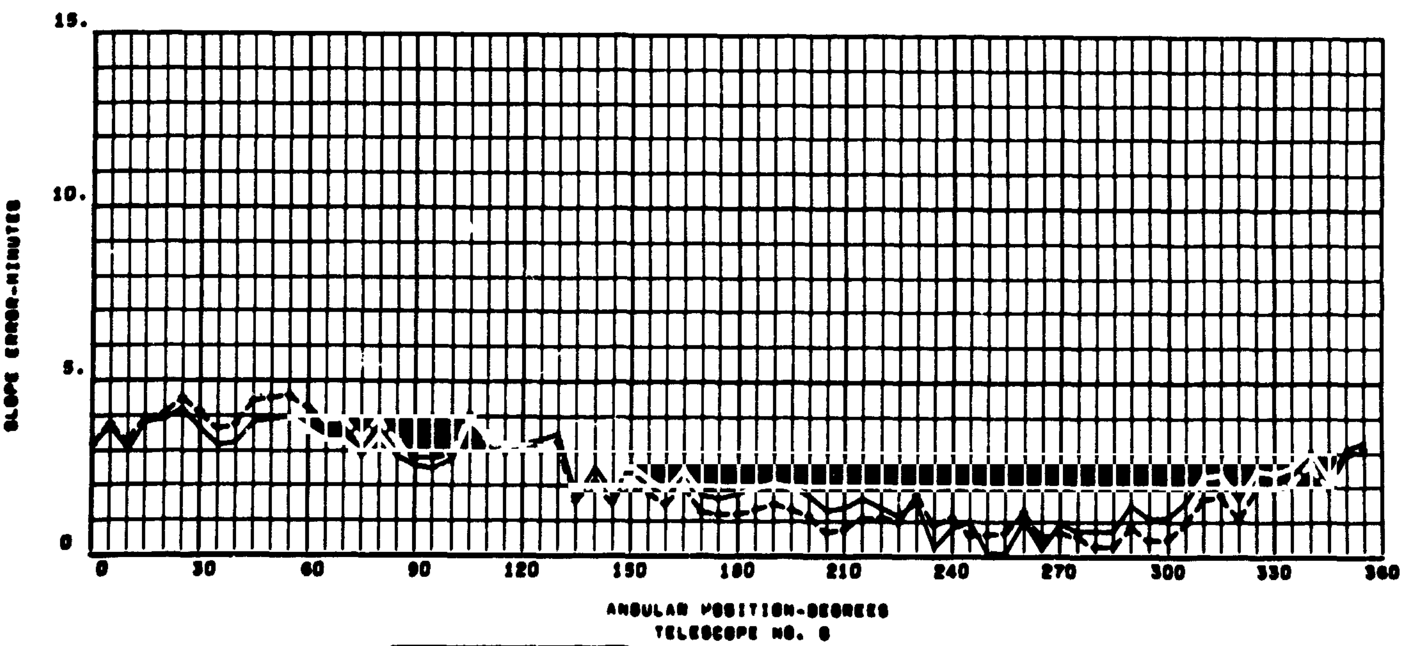


ANGULAR POSITION-DEGREES
TELESCOPE NO. 4

___ = ADJUSTED SLOPE ERROR $\sqrt{(X-\bar{X})^2 + (Y-\bar{Y})^2}$

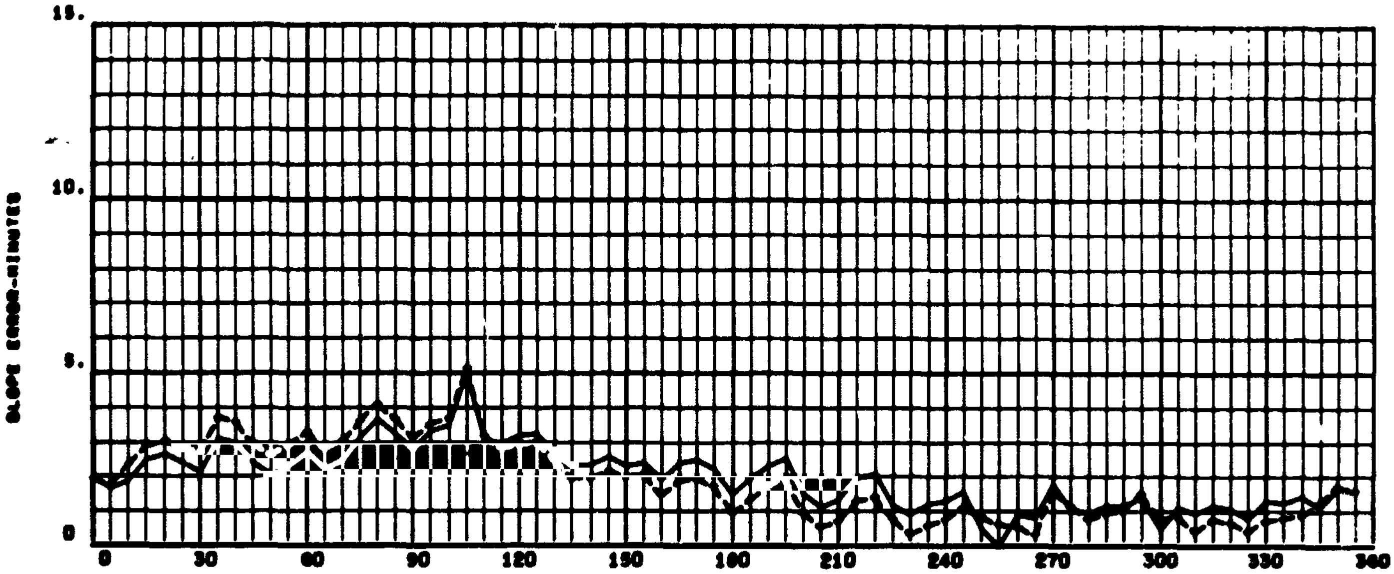
--- = RAW SLOPE ERROR $\sqrt{(X-50.)^2 + (Y-50.)^2}$



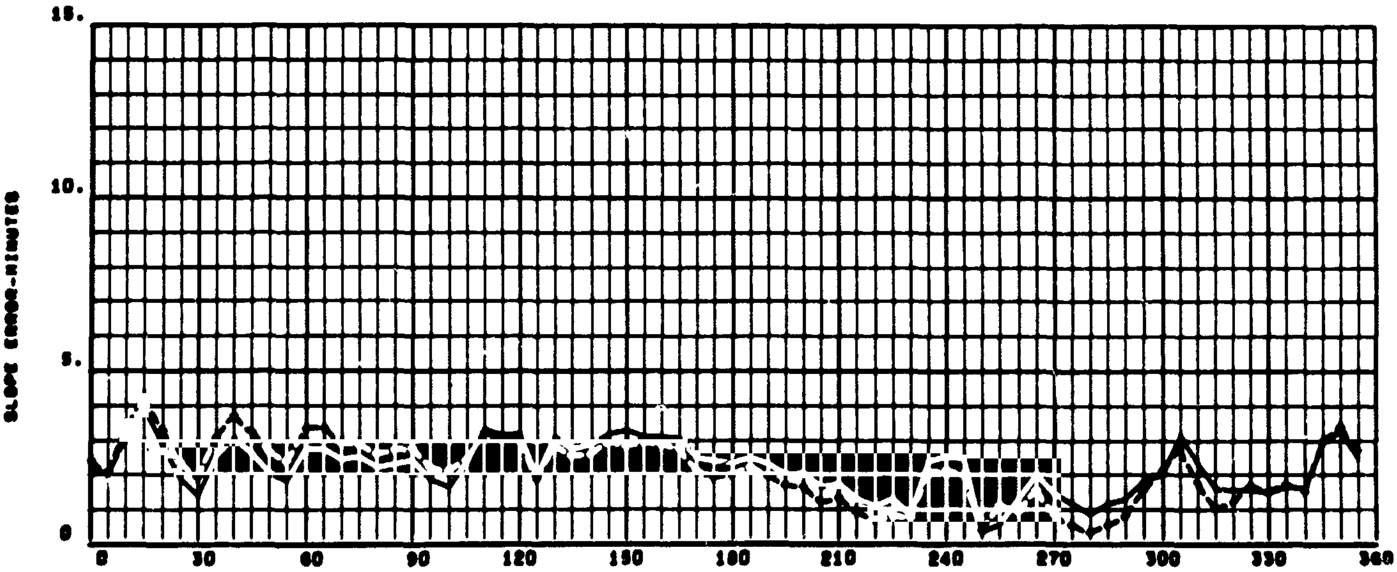


—— = ADJUSTED SLOPE ERROR $\sqrt{(X-\bar{X})^2 + (Y-\bar{Y})^2}$

- - - = RAW SLOPE ERROR $\sqrt{(X-50.)^2 + (Y-50.)^2}$



ANGULAR POSITION-DEGREES
TELESCOPE NO. 7



ANGULAR POSITION-DEGREES
TELESCOPE NO. 8

——— = ADJUSTED SLOPE ERROR $\sqrt{(X-\bar{X})^2 + (Y-\bar{Y})^2}$

- - - = RAW SLOPE ERROR $\sqrt{(X-50.)^2 + (Y-50.)^2}$

APPENDIX J

NICKEL MIRROR

FIRST OPTICAL INSPECTION

BLANK PAGE

OPTICAL INSPECTION OF . FOOT ELECTROFORMED MIRROR
*ALL STD, DEVIATIONS * BY ,0925 ARCMIN/DIVISION

TELESCOPE	AVERAGE X READING	STANDARD DEVIATION	AVERAGE Y READING	STANDARD DEVIATION	AVERAGE SLOPE ERROR
1	33,54	2,366	44,43	4,105	3,892
2	92,01	4,131	71,89	5,144	5,932
3	60,18	2,735	44,79	3,190	3,741
4	53,03	3,067	37.17	2,983	3,854
5	57,44	2,744	43,65	2,658	3,396
6	64,40	2,760	42.42	2,601	3,302
7	34,18	2.822	49,61	3,228	3,301
8	68,11	4,226	62,68	4,254	5,223

TELESCOPES 1-8

AVERAGE X READING	57,86
STANDARD DEVIATION	3.153
AVERAGE Y READING	49,58
STANDARD DEVIATION	3.596
X VS Y	
STANDARD DEVIATION	4,783

RAW MEASURED SLOPE ERROR

ANGULAR POSITION (DEGREES)	TELESCOPE 1	TELESCOPE 2	TELESCOPE 3	TELESCOPE 4	TELESCOPE 5	TELESCOPE 6	TELESCOPE 7	TELESCOPE 8
0	3.904	4.762	1.668	1.639	2.540	1.114	2.800	4.397
5	6.205	5.003	1.942	0.555	2.167	1.285	2.775	2.663
10	6.222	2.590	2.097	1.668	2.318	1.905	2.407	2.830
15	4.625	0.952	2.068	2.035	1.945	0.925	2.313	1.177
20	4.779	0.832	2.167	1.298	1.572	0.462	1.206	3.422
25	4.717	1.706	1.843	1.738	0.277	1.125	3.491	2.961
30	3.774	0.983	2.268	3.516	1.079	0.746	3.863	2.109
35	4.981	0.498	2.268	2.869	1.288	0.000	3.683	1.445
40	6.030	0.722	1.993	1.993	1.850	1.492	3.520	2.054
45	8.884	3.342	2.616	2.592	2.020	1.412	3.522	2.516
50	5.923	2.697	2.516	2.035	2.313	1.079	4.810	2.925
55	4.312	1.572	1.144	1.688	2.054	1.324	4.856	3.532
60	2.405	3.569	6.205	1.483	1.575	1.324	4.517	3.142
65	2.890	3.472	0.746	1.796	1.636	1.572	3.718	2.983
70	1.960	4.556	0.000	5.721	1.492	1.767	4.016	2.157
75	2.358	2.868	0.763	5.627	2.421	2.407	4.593	2.029
80	1.079	3.952	2.183	3.944	3.797	3.058	4.601	2.605
85	1.375	4.774	2.087	6.161	3.222	3.150	4.109	3.190
90	3.746	3.109	6.222	5.394	3.715	3.515	2.819	3.278
95	9.250	7.903	5.003	3.635	3.422	3.483	4.840	2.891
100	9.296	5.108	4.137	3.864	3.729	3.952	4.840	2.054
105	9.296	6.876	5.171	5.171	4.062	4.762	3.103	1.850
110	9.433	8.273	5.553	6.475	4.308	3.979	2.364	2.235
115	9.657	13.081	6.622	7.075	4.717	4.625	2.813	2.313
120	6.425	13.081	6.291	7.045	5.413	6.938	2.087	3.729
125	6.425	13.081	5.273	6.425	5.413	7.224	2.087	6.938
130	4.633	13.081	4.555	6.425	5.003	7.698	3.545	13.081
135	3.592	13.081	5.003	6.425	5.646	6.670	4.717	13.081
140	3.612	13.081	3.830	6.573	5.887	9.157	5.627	13.081
145	3.733	13.081	6.019	5.273	6.876	8.235	5.627	13.081
150	5.394	13.081	5.040	5.421	7.458	7.458	4.445	13.081
155	4.264	13.081	5.103	6.222	6.670	7.045	3.101	13.081
160	4.762	13.081	4.223	6.876	6.205	7.045	13.081	13.081
165	1.951	13.081	3.729	5.795	6.734	6.622	13.081	13.081
170	0.000	13.081	3.427	3.803	6.475	6.938	1.836	13.081
175	1.368	13.081	2.838	4.535	6.517	6.999	13.081	13.081
180	5.129	13.081	3.294	4.535	6.622	5.721	1.445	6.012
185	3.231	7.045	4.137	4.981	5.588	5.413	2.721	5.088
190	2.989	13.081	4.854	5.108	4.711	6.205	2.857	5.551
195	2.872	6.291	4.916	5.795	5.569	5.273	3.146	5.721
200	3.994	13.081	7.903	4.319	5.389	6.222	4.125	7.698
205	7.628	8.273	4.902	2.944	7.957	5.301	4.981	7.957
210	7.628	13.081	6.012	5.850	6.670	5.053	5.850	13.081
215	13.081	13.081	3.729	4.981	5.721	5.207	5.588	7.849
220	7.529	13.081	13.081	7.628	4.464	4.455	6.829	9.157
225	7.628	6.491	5.646	5.239	4.564	5.091	6.670	13.081
230	3.437	13.081	4.004	4.916	2.989	2.869	6.012	0.763
235	1.836	1.873	4.774	3.972	2.136	2.513	2.989	1.244
240	3.860	2.029	3.729	4.652	2.966	2.694	2.491	0.966
245	3.237	0.952	2.412	4.829	2.694	2.878	3.651	2.449
250	2.320	0.462	1.907	5.095	2.068	2.850	4.303	2.540
255	2.054	1.706	1.931	4.648	1.615	2.199	4.054	2.616
260	2.405	1.185	1.144	2.789	0.462	1.034	2.824	1.887
265	4.633	4.131	1.185	3.571	1.234	1.203	3.700	1.745
270	1.951	5.553	0.925	3.231	1.817	1.203	4.356	2.489
275	2.405	3.335	1.288	3.150	0.563	1.463	4.464	3.270
280	0.539	2.813	1.034	2.813	1.110	1.409	4.395	3.612
285	0.472	2.068	2.313	2.037	1.258	1.777	3.392	3.190
290	3.270	3.294	2.253	2.881	2.029	2.355	2.857	3.335
295	5.646	5.569	2.813	3.143	2.167	2.364	2.428	2.697
300	4.450	6.030	2.750	3.302	2.313	1.873	2.151	1.288
305	3.927	5.588	3.164	2.087	2.224	2.405	1.334	3.145
310	2.663	4.981	3.137	1.308	1.636	1.615	2.320	3.411
315	2.813	4.829	3.741	1.236	2.020	1.850	1.308	2.358
320	3.294	5.413	4.388	1.668	2.193	1.217	1.706	2.694
325	3.569	5.795	5.588	2.313	2.428	1.675	1.308	1.871
330	3.592	5.795	7.045	4.406	3.270	1.591	0.539	3.814
335	2.130	6.030	7.458	5.394	2.206	0.334	2.097	3.330
340	2.405	5.108	5.795	4.916	1.942	0.763	2.183	2.499
345	2.313	3.729	4.388	4.775	1.980	1.308	2.491	1.760
350	2.313	4.648	3.054	3.599	2.035	0.207	2.722	1.506
355	0.996	5.171	3.441	3.179	2.127	0.462	2.251	2.220

UNIT 26, TAPE SERIAL NO. 00001, FILE NO. 002, REEL NO. 001
RECORDS PROCESSED 00002, PERMANENT RTT RECORDS 00000, NOISE RECORDS IGNORED 00090

MEAN	4.275	6.499	3.747	4.057	3.369	3.285	3.842	4.635
STD.DEV.	2.556	4.491	2.135	1.767	1.978	2.395	2.363	4.061

TELESCOPES 1-8 (ALL READINGS)
MEAN SLOPE ERROR 4.239
STD. DEVIATION 3.018
MEDIAN SLOPE ERROR 3.503

ADJUSTED SLOPE ERROR

ANGULAR POSITION (DEGREES)	TELESCOPE 1	TEL'SCOPE 2	TELESCOPE 3	TELESCOPE 4	TELESCOPE 5	TELESCOPE 6	TELESCOPE 7	TELESCOPE 8
0	4.172	4,163	1,160	0.945	1,944	1.710	3,518	4,688
5	6,596	4,674	2,111	0,892	1,795	1.074	3,503	3,344
10	6,804	2,728	2,459	2,393	1,690	1.290	3,133	3,092
15	5,352	1,638	2,752	2,763	1,222	0.201	3,040	1,750
20	5,477	1,135	2,785	2,027	1,021	0.268	1,848	3,689
25	5,438	1,380	2,555	2,428	1,006	1.201	4,108	3,187
30	4,404	0,783	2,990	4,244	1,750	0.341	4,555	2,373
35	5,676	0,347	2,990	3,597	1,994	0.728	4,391	1,969
40	6,758	1,297	2,071	2,671	2,578	2.219	4,245	2,060
45	9,440	3,441	3,150	2,680	2,719	2.053	4,152	3,110
50	6,485	2,368	2,784	2,125	2,909	1.559	5,476	3,529
55	5,004	1,426	1,853	1,912	2,660	1.334	5,543	4,055
60	2,475	1,216	5,879	2,208	2,164	1.334	5,228	3,650
65	2.572	4,066	0.341	2,507	2,175	1.697	4,440	3,374
70	1,316	5,284	0,728	5,008	1,932	1.946	4,650	2,580
75	1,985	3,595	1,484	4,903	2,946	2.450	5,190	2,390
80	0.676	4,628	2,784	4,509	4,219	3.062	5,225	2,742
85	1.730	5,363	1,401	6,701	3,698	3.153	4,729	3,437
90	4.447	3,489	6,704	5,771	3,976	3.551	3,581	3,518
95	9.240	8,152	5,410	3,849	3,689	3.385	5,169	2,851
100	9.213	5,187	4,477	4,030	4,108	1.720	5,169	1,694
105	9.213	6.628	5,312	5,312	4,440	4.418	3,458	1,123
110	9.279	7,939	5,538	6,477	4.514	3.570	2,776	1,025
115	9.436	12,600	6.470	6,930	4.590	4.195	2,749	1,586
120	6.789	12,600	6.078	6,754	5,172	6.494	2,014	3,003
125	6.789	12,600	5,092	6,056	5,172	6.055	2.014	[illegible]
130	4.963	12,600	4,274	6,056	4,604	7.074	3.486	[illegible]
135	4.020	12,600	4,604	6,056	5,228	6.055	4.590	12,600
140	4.090	12,600	3,405	6,106	5,367	8.679	5.515	12,600
145	4.279	12,600	5,510	4.828	6,328	7.650	5.515	12,600
150	5.771	12,600	4,504	4.987	6,815	6.815	4.313	12,605
155	4.743	12,600	4,574	5.730	6,055	6.366	2.928	12,600
160	[illegible].123	12,600	3,581	6.378	5,545	6.366	12,600	12,600
165	2.385	12,600	3,003	5.148	6,026	5.904	12,500	12,600
170	0.728	12,600	2,704	3.091	5.748	6.210	1,430	12,600
175	1.440	12,600	2,180	3.836	5,800	6.285	12.600	12,600
180	5.127	12,600	2,788	3.836	5,988	5.029	1.037	5,285
185	3.506	6,400	3,904	4,331	4,954	4.752	2,412	4,361
190	3.361	12,600	4,559	4,758	4,242	5.584	2.621	4.824
195	3,173	5.613	4,503	5,189	5,147	4.747	3.247	5,029
200	4,258	12,600	7,716	3.889	4,992	5.792	4.457	7,120
205	7,873	7,739	4,596	3.510	7,402	5,072	5.329	7,472
210	7.873	12,600	5,809	6.155	6,330	4.844	6.155	12,600
215	12,606	12,600	3,748	4.797	5,678	5.141	5.960	7,382
220	7,734	12,600	12,600	7,523	4,634	4.493	7.235	8,687
225	7,873	6,519	6.121	5.779	4,870	5.207	7,130	12,600
230	3.872	12,600	4,189	5.508	3.361	2.975	6 362	[illegible].200
235	2,400	2,262	5,260	4.644	2,489	[illegible]728	3.361	[illegible].833
240	4.421	2,450	4,392	5.361	3.155	3.011	3.207	1.392
245	3.965	0.512	3.068	5.539	3.011	3.454	4.538	2.718
250	2.989	0.268	2.626	5.823	2.510	3.569	4.984	3.027
255	2.660	1,212	2,628	5.389	2.324	2.916	4.728	3.195
260	2.736	0.886	1,853	3.510	1.123	1.727	3.481	2.010
265	[illegible].608	3.526	1.795	4.264	1.958	1.904	4.427	2.409
270	1.224	4.825	1.653	3.915	2.535	1.930	5.080	3.048
275	2.287	2.677	1,994	3.875	1.283	2.157	5.185	3.843
280	1.123	2.108	1,727	3.538	1.838	2.087	5.121	4.218
285	1.197	1.430	2.909	2.821	1.764	2.279	4.045	3.855
290	3.908	2.867	2.553	3.431	2.697	2.893	3.495	3.979
295	6.062	5.070	2.749	3.626	2.748	2.776	3.120	3.358
300	4.952	5.408	2.559	3.482	2.784	2.323	2.813	1.994
305	4.462	4.917	2.599	2.014	2.501	2.736	1.967	3.190
310	3.344	4.298	3.481	0.978	2.207	1.992	2.663	3.291
315	3.461	4.124	3.017	0.942	2.719	2.335	1.875	2.568
320	[illegible].672	4.721	3.690	1.363	3.844	1.479	2.226	3.391
325	3.965	5.148	4.917	1.928	3.120	1.865	1.675	[illegible]
330	3.773	5.148	6.366	3.955	3.796	1.272	1.214	4.017
335	2.584	5.408	6.815	5.023	2.647	0.473	2.012	3.371
340	3.133	4.381	5.148	4.439	2.038	0.886	2.784	2.539
345	3.040	3.015	3.690	4.254	1.438	0.908	3.119	1.812
350	3.040	3.930	2.329	2.942	1.308	0.558	3.438	1.757
355	1.702	4.552	2.914	2.455	1.491	1.123	2.976	2.299

UNIT 26, TAPE SERIAL NO. 00031, FILE NO. 003, REEL NO. 001
RECORDS PROCESSED 00002, PERMANENT ATT RECORDS 00000, NOISE RECORDS IGNORED 00000

MEAN	4.818	6.233	3,747	4,117	3,463	3.277	4.2[illegible]	4.893
STD.DEV.	2.489	4.373	1.915	1.630	1.655	2.076	2.[illegible]32	3.753

TELESCOPES 1-8 (ALL READINGS)
MEAN SLOPE ERROR 4.320
STD. DEVIATION 3.155
MEDIAN SLOPE ERROR [illegible]

UNIT [illegible], TAPE SERIAL NO. 00000, FILE NO. 001, REEL NO. 001
RECORDS PROCESSED 00187, PERMANENT ATT RECORDS 00000, NOISE RECORDS IGNORED 00000

CALL APLOTV

CALL LINEV

CALL APLOTV

CALL LINEV

CALL APLOTV

CALL LINEV

CALL APLOTV

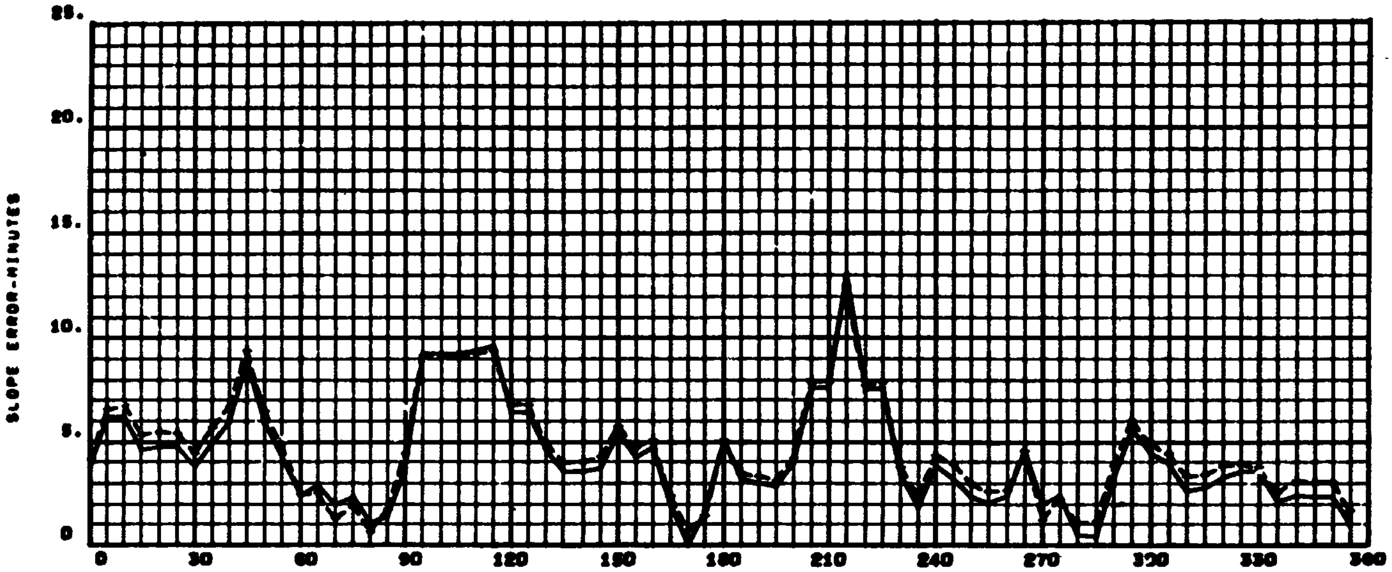
CALL LINEV

CALL APLOTV

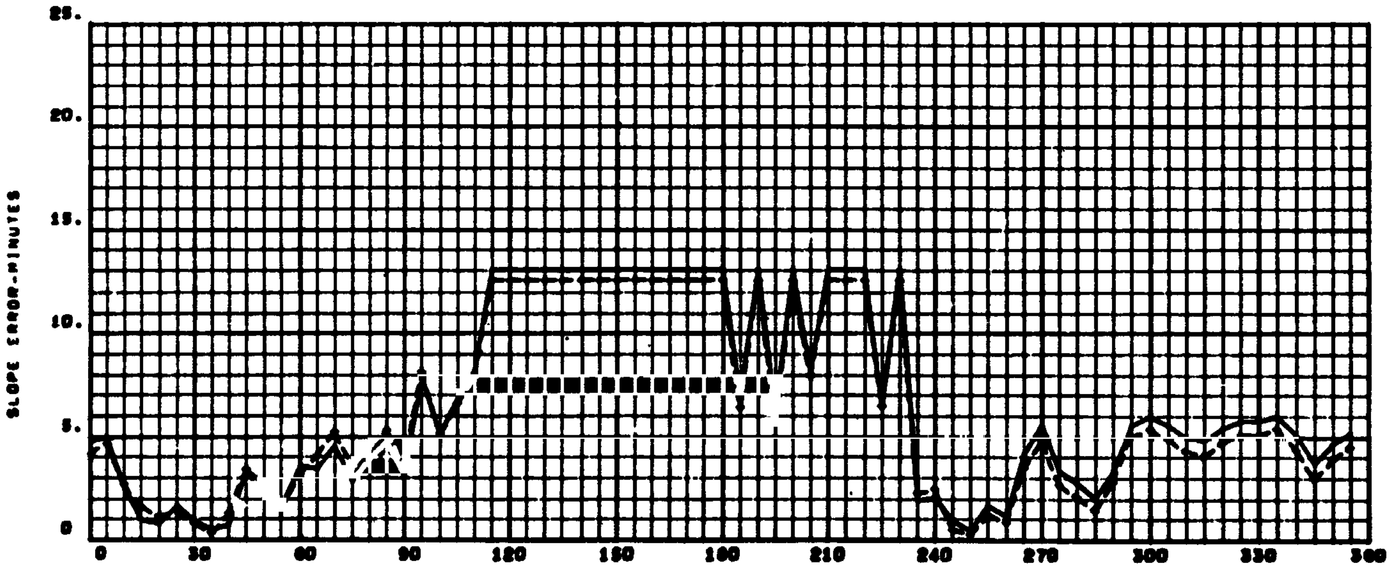
CALL LINEV

CALL APLOTV

CALL LINEV

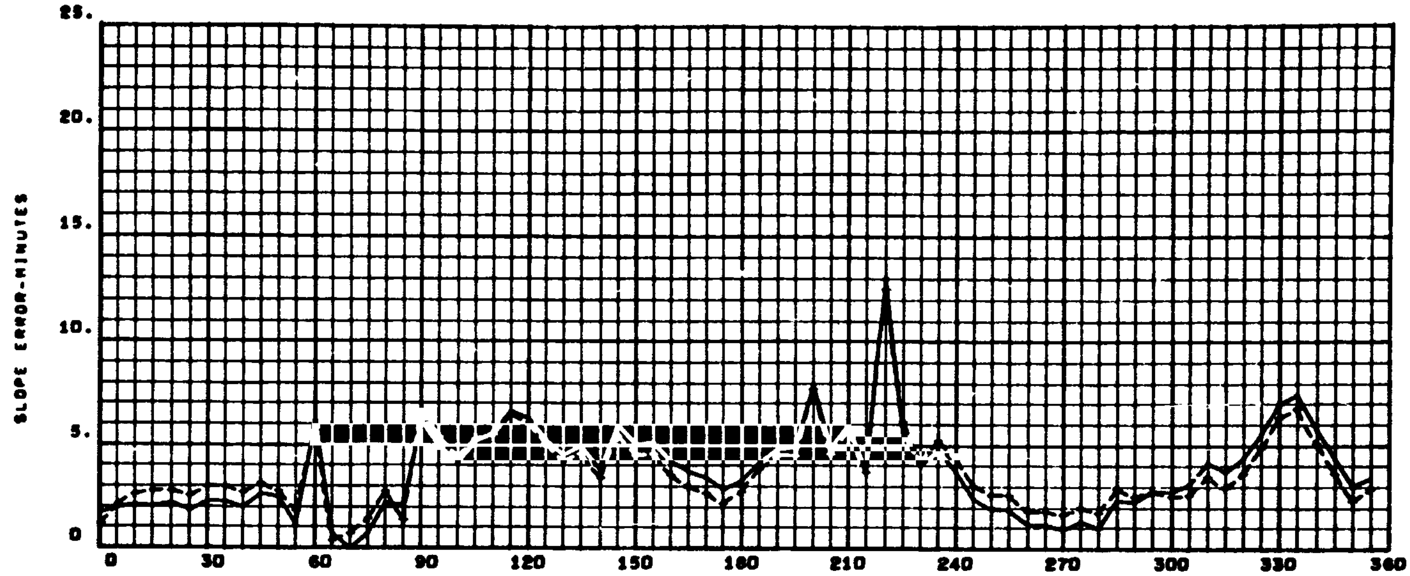


ANGULAR POSITION-DEGREES
TELESCOPE NO. 1

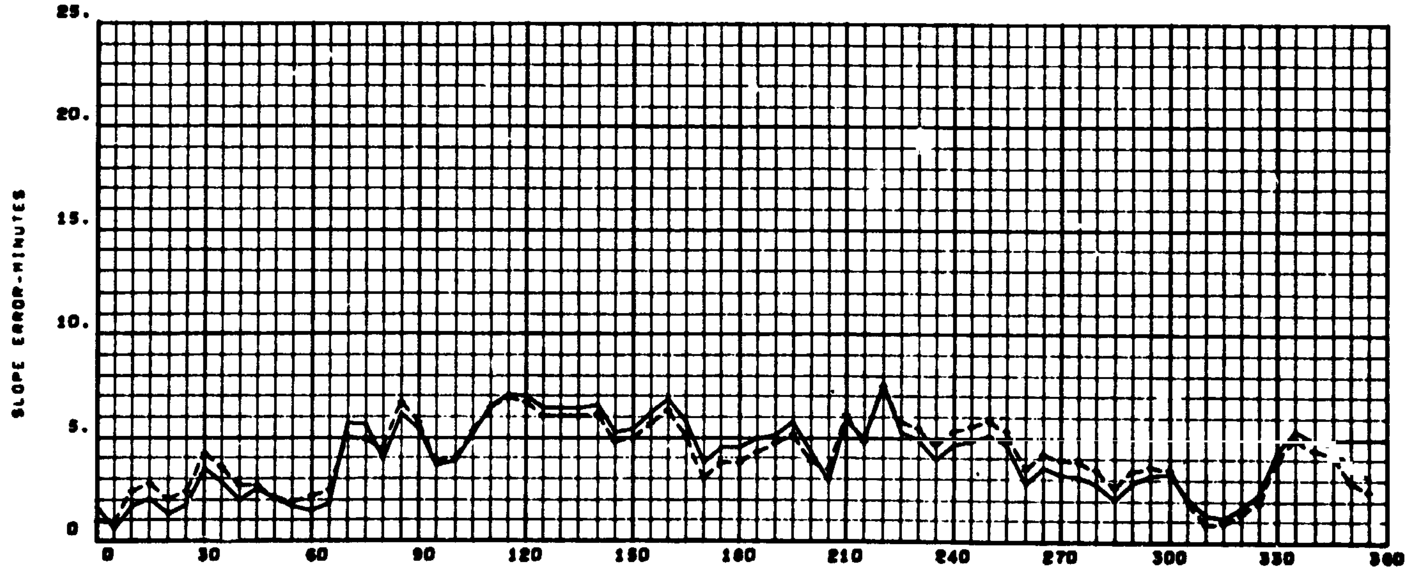


ANGULAR POSITION-DEGREES
TELESCOPE NO. 2

—— = ADJUSTED SLOPE ERROR
--- = RAW SLOPE ERROR

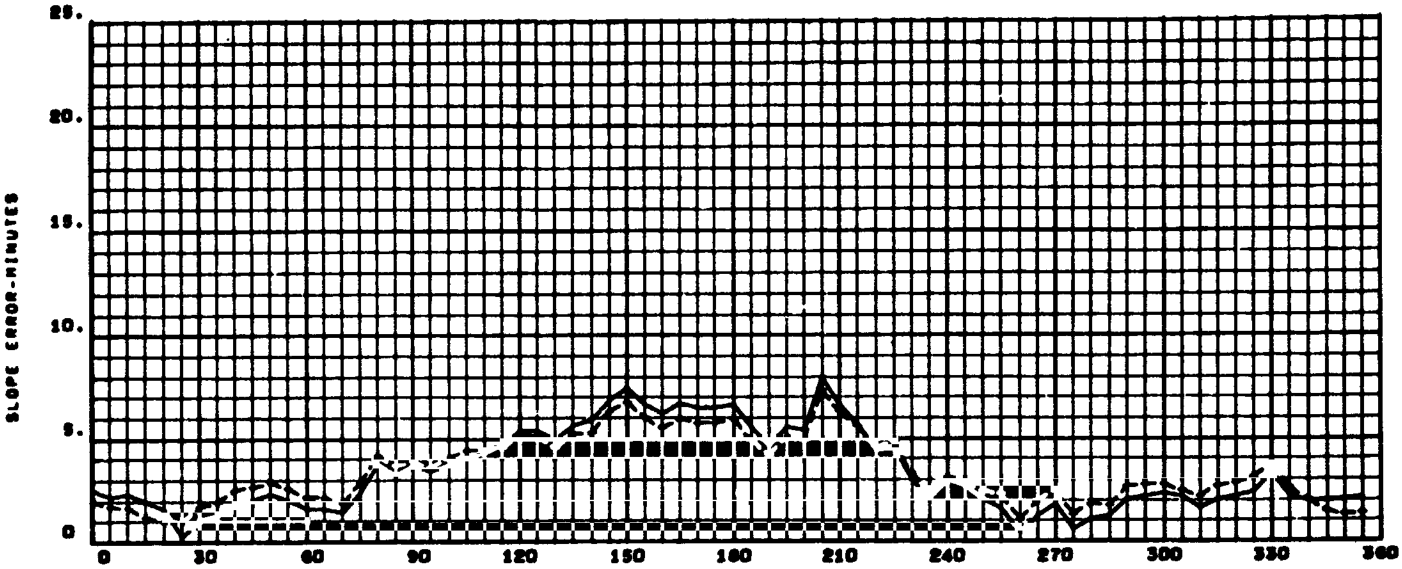


ANGULAR POSITION-DEGREES
TELESCOPE NO. 3

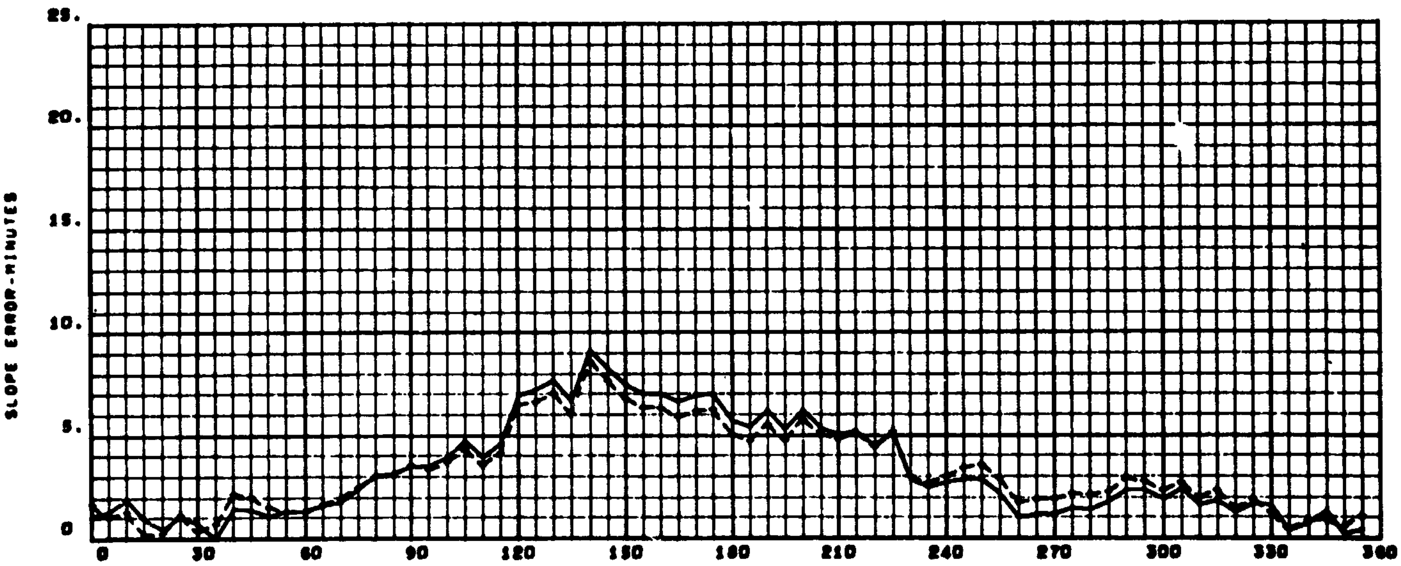


ANGULAR POSITION-DEGREES
TELESCOPE NO. 4

—— = ADJUSTED SLOPE ERROR
--- = RAW SLOPE ERROR

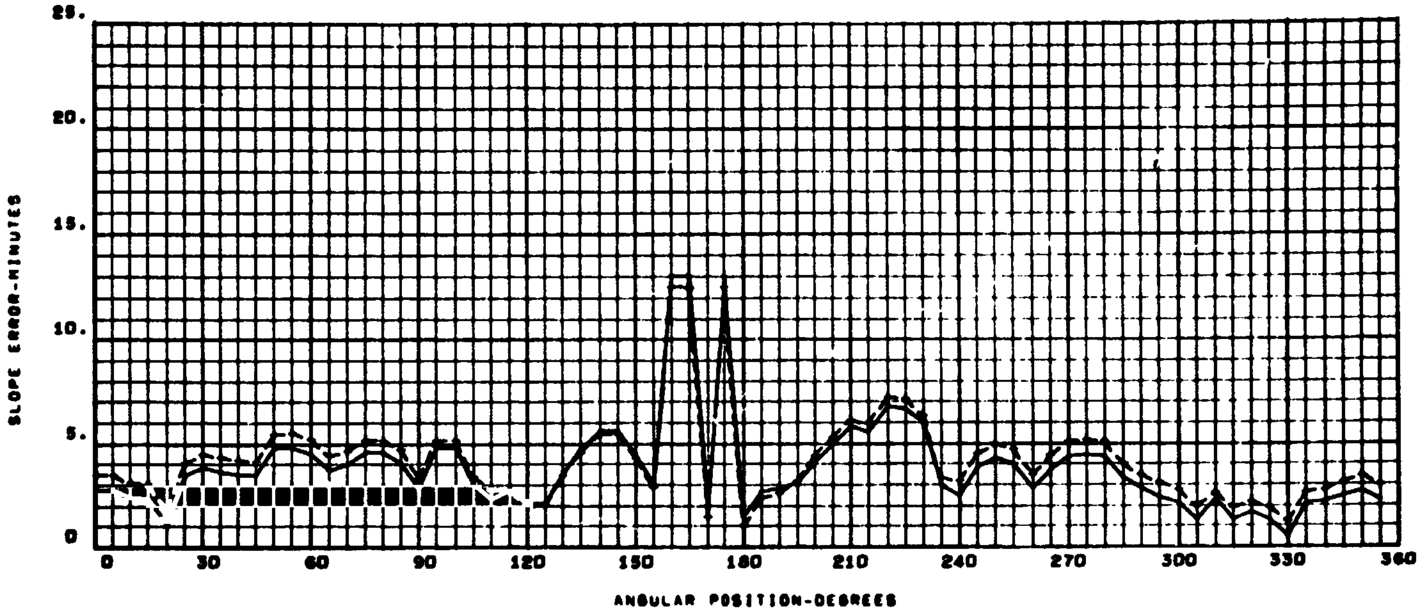


ANGULAR POSITION-DEGREES
TELESCOPE NO. 5

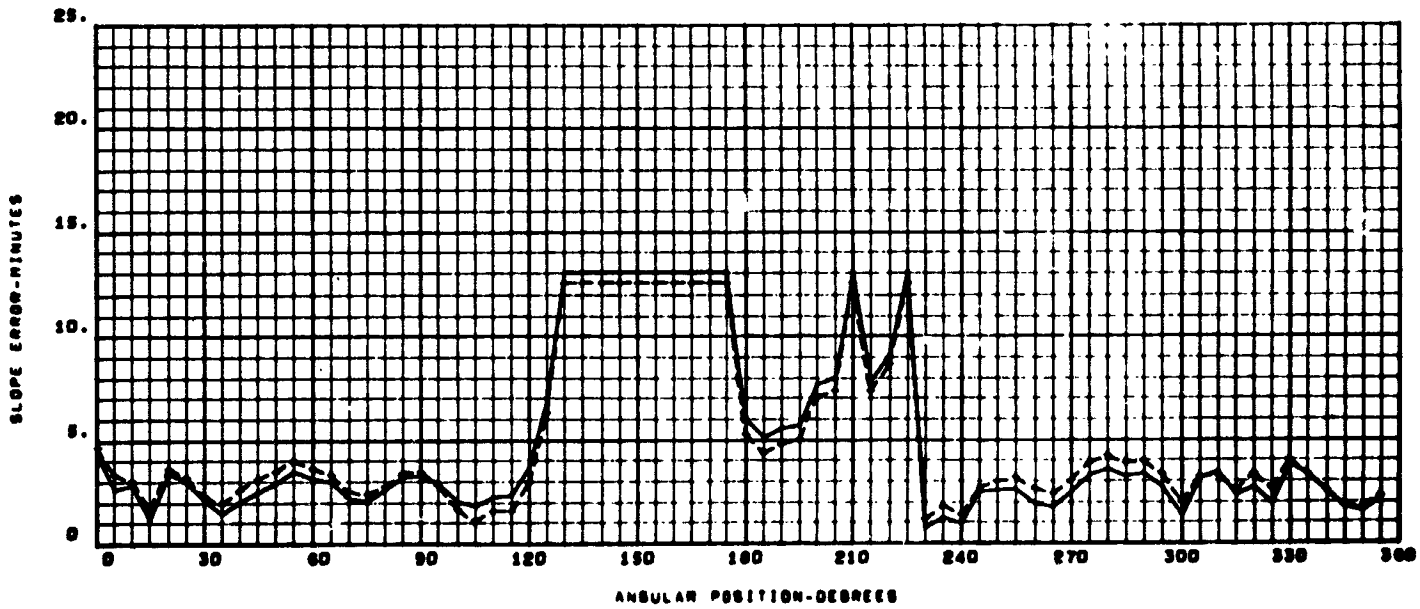


ANGULAR POSITION-DEGREES
TELESCOPE NO. 6

——— = ADJUSTED SLOPE ERROR
- - - = RAW SLOPE ERROR



TELESCOPE NO. 7



TELESCOPE NO. 8

—— = ADJUSTED SLOPE ERROR
- - - = RAW SLOPE ERROR

APPENDIX K

NICKEL MIRROR

SECOND OPTICAL INSPECTION

OPTICAL INSPECTION OF 9.5 FOOT ELECTROFORMED MIRROR
*ALL STD. DEVIATIONS * BY .0925 ARCMIN/DIVISION

TELESCOPE	AVERAGE X READING	STANDARD DEVIATION	AVERAGE Y READING	STANDARD DEVIATION	AVERAGE SLOPE ERROR
1	33.67	3.460	51.75	3.876	4.167
2	83.50	3.534	49.61	3.619	4.208
3	51.92	2.541	41.94	3.269	3.711
4	46.94	2.347	35.00	2.922	3.402
5	51.28	2.891	40.64	2.691	3.634
6	56.94	2.604	39.22	2.666	3.396
7	25.81	2.090	42.61	2.764	3.051
8	60.91	3.464	38.50	2.920	3.944

TELESCOPES 1-8

AVERAGE X READING	51.38
STANDARD DEVIATION	2.878
AVERAGE Y READING	42.41
STANDARD DEVIATION	3.081
X VS Y	
STANDARD DEVIATION	4.217

ADJUSTED SLOPE ERROR

ANGULAR POSITION (DEGREES)	TELESCOPE 1	TELESCOPE 2	TELESCOPE 3	TELESCOPE 4	TELESCOPE 5	TELESCOPE 6	TELESCOPE 7	TELESCOPE 8
0	4.997	4.897	2.237	1.264	1.283	2.000	[illegible].592	1.717
10	7.455	3.512	3.228	2.252	1.102	0.778	3.592	3.963
20	4.789	1.352	3.156	2.265	2.237	1.731	2.295	2.286
30	4.040	2.237	3.189	4.028	2.551	1.266	4.804	1.714
40	6.846	1.249	2.361	2.742	3.327	3.421	4.940	3.328
50	5.362	0.736	1.658	0.895	2.948	2.490	5.677	4.012
60	1.557	2.093	1.425	2.834	2.986	2.005	5.904	4.514
70	2.498	5.806	2.137	3.624	2.584	2.726	5.758	3.253
80	1.971	5.240	3.256	5.792	4.550	3.027	6.246	3.238
90	6.268	6.476	6.833	5.261	3.898	3.621	4.801	3.976
100	13.501	4.417	4.847	4.327	5.224	3.463	6.137	1.717
110	13.501	6.849	6.052	6.461	5.484	3.152	4.685	0.714
120	7.[illegible]43	8.360	6.439	6.237	5.805	5.312	3.865	2.070
130	4.862	7.462	4.489	5.038	4.853	4.966	5.901	7.591
140	5.160	5.944	4.086	6.872	5.458	7.136	8.004	8.335
150	8.212	8.244	5.313	5.774	5.934	6.154	6.488	7.927
160	7.912	8.636	5.313	6.774	6.670	7.151	3.937	7.274
170	4.808	13.501	3.619	3.458	5.968	6.156	3.937	7.340
180	0.889	7.739	2.488	4.547	5.091	5.084	3.138	6.288
190	1.542	7.739	5.376	2.717	3.732	5.427	1.325	7.267
200	0.587	7.365	5.247	3.580	4.584	5.207	1.060	6.909
210	3.633	7.702	4.921	2.472	5.578	4.180	3.117	7.647
220	4.907	7.853	8.103	3.964	3.079	4.139	4.246	7.938
230	0.862	2.764	3.939	2.262	2.507	4.006	4.020	1.822
240	2.934	3.758	1.817	1.570	4.153	3.691	0.991	2.120
250	0.429	4.723	1.620	1.925	2.500	2.065	2.425	2.350
260	1.363	4.849	2.910	1.009	2.893	2.594	2.472	1.263
270	4.543	8.010	3.516	2.629	3.309	2.789	2.856	3.033
280	5.336	5.495	4.413	4.367	2.847	2.093	4.067	4.014
290	4.447	1.695	2.546	2.727	3.026	1.764	2.189	3.661
300	4.203	3.026	0.325	1.806	2.217	1.727	2.373	2.582
310	4.000	2.607	2.033	1.276	2.620	1.578	1.256	1.638
320	3.840	3.218	2.577	0.880	3.212	1.423	1.804	2.706
330	3.289	3.958	5.563	2.475	3.389	0.623	2.176	1.557
340	3.709	3.519	4.162	3.027	1.128	1.241	2.450	0.226
350	2.998	3.642	2.157	1.820	1.695	1.785	3.736	1.119
MEAN	4.559	5.177	3.704	3.359	3.612	3.275	3.786	3.864
STD.DEV.	3.024	2.790	1.743	1.759	1.488	1.793	1.738	2.472

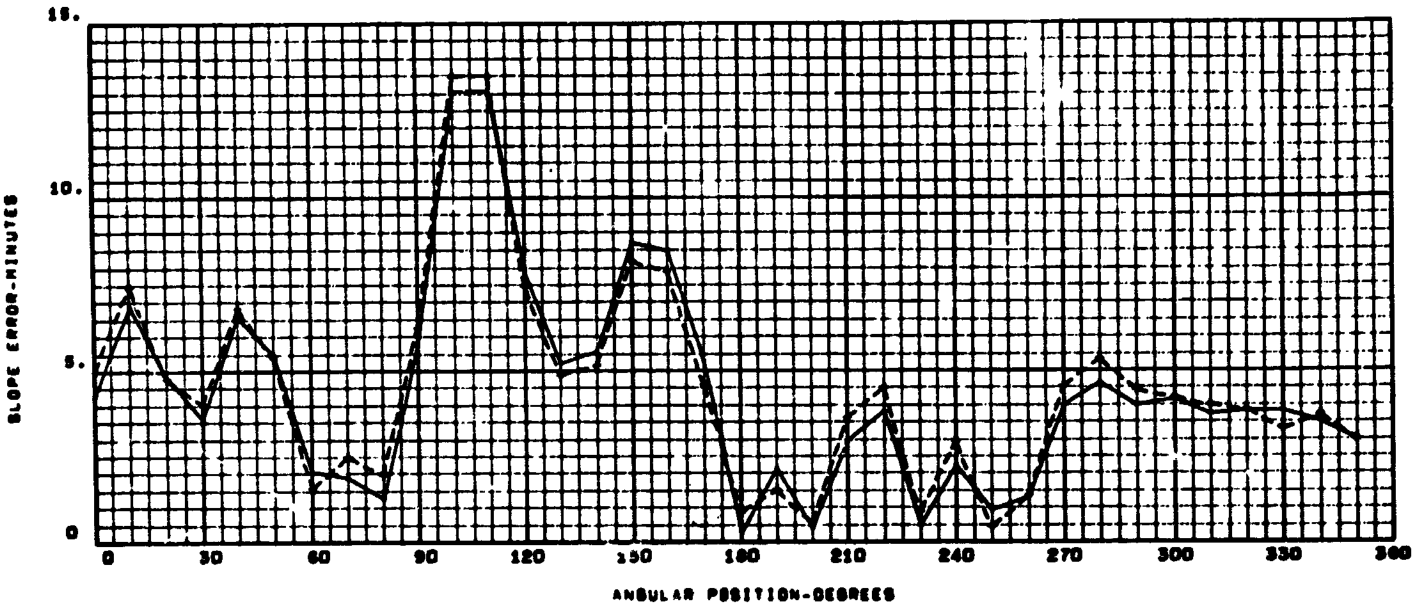
TELESCOPES 1-8 (ALL READINGS)
MEAN SLOPE ERROR 3.917
STD. DEVIATION 4.508
MEDIAN SLOPE ERROR 3.592

RAW MEASURED SLOPE ERROR

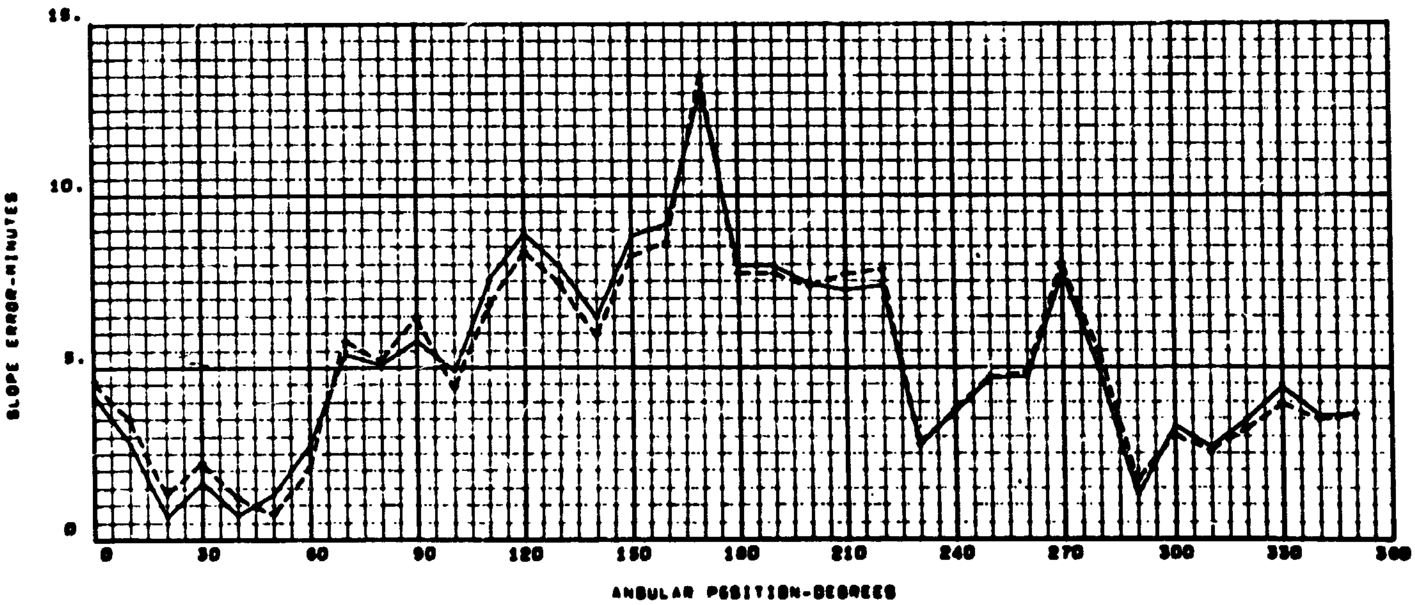
ANGULAR POSITION (DEGREES)	TELESCOPE 1	TELESCOPE 2	TELESCOPE 3	TELESCOPE 4	TELESCOPE 5	TELESCOPE 6	TELESCOPE 7	TELESCOPE 8
0	4.285	4.204	1.668	1.114	1.463	1.675	3.285	2.407
10	6.876	2.800	2.616	1.951	1.288	0.462	3.285	3.269
20	4.803	0.667	2.552	1.843	1.668	1.034	1.907	2.616
30	3.607	1.668	2.733	3.741	2.031	0.592	4.625	1.824
40	6.569	0.704	2.127	2.499	2.925	2.989	4.670	3.146
50	5.479	1.334	1.850	1.185	2.781	2.220	5.599	3.955
60	2.068	2.772	1.110	2.428	2.775	1.887	5.735	4.536
70	1.905	5.413	1.728	3.701	2.412	2.750	5.794	3.353
80	1.285	5.091	3.052	5.850	4.717	3.294	6.291	3.542
90	5.795	5.795	7.060	5.517	4.003	3.990	4.829	4.319
100	13.081	4.934	5.178	4.711	5.495	3.952	6.484	2.109
110	13.081	7.543	6.622	7.045	5.900	3.746	4.958	0.000
120	7.876	8.884	7.094	6.938	6.239	6.012	4.256	2.616
130	5.233	7.957	5.155	5.736	5.551	5.679	6.425	8.273
140	5.569	6.458	4.736	7.585	6.171	7.840	8.640	8.980
150	8.726	8.836	6.019	6.475	6.622	6.829	7.135	8.503
160	8.503	9.180	6.019	7.472	7.313	7.799	4.648	7.849
170	5.293	13.081	4.303	4.137	6.541	6.692	4.648	7.876
180	0.262	7.917	3.108	5.103	5.413	5.507	2.697	6.775
190	2.136	7.917	6.030	2.777	3.792	3.627	1.777	7.656
200	0.392	7.414	4.884	3.814	4.629	5.210	0.370	6.953
210	2.925	7.224	4.603	1.796	5.413	4.084	2.433	7.472
220	3.821	7.368	7.400	3.412	2.616	3.952	3.534	7.586
230	0.472	2.777	3.571	1.572	2.235	3.863	3.367	2.258
240	2.224	3.729	1.110	1.034	3.733	3.281	0.392	2.127
250	0.925	4.684	1.055	1.665	2.157	1.517	1.745	1.836
260	1.295	4.756	2.499	0.462	2.570	2.167	1.796	0.966
270	4.002	7.777	2.850	1.951	2.631	2.206	2.405	2.358
280	4.629	4.934	3.705	3.684	2.136	1.388	3.467	3.308
290	3.972	1.258	1.873	2.285	2.421	1.241	1.755	2.956
300	4.174	3.278	0.472	1.905	1.945	1.324	1.907	1.852
310	3.729	2.689	2.035	0.563	2.268	1.144	1.034	2.258
320	3.837	3.482	2.708	0.370	2.966	1.110	1.415	2.235
330	3.809	4.413	5.860	3.145	3.422	0.093	1.517	2.068
340	3.515	3.612	4.550	3.669	1.445	0.763	2.220	0.930
350	2.986	3.626	1.997	2.113	1.258	1.185	3.454	0.585
MEAN	4.421	5.172	3.671	3.368	3.582	3.197	3.625	3.926
STD.DEV.	3.044	2.821	1.972	2.107	1.787	2.195	2.031	2.624

TELESCOPES 1-8 (ALL READINGS)

MEAN SLOPE ERROR	3.870
STD. DEVIATION	2.408
MEDIAN SLOPE ERROR	3.460

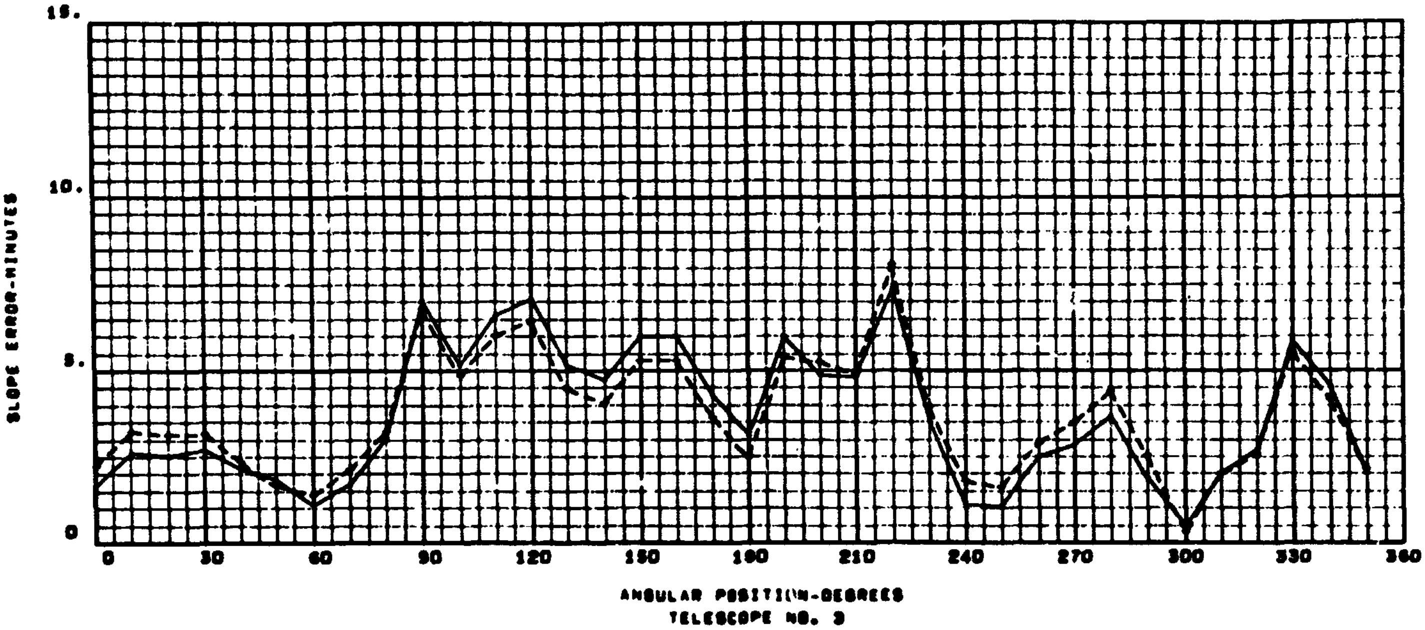


TELESCOPE NO. 1

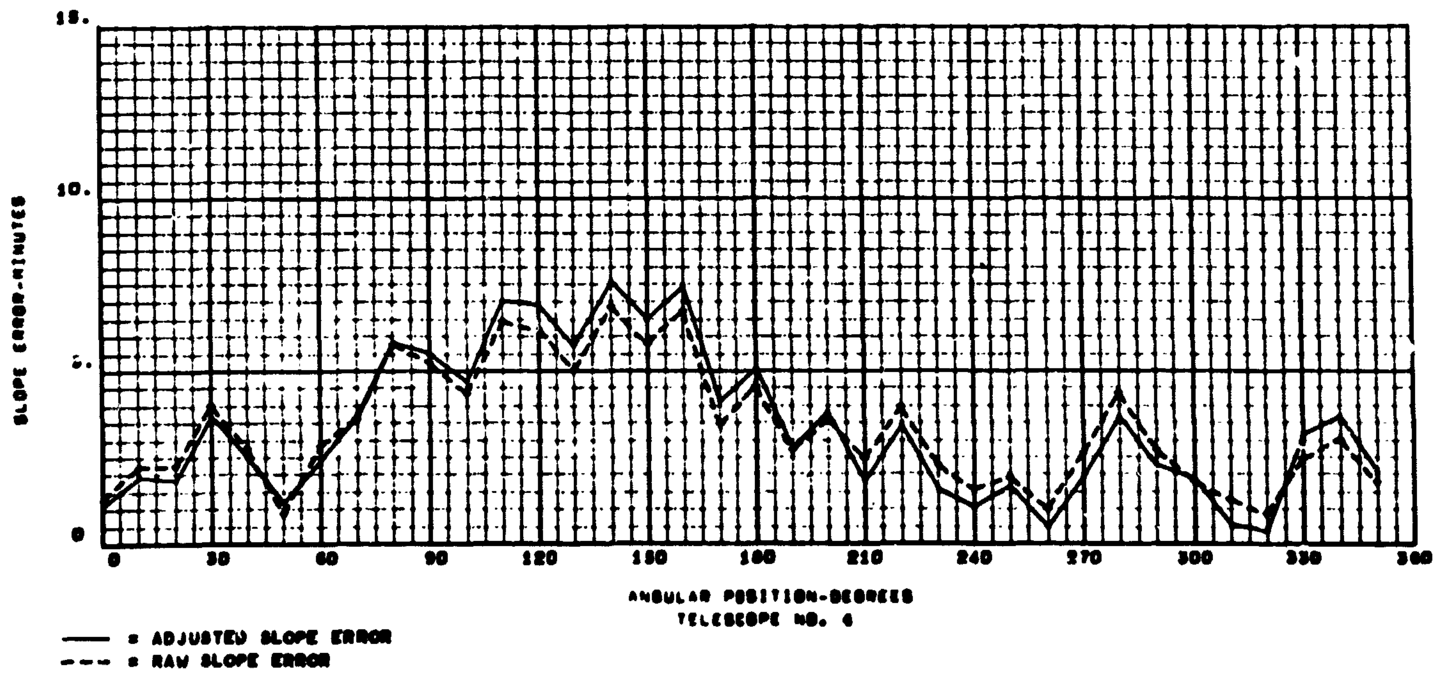


TELESCOPE NO. 2

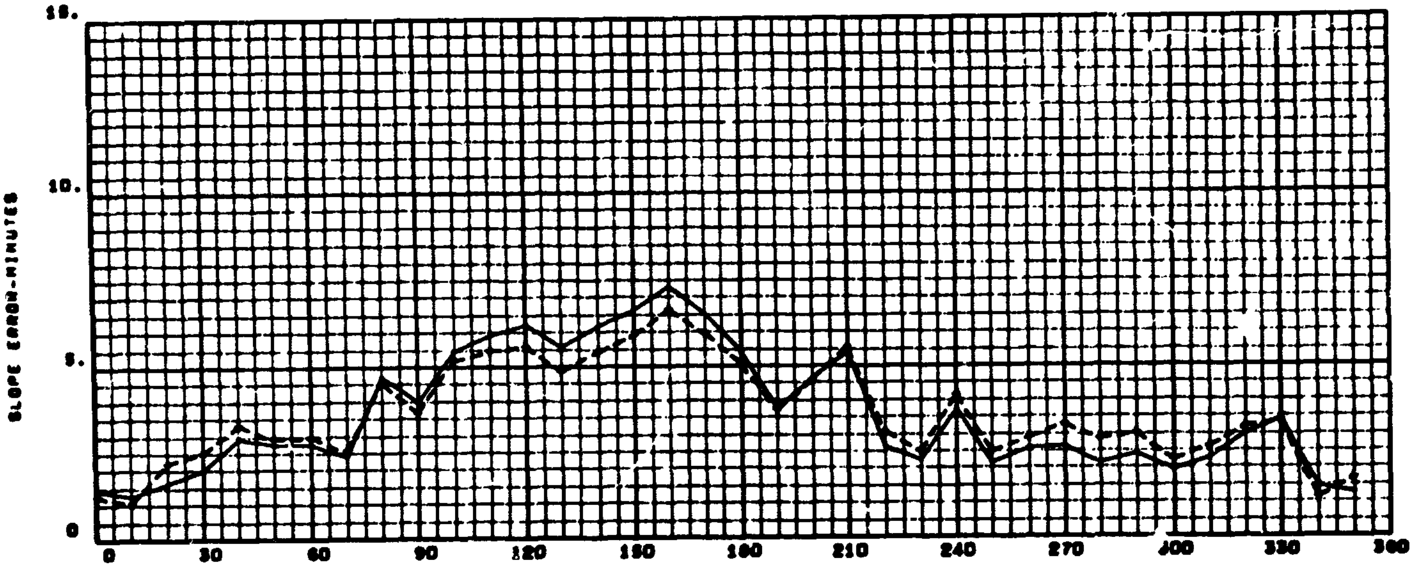
——— = ADJUSTED SLOPE ERROR
- - - = RAW SLOPE ERROR



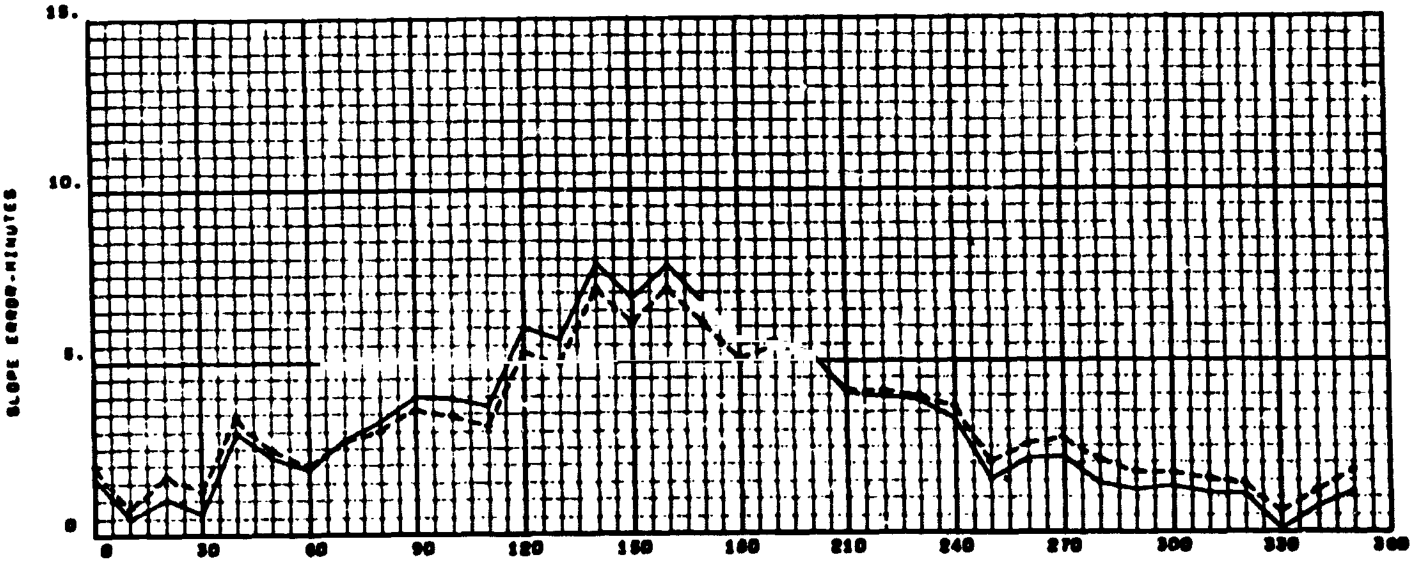
15.
10.
5.
0
SLOPE ERROR-MINUTES
0
30
60
90
120
150
180
210
240
270
300
330
360
ANGULAR POSITION-DEGREES
TELESCOPE NO. 3



15.
10.
5.
0
SLOPE ERROR-MINUTES
0
30
60
90
120
150
180
210
240
270
300
330
360
ANGULAR POSITION-DEGREES
TELESCOPE NO. 4
= ADJUSTED SLOPE ERROR
= RAW SLOPE ERROR

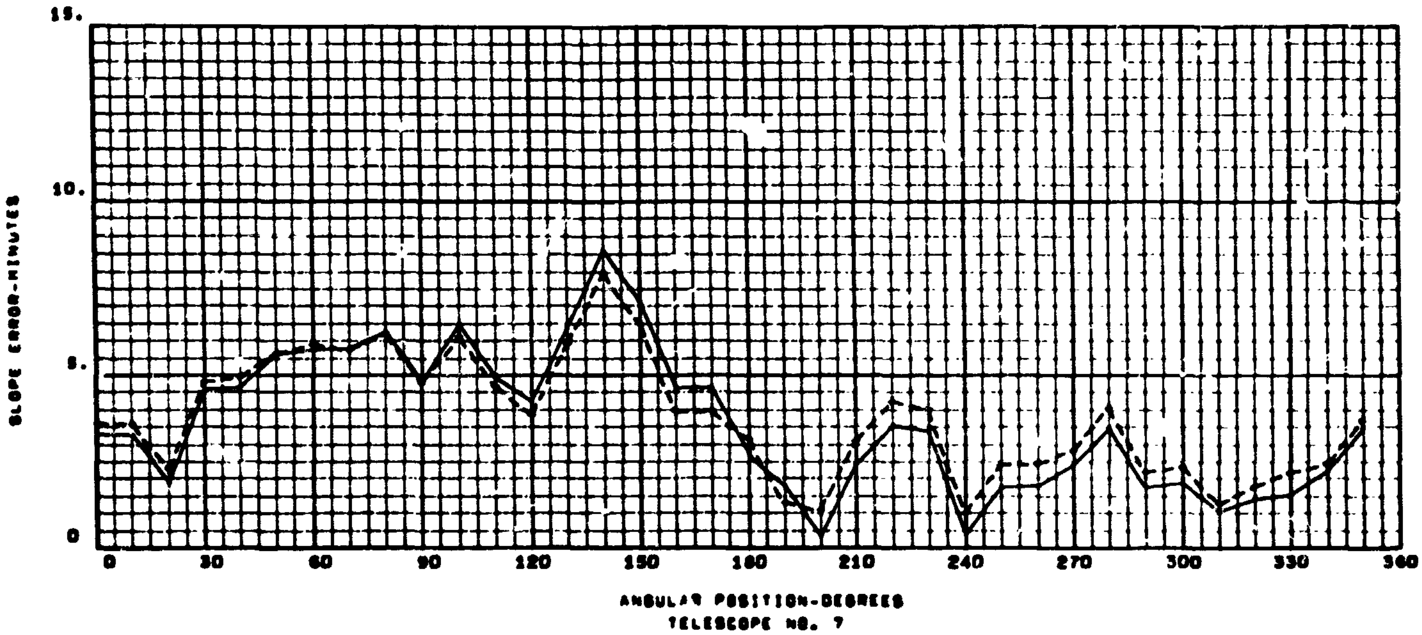


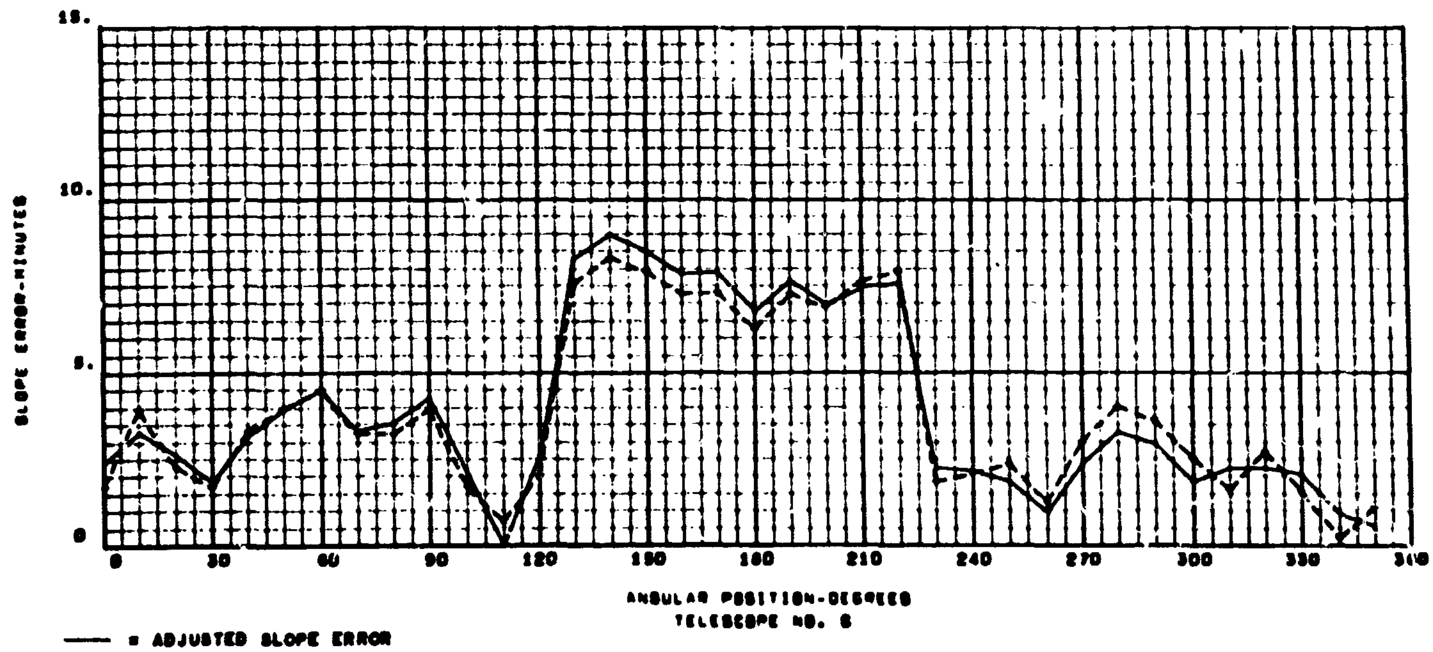
TELESCOPE NO. 5



TELESCOPE NO. 6

—— = ADJUSTED SLOPE ERROR
- - - = RAW SLOPE ERROR





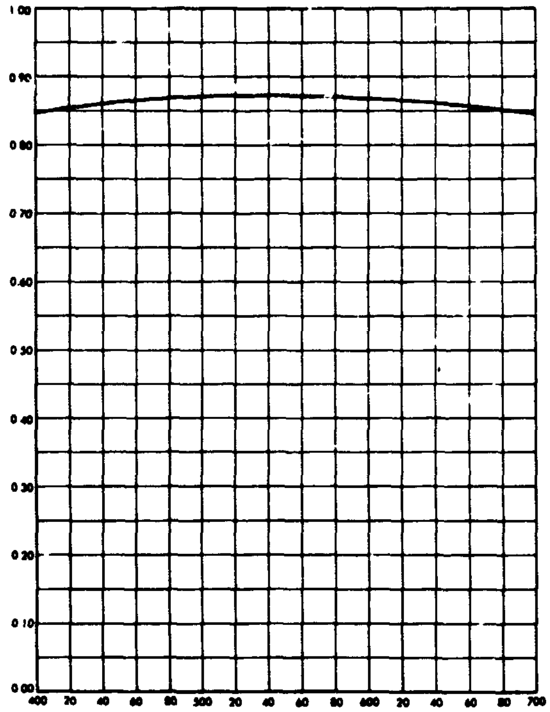
——— = ADJUSTED SLOPE ERROR
- - - = RAW SLOPE ERROR

APPENDIX L

COATING SPECIFICATIONS

Front Surface Aluminum Mirror No. 749

Spectrophotometric curve shown in the visible region is measured at normal incidence.



Wave length in millimicrons

*When the coated element is used at angles other than normal, curve peaks will shift toward shorter wave lengths (down scale). This variation is dependent on degree of angularity from normal incidence.

SPECIFICATION No. 1051

Reflectivity

The mirror shall have not less than 85% total reflectivity for light in the visible region as measured with a Weston photronic cell with a Viscor filter and a tungsten lamp supplying light at an angle of incidence of 22.5°.

Adherence

No visible part of the mirror coating shall be removed by the cellulose tape test described here:

Test: The tacky surface of cellulose tape shall be carefully placed in contact with a portion of the mirror surface and firmly rubbed against that surface. It shall then be quickly removed with a snap action which exerts the greatest possible stripping action on the mirror film.

Hardness

No evidence of film removal or film abrasion shall be visible to the eye when the following test is applied:

Test: A pad of clean dry cheese cloth (previously laundered) 3/8 inch in diameter, 1/2 inch thick, bearing with a force of one pound on the coating shall be rubbed across the coated element in any direction 25 times.

Note: During the above test, care should be exercised to prevent contaminating abrasives contacting the coated surface causing slight sleeks.

Corrosion Resistance

There shall be no noticeable deterioration of the finished mirror when given the salt atmosphere test described here:

Test: The mirror shall be placed in a thermostatically controlled cabinet with a salt atmosphere for 24 continuous hours at a temperature of 95° F. The salt atmosphere shall be obtained by allowing a stream of air to bubble through a salt solution containing 1½ pounds of sodium chloride per cubic foot of water.

Effect of Temperature

The coating shall function satisfactorily and shall not be damaged by exposure to an ambient temperature of minus 60° F. and plus 500° F.

APPENDIX M

TORUS ANALYSIS

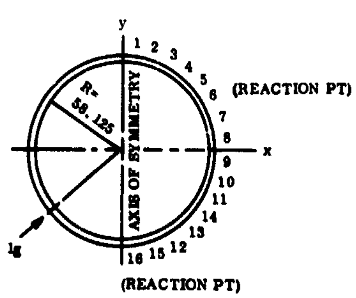
Preliminary analysis indicated that the torus was critical in torsional rotation under applied normal loading. Since the torsional load is directly influenced by the weight of the torus, a section yielding the lowest polar moment of inertia/weight ratio was desired. A 3.58 in. OD, 0.040 in. wall torus has been selected. The D/t ratio of 90 approaches a maximum for wall stability.

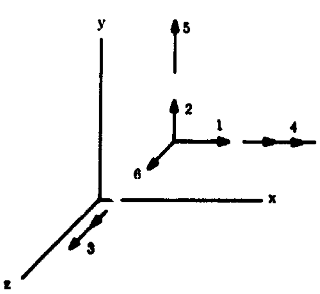
To further keep rotational deflection to a minimum, it is desirable to torsionally restrain the torus at the three reaction points. The hard point inserts have been redesigned to accomplish this.

The analysis presented here has been performed via the General Electric Company MASS Digital computer program. The program has as its basis the Matrix Force Method of Analysis, and is capable of analyzing structures composed of straight or curved members with varying end restraints, under the influence of the complete spectrum of applied steady state inertial and thermal loading.

One-g loading conditions, in the plane and normal to the plane of the torus, have been investigated. This allows for superpositioning with appropriate load factors to obtain worst case conditions. The following assumptions are made:

1. The restraint effects of the mirror are neglected.
2. The reaction points offer full torsional restraint.
3. Torus distortions produce like rigid body distortions in the mirror.
4. In-plane mirror loads are introduced into the torus by a "VQ/I" distribution.



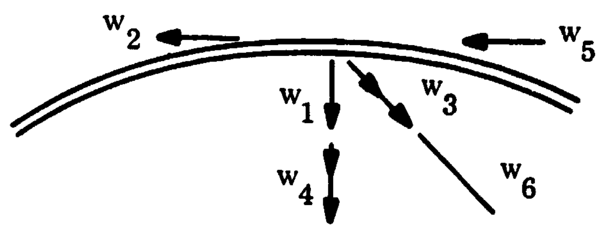


BOUNDARY CONDITIONS

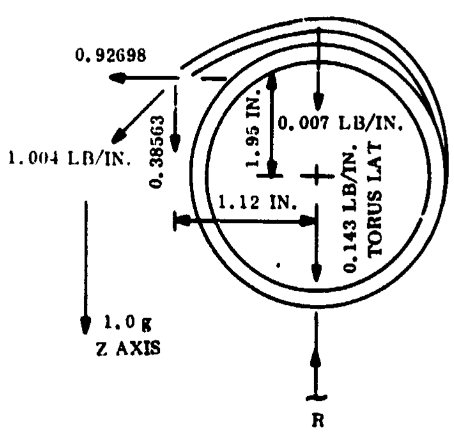
The external load and initial deflection values for each joint are programmed here. Designation of the deflection equal to zero indicates a fixed reaction point. For example, at joint 6, which is a reaction point, the deflections in the 1, 2, 4, 5 and 6 directions are given as zero to specify the restraint given by the reaction point in these directions.

MEMBER INFORMATION

The section properties and member geometry are given here. The distributed load direction rotation is as shown.



The applied one-g loads were derived from a membrane stress analysis of the mirror. At the tangent point, the mirror load in in.-lbs. per inch of circumference is 1.004. The applied load calculations are:



$W_1 = 0.927$ lb/in.

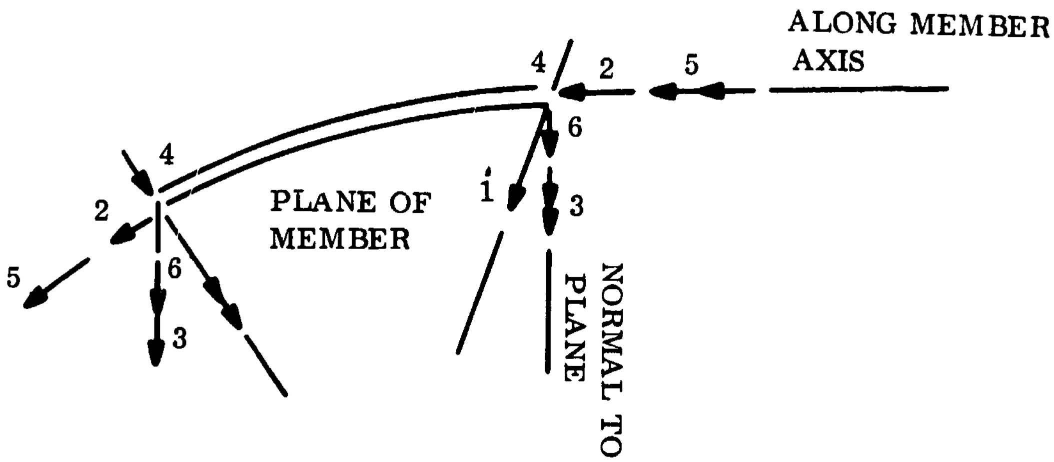
$W_5 = 0.386\ (1.12) + 0.927\ (1.95)$

$= 2.240$ in-lb/in.

$W_6 = 0.143 + 0.007 + 0.386$

$= 0.536$ lb/in.

Given next on the output sheets are the member loads and deflections at each joint. Member loads and joint deflections (given following the member data) are oriented in respect to the basic coordinate system. Normalized deflection and loads are given in respect to the member, and directions are as shown.

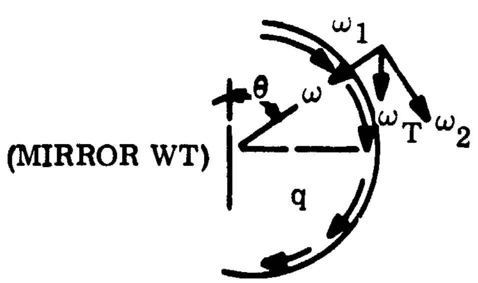


The stress output is self-explanatory.

The summation of forces given at the end of the runs show a balance of forces at each joint and the reactions.

CASE II - IN-PLANE LOADING

The distribution loads are as shown:



$q = \frac{V}{\pi \epsilon} \sin \theta \quad \omega_t = \text{unit } \omega_r \text{ of torus}$

$\omega_1 = \omega_t \text{ Cos } \theta$

$\omega_2 = q\, r\, \omega_r \text{ Sin } \theta$

Substantiation of Structural Integrity

The torus is checked against the following criteria

Yield Loads - 1.15 Limit Loads

Yield stress of annealed Nickel - 8500 psi
(Ref. Metals Handbook 8th Edition-A.S.M.)

Load Factors

1. Transportation - Loads are to be attenuated by resilient packaging and special handling procedures.

2. Handling, hoist, etc. - 3.0 applied along any coordinate axis.

3. Operation -

   a. 2.0 g's (suddenly applied load) in any direction

   b. Deflection Criteria

   Distortion of true parabolic surface not to exceed one minute of arc.

   c. Thermal Environment

   A maximum Δ T of 20^{o} is assumed between the mirror surface and the torus. Gradients through the sections are negligible (not critical for tourus design).

Condition (2) Hoist. (With the use of spreader bars)

At Reaction Pts. (Joints 6, 16)

Max. Axial Stress = 3.0 (1.15) (120) = 4.4 psi

Max. Bending Stress = 3.0 (1.15) (1767.2) = 6970 psi

Torsional Stress = 3.0 (1.15) (227.5) = 785 psi

$$\text{Maximum Stress} = \frac{f_c}{2} + \sqrt{\left(\frac{f_c}{2}\right)^2 + f_s^2} = 7467 \text{ psi}$$

$$\text{M.S.} = \frac{8500}{7467} - 1 = + 0.14$$

Condition (3) Operation.

Maximum Torsional Deflection = 0.0002941 Radians at Joint 11

Change in parabolic slope

$$= (0.0002941) \frac{360}{2} (60) = 1.001 \text{ min.}$$

$$\text{Margin of Safety} = \frac{\text{Allowable Deflection}}{\text{Actual Deflection}} - 1 = \frac{1.00}{1.001} - 1 = \underline{0}$$

In consideration of the conservative analytical approach by neglecting the restraint of the mirror, this margin is adequate.

A review of the analysis shows that the plane loading is not significant to the torus designs. The maximum bending stress is 452 psi/g and occurs at Joint 6. The in plane load capability is

$$\frac{8500}{452\ (1.15)} = 16.3 \text{ g's}$$

M E C H A N I C A L   A N A L Y S I S

O F

S P A C E   S T R U C T U R E S

*** M A S S ***

U33400

J.CHRISTOPHER   EXT 3045   CHARGE 44P730

U2612 VF   DROP   DATE 3/17/65

9 1/2 FT. TORUS-TRANSVERSE LOADING

BOUNDARY CONDITIONS

JOINT	DIRECTION 1		DIRECTION 2		DIRECTION 3		DIRECTION 4		DIRECTION 5		DIRECTION 6	
1	*D*	0.	LOAD	0.	*D*	0.	LOAD	0.	*D*	0.	LOAD	0.
	WGT.	0.	WGT.	0.	W.M.I.	0.	W.M.I.	0.	W.M.I.	0.	WGT.	0.
2	LOAD	0.	LOAD	0.	LOAD	0.	LOAD	0.	LOAD	0.	LOAD	0.
	WGT.	0.	WGT.	0.	W.M.I.	0.	W.M.I.	0.	W.M.I.	0.	WGT.	0.
3	LOAD	0.	LOAD	0.	LOAD	0.	LOAD	0.	LOAD	0.	LOAD	0.
	WGT.	0.	WGT.	0.	W.M.I.	0.	W.M.I.	0.	W.M.I.	0.	WGT.	0.
4	LOAD	0.	LOAD	0.	LOAD	0.	LOAD	0.	LOAD	0.	LOAD	0.
	WGT.	0.	WGT.	0.	W.M.I.	0.	W.M.I.	0.	W.M.I.	0.	WGT.	0.
5	LOAD	0.	LOAD	0.	LOAD	0.	LOAD	0.	LOAD	0.	LOAD	0.
	WGT.	0.	WGT.	0.	W.M.I.	0.	W.M.I.	0.	W.M.I.	0.	WGT.	0.
6	*D*	0.	*D*	0.	LOAD	0.	*D*	0.	*D*	0.	*D*	0.
	WGT.	0.	WGT.	0.	W.M.I.	0.	W.M.I.	0.	W.M.I.	0.	WGT.	0.
7	LOAD	0.	LOAD	0.	LOAD	0.	LOAD	0.	LOAD	0.	LOAD	0.
	WGT.	0.	WGT.	0.	W.M.I.	0.	W.M.I.	0.	W.M.I.	0.	WGT.	0.
8	LOAD	0.	LOAD	0.	LOAD	0.	LOAD	0.	LOAD	0.	LOAD	0.
	WGT.	0.	WGT.	0.	W.M.I.	0.	W.M.I.	0.	W.M.I.	0.	WGT.	0.
9	LOAD	0.	LOAD	0.	LOAD	0.	LOAD	0.	LOAD	0.	LOAD	0.
	WGT.	0.	WGT.	0.	W.M.I.	0.	W.M.I.	0.	W.M.I.	0.	WGT.	0.
10	LOAD	0.	LOAD	0.	LOAD	0.	LOAD	0.	LOAD	0.	LOAD	0.
	WGT.	0.	WGT.	0.	W.M.I.	0.	W.M.I.	0.	W.M.I.	0.	WGT.	0.
11	LOAD	0.	LOAD	0.	LOAD	0.	LOAD	0.	LOAD	0.	LOAD	0.
	WGT.	0.	WGT.	0.	W.M.I.	0.	W.M.I.	0.	W.M.I.	0.	WGT.	0.
12	LOAD	0.	LOAD	0.	LOAD	0.	LOAD	0.	LOAD	0.	LOAD	0.
	WGT.	0.	WGT.	0.	W.M.I.	0.	W.M.I.	0.	W.M.I.	0.	WGT.	0.
13	LOAD	0.	LOAD	0.	LOAD	0.	LOAD	0.	LOAD	0.	LOAD	0.
	WGT.	0.	WGT.	0.	W.M.I.	0.	W.M.I.	0.	W.M.I.	0.	WGT.	0.
14	LOAD	0.	LOAD	0.	LOAD	0.	LOAD	0.	LOAD	0.	LOAD	0.
	WGT.	0.	WGT.	0.	W.M.I.	0.	W.M.I.	0.	W.M.I.	0.	WGT.	0.
15	LOAD	0.	LOAD	0.	LOAD	0.	LOAD	0.	LOAD	0.	LOAD	0.
	WGT.	0.	WGT.	0.	W.M.I.	0.	W.M.I.	0.	W.M.I.	0.	WGT.	0.
16	*D*	0.	*D*	0.	*D*	0.	LOAD	0.	*D*	0.	*D*	0.
	WGT.	0.	WGT.	0.	W.M.I.	0.	W.M.I.	0.	W.M.I.	0.	WGT.	0.

```
MEMBER    1    2  ( CURVED  BAR  )                              FREQUENCY           0

RADIUS OF CURVATURE  =  58.125          INCLUDED  ANGLE  =  12.000          REFERENCE TEMPERATURE =            0

          COORDINATES  OF  JOINT  NO.    1   (           0 ,  58.125    ,          0 )    I  JOINT
          COORDINATES  OF  JOINT  NO.    2   (  12.085     ,  56.855    ,          0 )    J  JOINT
          COORDINATES  OF  REFERENCE  JOINT  (           0 ,           0 ,          0 )    0  JOINT

     RESTRAINT  CODES       JOINT    1  ( 0 , 0 , 0 , 0 , 0 , 0 )     JOINT    2  ( 0 , 0 , 0 , 0 , 0 , 0 )

YOUNGS  MODULUS       =  0.3000+08       TORSIONAL  CONSTANT  =  1.3940        DISTRIBUTED  LOADS  I  =  0.1430

SHEAR   MODULUS       =  0.1150+08       SHEAR  CONSTANT  1  =           0                      2  = -0.9700-01

THERMAL  COEFFICIENT =           0       SHEAR  CONSTANT  2  =           0                      3  =           0

CROSS SECTIONAL AREA =  0.4450           TEMPERATURE  GRAD 1  =          0                      4  =           0

MOMENT OF INERTIA  1 =  0.6970           TEMPERATURE  GRAD 2  =          0                      5  =           0

MOMENT OF INERTIA  2 =  0.6970           TEMPERATURE AVERAGE  =          0                      6  =           0

ROTATION   OF   AXIS =           0       WEIGHT  DENSITY      =  0.3220        WEIGHT  OF  MEMBER    =  1.7444

********************************************  CALCULATIONS  ******  ****************************************

                          DIRECTION 1     DIRECTION 2     DIRECTION 3     DIRECTION 4     DIRECTION 5     DIRECTION 6

MEMBER LOADS   JOINT   1   -4.3116        0.2861-05       -60.547               0               0              -0
               JOINT   2    3.3210        1.8514           45.013              -0              -0              -0

NORM.  DEFL.   JOINT   1    0.9153-03            -0              -0             -0              -0              -0
               JOINT   2    0.6905-03    -0.1790-03       0.3221-04             -0              -0              -0

NORM.  LOADS   JOINT   1   -0.2861-05     4.3116          -60.547              -0              -0              -0
               JOINT   2   -2.5014       -2.8635           45.013              -0              -0              -0

****************************************  STRESS  CALCULATION  1053  ****************************************

          INPUT CONSTANTS                TYPE  OF  STRESS                      JOINT    1        JOINT    2

          C1 =  1.7900                   AXIAL  STRESS                         9.6890            6.4348
          C2 =  1.7900                   IN-PLANE  BENDING  STRESS 1        -155.49           -115.60
          C3 =  1.7900                   IN-PLANE  BENDING  STRESS 2         155.49            115.60
          C4 =  1.7900                   NORMAL PLANE BENDING STRESS 1            -0                 0
          F1 =  1.2840                   NORMAL PLANE BENDING STRESS 2             0                -0
          F2 =  2.2000                   TORSIONAL  STRESS                        -0                -0
          F3 =  2.2000                   IN-PLANE  SHEAR  STRESS          -0.6294-05          -5.5030
                                         NORMAL PLANE SHEAR STRESS                -0                -0
```

MEMBER 2 3 (CURVED BAR) FREQUENCY 0

RADIUS OF CURVATURE = 58.125 INCLUDED ANGLE = 12.000 REFERENCE TEMPERATURE = 0

COORDINATES OF JOINT NO. 2	(12.085 ,	56.855 ,	0)	I	JOINT
COORDINATES OF JOINT NO. 3	(23.642 ,	53.100 ,	0)	J	JOINT
COORDINATES OF REFERENCE JOINT	(0 ,	0 ,	0)	O	JOINT

RESTRAINT CODES JOINT 2 (0 , 0 , 0 , 0 , 0 , 0) JOINT 3 (0 , 0 , 0 , 0 , 0 , 0)

YOUNGS MODULUS = 0.3000+08	TORSIONAL CONSTANT = 1.3940	DISTRIBUTED LOADS 1 =	0.1360
SHEAR MODULUS = 0.1150+08	SHEAR CONSTANT 1 = 0	2 =	-0.2870
THERMAL COEFFICIENT = 0	SHEAR CONSTANT 2 = 0	3 =	0
CROSS SECTIONAL AREA = 0.4450	TEMPERATURE GRAD 1 = 0	4 =	0
MOMENT OF INERTIA 1 = 0.6970	TEMPERATURE GRAD 2 = 0	5 =	0
MOMENT OF INERTIA 2 = 0.6970	TEMPERATURE AVERAGE = 0	6 =	0
ROTATION OF AXIS = 0	WEIGHT DENSITY = 0.3220	WEIGHT OF MEMBER =	1.7444

•• CALCULATIONS ••

		DIRECTION 1	DIRECTION 2	DIRECTION 3	DIRECTION 4	DIRECTION 5	DIRECTION 6
MEMBER LOADS	JOINT 2	-3.3210	-1.8514	-45.013	0	0	-0
	JOINT 3	0.5148	4.5008	2.5866	-0	-0	-0
NORM. DEFL.	JOINT 2	0.6905-03	-0.1790-03	0.3221-04	-0	-0	-0
	JOINT 3	0.1332-02	-0.2696-03	0.4714-04	-0	-0	-0
NORM. LOADS	JOINT 2	2.5014	2.8635	-45.013	-0	-0	-0
	JOINT 3	-4.3211	1.3603	2.5866	-0	-0	-0

•• STRESS CALCULATION 1053 ••

INPUT CONSTANTS	TYPE OF STRESS	JOINT 2	JOINT 3
C1 = 1.7900	AXIAL STRESS	6.4348	-3.0570
C2 = 1.7900	IN-PLANE BENDING STRESS 1	-115.60	-6.6427
C3 = 1.7900	IN-PLANE BENDING STRESS 2	115.60	6.6427
C4 = 1.7900	NORMAL PLANE BENDING STRESS 1	-0	0
F1 = 1.2840	NORMAL PLANE BENDING STRESS 2	0	-0
F2 = 2.2000	TORSIONAL STRESS	-0	-0
F3 = 2.2000	IN-PLANE SHEAR STRESS	5.5030	-9.5064
	NORMAL PLANE SHEAR STRESS	-0	-0

MEMBER 3 4 (CURVED BAR) FREQUENCY 0

RADIUS OF CURVATURE = 58.125 INCLUDED ANGLE = 12.000 REFERENCE TEMPERATURE = 0

COORDINATES OF JOINT NO. 3 (23.642 , 53.100 , 0) I JOINT
COORDINATES OF JOINT NO. 4 (34.165 , 47.824 , 0) J JOINT
COORDINATES OF REFERENCE JOINT (0 , 0 , 0) 0 JOINT

RESTRAINT CODES JOINT 3 (0 , 0 , 0 , 1 , 0 , 0) JOINT 4 (0 , 0 , 0 , 0 , 0 , 0)

YOUNGS MODULUS	= 0.3000+08	TORSIONAL CONSTANT	= 1.3940	DISTRIBUTED LOADS 1	= 0.1240
SHEAR MODULUS	= 0.1150+08	SHEAR CONSTANT 1	= 0	2	= -0.4650
THERMAL COEFFICIENT	= 0	SHEAR CONSTANT 2	= 0	3	= 0
CROSS SECTIONAL AREA	= 0.4450	TEMPERATURE GRAD 1	= 0	4	= 0
MOMENT OF INERTIA 1	= 0.6970	TEMPERATURE GRAD 2	= 0	5	= 0
MOMENT OF INERTIA 2	= 0.6970	TEMPERATURE AVERAGE	= 0	6	= 0
ROTATION OF AXIS	= 0	WEIGHT DENSITY	= 0.3220	WEIGHT OF MEMBER	= 1.7443

** CALCULATIONS **

		DIRECTION 1	DIRECTION 2	DIRECTION 3	DIRECTION 4	DIRECTION 5	DIRECTION 6
MEMBER LOADS	JOINT 3	-0.5148	-4.9008	-2.5866	0	0	-0
	JOINT 4	-3.6251	8.6309	-54.659	-0	-0	-0
NORM. DEFL.	JOINT 3	0.1332-03	-0.2696-03	0.4714-04	-0	-0	-0
	JOINT 4	-0.4388-03	-0.2300-03	0.3229-04	-0	-0	-0
NORM. LOADS	JOINT 3	4.3211	-1.3604	-2.5866	-0	-0	-0
	JOINT 4	-4.8518	8.0059	-54.659	-0	-0	-0

** STRESS CALCULATION 1053 **

INPUT CONSTANTS

C1 = 1.7900
C2 = 1.7900
C3 = 1.7900
C4 = 1.7900
F1 = 1.2840
F2 = 2.2000
F3 = 2.2000

TYPE OF STRESS	JOINT 3	JOINT 4
AXIAL STRESS	-3.0570	-17.991
IN-PLANE BENDING STRESS 1	-6.6427	140.37
IN-PLANE BENDING STRESS 2	6.6427	-140.37
NORMAL PLANE BENDING STRESS 1	-0	0
NORMAL PLANE BENDING STRESS 2	0	-0
TORSIONAL STRESS	-0	-0
IN-PLANE SHEAR STRESS	9.5064	-10.674
NORMAL PLANE SHEAR STRESS	-0	-0

MEMBER 4 5 (CURVED BAR) FREQUENCY 0

RADIUS OF CURVATURE = 58.125 INCLUDED ANGLE = 12.000 REFERENCE TEMPERATURE = 0

COORDINATES OF JOINT NO. 4	(34.165 ,	47.024 ,	0)	I JOINT
COORDINATES OF JOINT NO. 5	(43.195 ,	38.893 ,	0)	J JOINT
COORDINATES OF REFERENCE JOINT	(0 ,	0 ,	0)	O JOINT

RESTRAINT CODES JOINT 4 (0 , 0 , 0 , 0 , 0 , 0) JOINT 5 (0 , 0 , 0 , 0 , 0 , 0)

YOUNGS MODULUS =	0.3000+08	TORSIONAL CONSTANT =	1.3940	DISTRIBUTED LOADS 1 =	0.1060
SHEAR MODULUS =	0.1150+08	SHEAR CONSTANT 1 =	0	2 =	-0.6210
THERMAL COEFFICIENT =	0	SHEAR CONSTANT 2 =	0	3 =	0
CROSS SECTIONAL AREA =	0.4450	TEMPERATURE GRAD 1 =	0	4 =	0
MOMENT OF INERTIA 1 =	0.6970	TEMPERATURE GRAD 2 =	0	5 =	0
MOMENT OF INERTIA 2 =	0.6970	TEMPERATURE AVERAGE =	0	6 =	0
ROTATION OF AXIS =	0	WEIGHT DENSITY =	0.3220	WEIGHT OF MEMBER =	1.7443

** CALCULATIONS **

		DIRECTION 1	DIRECTION 2	DIRECTION 3	DIRECTION 4	DIRECTION 5	DIRECTION 6
MEMBER LOADS	JOINT 4	3.6251	-8.6309	54.659	0	0	-0
	JOINT 5	-8.3710	14.637	-107.74	0	0	0
NORM. DEFL.	JOINT 4	-0.4360-03	-0.2300-03	0.3229-04	0	0	0
	JOINT 5	-0.6063-03	-0.9868-04	-0.1573-04	0	0	0
NORM. LOADS	JOINT 4	4.8518	-8.0059	54.659	-0	-0	-0
	JOINT 5	-3.5734	16.479	-107.74	0	0	0

** STRESS CALCULATION 1053 **

INPUT CONSTANTS

C1 = 1.7900
C2 = 1.7900
C3 = 1.7900
C4 = 1.7900
F1 = 1.2840
F2 = 2.2000
F3 = 2.2000

TYPE OF STRESS	JOINT 4	JOINT 5
AXIAL STRESS	-17.991	-37.031
IN-PLANE BENDING STRESS 1	140.37	276.70
IN-PLANE BENDING STRESS 2	-140.37	-276.70
NORMAL PLANE BENDING STRESS 1	-0	-0
NORMAL PLANE BENDING STRESS 2	0	0
TORSIONAL STRESS	-0	0
IN-PLANE SHEAR STRESS	10.674	-7.8616
NORMAL PLANE SHEAR STRESS	-0	0

MEMBER 5 6 (CURVED BAR) FREQUENCY 0

RADIUS OF CURVATURE = 58.125 INCLUDED ANGLE = 12.001 REFERENCE TEMPERATURE = 0

COORDINATES OF JOINT NO. 5 (43.195 , 38.893 , 0) I JOINT
COORDINATES OF JOINT NO. 6 (50.338 , 29.062 , 0) J JOINT
COORDINATES OF REFERENCE JOINT (0 , 0 , 0) O JOINT

RESTRAINT CODES JOINT 5 (0 , 0 , 0 , 0 , 0 , 0) JOINT 6 (0 , 0 , 0 , 0 , 0 , 0)

YOUNGS MODULUS =	0.3000+08	TORSIONAL CONSTANT =	1.3940	DISTRIBUTED LOADS 1 =	0.8400-01
SHEAR MODULUS =	0.1150+08	SHEAR CONSTANT 1 =	0	2 =	-0.7510
THERMAL COEFFICIENT =	0	SHEAR CONSTANT 2 =	0	3 =	0
CROSS SECTIONAL AREA =	0.4450	TEMPERATURE GRAD 1 =	0	4 =	0
MOMENT OF INERTIA 1 =	0.6970	TEMPERATURE GRAD 2 =	0	5 =	0
MOMENT OF INERTIA 2 =	0.6970	TEMPERATURE AVERAGE =	0	6 =	0
ROTATION OF AXIS =	0	WEIGHT DENSITY =	0.3220	WEIGHT OF MEMBER =	1.7444

** CALCULATIONS **

			DIRECTION 1	DIRECTION 2	DIRECTION 3	DIRECTION 4	DIRECTION 5	DIRECTION 6
MEMBER LOADS	JOINT	5	8.3710	-14.637	107.74	-0	-0	0
	JOINT	6	-12.909	22.621	-132.32	0	0	0
NORM. DEFL.	JOINT	5	-0.6063-03	-0.9868-04	-0.1573-04	0	0	0
	JOINT	6	0	0	-0.8766-04	0	0	0
NORM. LOADS	JOINT	5	3.5734	-16.479	107.74	0	0	0
	JOINT	6	-0.1302	26.045	-132.32	0	0	0

*************************************** STRESS CALCULATION 1053 ***************************************

INPUT CONSTANTS	TYPE OF STRESS	JOINT 5	JOINT 6
C1 = 1.7900	AXIAL STRESS	-37.031	-58.527
C2 = 1.7900	IN-PLANE BENDING STRESS 1	276.70	339.82
C3 = 1.7900	IN-PLANE BENDING STRESS 2	-276.70	-339.82
C4 = 1.7900	NORMAL PLANE BENDING STRESS 1	0	-0
F1 = 1.2840	NORMAL PLANE BENDING STRESS 2	-0	0
F2 = 2.2000	TORSIONAL STRESS	0	0
F3 = 2.2000	IN-PLANE SHEAR STRESS	7.8616	-0.2865
	NORMAL PLANE SHEAR STRESS	0	0

MEMBER 6 7 (CURVED BAR) FREQUENCY 0

RADIUS OF CURVATURE = 58.125 INCLUDED ANGLE = 11.999 REFERENCE TEMPERATURE = 0

COORDINATES OF JOINT NO. 6	(50.338 ,	29.062 ,	0)	I	JOINT
COORDINATES OF JOINT NO. 7	(55.280 ,	17.962 ,	0)	J	JOINT
COORDINATES OF REFERENCE JOINT	(0 ,	0 ,	0)	O	JOINT

RESTRAINT CODES JOINT 6 (0 , 0 , 0 , 0 , 0 , 0) JOINT 7 (0 , 0 , 0 , 0 , 0 , 0)

YOUNGS MODULUS =	0.3000+08	TORSIONAL CONSTANT =	1.3940	DISTRIBUTED LOADS 1 =	0.5000-01
SHEAR MODULUS =	0.1150+08	SHEAR CONSTANT 1 =	0	2 =	-0.8480
THERMAL COEFFICIENT =	0	SHEAR CONSTANT 2 =	0	3 =	0
CROSS SECTIONAL AREA =	0.4450	TEMPERATURE GRAD 1 =	0	4 =	0
MOMENT OF INERTIA 1 =	0.6970	TEMPERATURE GRAD 2 =	0	5 =	0
MOMENT OF INERTIA 2 =	0.6970	TEMPERATURE AVERAGE =	0	6 =	0
ROTATION OF AXIS =	0	WEIGHT DENSITY =	0.3220	WEIGHT OF MEMBER =	1.7442

** CALCULATIONS **

		DIRECTION 1	DIRECTION 2	DIRECTION 3	DIRECTION 4	DIRECTION 5	DIRECTION 6
MEMBER LOADS	JOINT 6	-6.9027	53.901	132.32	-0	-0	0
	JOINT 7	3.3557	-44.202	57.535	0	0	0
NORM. DEFL.	JOINT 6	0	0	-0.8766-04	0	0	0
	JOINT 7	0.1260-02	-0.1722-03	-0.1032-03	0	0	0
NORM. LOADS	JOINT 6	-20.972	50.131	132.32	0	0	0
	JOINT 7	10.468	-43.075	57.535	0	0	0

** STRESS CALCULATION 1053 **

INPUT CONSTANTS	TYPE OF STRESS	JOINT 6	JOINT 7
C1 = 1.7900	AXIAL STRESS	112.66	96.799
C2 = 1.7900	IN-PLANE BENDING STRESS 1	339.82	-147.76
C3 = 1.7900	IN-PLANE BENDING STRESS 2	-339.82	147.76
C4 = 1.7900	NORMAL PLANE BENDING STRESS 1	0	-0
F1 = 1.2840	NORMAL PLANE BENDING STRESS 2	-0	0
F2 = 2.2000	TORSIONAL STRESS	0	0
F3 = 2.2000	IN-PLANE SHEAR STRESS	-46.139	23.030
	NORMAL PLANE SHEAR STRESS	0	0

MAXIMUM STRESS FOR INPLANE LOADING AT JOINT 6 = 452.48 p

ALLOWABLE INPLANE LOAD = $\frac{\text{[illegible]}}{1.15(452.48)}$ =

= **16.3 g's**

MEMBER 7 8 (CURVED BAR) FREQUENCY 0

RADIUS OF CURVATURE = 58.125 INCLUDED ANGLE = 12.000 REFERENCE TEMPERATURE = 0

COORDINATES OF JOINT NO. 7 (55.280 , 17.962 , 0) I JOINT
COORDINATES OF JOINT NO. 8 (57.806 , 6.0760 , 0) J JOINT
COORDINATES OF REFERENCE JOINT (0 , 0 , 0) O JOINT

RESTRAINT CODES JOINT 7 (0 , 0 , 0 , 0 , 0 , 0) JOINT 8 (0 , 0 , 0 , 0 , 0 , 0)

YOUNGS MODULUS =	0.3000+08	TORSIONAL CONSTANT =	1.3940	DISTRIBUTED LOADS 1 =	0.3000-01
SHEAR MODULUS =	0.1150+08	SHEAR CONSTANT 1 =	0	2 =	-0.9080
THERMAL COEFFICIENT =	0	SHEAR CONSTANT 2 =	0	3 =	0
CROSS SECTIONAL AREA =	0.4450	TEMPERATURE GRAD 1 =	0	4 =	0
MOMENT OF INERTIA 1 =	0.6970	TEMPERATURE GRAD 2 =	0	5 =	0
MOMENT OF INERTIA 2 =	0.6970	TEMPERATURE AVERAGE =	0	6 =	0
ROTATION OF AXIS =	0	WEIGHT DENSITY =	0.3220	WEIGHT OF MEMBER =	1.7444

** CALCULATIONS **

		DIRECTION 1	DIRECTION 2	DIRECTION 3	DIRECTION 4	DIRECTION 5	DIRECTION 6
MEMBER LOADS	JOINT 7	-3.3557	44.202	-57.535	-0	-0	0
	JOINT 8	1.4182	-33.334	131.80	-0	-0	-0
NORM. DEFL.	JOINT 7	0.1260-02	-0.1722-03	-0.1032-03	-0	-0	-0
	JOINT 8	0.2119-02	-0.5755-03	-0.4214-04	-0	-0	-0
NORM. LOADS	JOINT 7	-10.448	43.075	-57.535	0	0	0
	JOINT 8	2.0741	-33.299	131.80	-0	-0	-0

** STRESS CALCULATION 1053 **

INPUT CONSTANTS	TYPE OF STRESS	JOINT 7	JOINT 8
C1 = 1.7900	AXIAL STRESS	96.799	74.830
C2 = 1.7900	IN-PLANE BENDING STRESS 1	-147.76	-338.48
C3 = 1.7900	IN-PLANE BENDING STRESS 2	147.76	338.48
C4 = 1.7900	NORMAL PLANE BENDING STRESS 1	0	0
F1 = 1.2840	NORMAL PLANE BENDING STRESS 2	-0.	-0
F2 = 2.2000	TORSIONAL STRESS	0	-0
F3 = 2.2000	IN-PLANE SHEAR STRESS	-23.030	4.5630
	NORMAL PLANE SHEAR STRESS	0	-0

MEMBER 8 9 (CURVED BAR) FREQUENCY 0

RADIUS OF CURVATURE = 58.124 INCLUDED ANGLE = 12.001 REFERENCE TEMPERATURE = 0

COORDINATES OF JOINT NO. 8 (57.806 , 6.0760 , 0) I JOINT
COORDINATES OF JOINT NO. 9 (57.806 , -6.0760 , 0) J JOINT
COORDINATES OF REFERENCE JOINT (0 , 0 , 0) O JOINT

RESTRAINT CODES JOINT 8 (0 , 0 , 0 , 0 , 0 , 0) JOINT 9 (0 , 0 , 0 , 0 , 0 , 0)

YOUNGS MODULUS =	0.3000+08	TORSIONAL CONSTANT =	1.3940	DISTRIBUTED LOADS 1 =	0
SHEAR MODULUS =	0.1150+08	SHEAR CONSTANT 1 =	0	2 =	-0.9280
THERMAL COEFFICIENT =	0	SHEAR CONSTANT 2 =	0	3 =	0
CROSS SECTIONAL AREA =	0.4450	TEMPERATURE GRAD 1 =	0	4 =	0
MOMENT OF INERTIA 1 =	0.6970	TEMPERATURE GRAD 2 =	0	5 =	0
MOMENT OF INERTIA 2 =	0.6970	TEMPERATURE AVERAGE =	0	6 =	0
ROTATION OF AXIS =	0	WEIGHT DENSITY =	0.3220	WEIGHT OF MEMBER =	1.7444

** CALCULATIONS **

		DIRECTION 1	DIRECTION 2	DIRECTION 3	DIRECTION 4	DIRECTION 5	DIRECTION 6
MEMBER LOADS	JOINT 8	-1.4182	33.334	-131.80	0	0	-0
	JOINT 9	1.4182	-22.057	119.35	0	-0	0
NORM. DEFL.	JOINT 8	0.2119-02	-0.5755-03	-0.4314-04	0	0	0
	JOINT 9	0.2000-02	-0.1050-02	0.3339-04	0	0	0
NORM. LOADS	JOINT 8	-2.0741	33.299	-131.80	-0	-0	-0
	JOINT 9	-3.7161	-21.788	119.35	0	0	0

** STRESS CALCULATION 1053 **

INPUT CONSTANTS

C1 = 1.7900
C2 = 1.7900
C3 = 1.7900
C4 = 1.7900
F1 = 1.2840
F2 = 2.2000
F3 = 2.2000

TYPE OF STRESS	JOINT 8	JOINT 9
AXIAL STRESS	74.830	48.961
IN-PLANE BENDING STRESS 1	-338.48	-306.52
IN-PLANE BENDING STRESS 2	338.48	306.52
NORMAL PLANE BENDING STRESS 1	-0	-0
NORMAL PLANE BENDING STRESS 2	0	0
TORSIONAL STRESS	-0	0
IN-PLANE SHEAR STRESS	-4.5630	-8.1755
NORMAL PLANE SHEAR STRESS	-0	0

MEMBER 9 10 (CURVED BAR) FREQUENCY 0

RADIUS OF CURVATURE = 58.125 INCLUDED ANGLE = 12.000 REFERENCE TEMPERATURE = 0

COORDINATES OF JOINT NO. 9	(57.806	, -6.0760	, 0)	I JOINT
COORDINATES OF JOINT NO. 10	(55.280	, -17.962	, 0)	J JOINT
COORDINATES OF REFERENCE JOINT	(	0 ,	0 ,	0)	0 JOINT

RESTRAINT CODES JOINT 9 (0 , 0 , 0 , 0 , 0 , 0) JOINT 10 (0 , 0 , 0 , 0 , 0 , 0)

YOUNGS MODULUS =	0.3000+08	TORSIONAL CONSTANT =	1.3940	DISTRIBUTED LOADS 1 =	-0.3000-01
SHEAR MODULUS =	0.1150+08	SHEAR CONSTANT 1 =	0	2 =	-0.9080
THERMAL COEFFICIENT =	0	SHEAR CONSTANT 2 =	0	3 =	0
CROSS SECTIONAL AREA =	0.4450	TEMPERATURE GRAD 1 =	0	4 =	0
MOMENT OF INERTIA 1 =	0.6970	TEMPERATURE GRAD 2 =	0	5 =	0
MOMENT OF INERTIA 2 =	0.6970	TEMPERATURE AVERAGE =	0	6 =	0
ROTATION OF AXIS =	0	WEIGHT DENSITY =	0.3220	WEIGHT OF MEMBER =	1.7444

************************************** CALCULATIONS **************************************

		DIRECTION 1	DIRECTION 2	DIRECTION 3	DIRECTION 4	DIRECTION 5	DIRECTION 6
MEMBER LOADS	JOINT 9	-1.4182	22.057	-119.35	-0	0	0
	JOINT 10	3.3557	-11.189	53.673	-0	0	-0
NORM. DEFL.	JOINT 9	0.2000-02	-0.1050-02	0.3339-04	-0	-0	-0
	JOINT 10	0.9780-03	-0.1389-02	0.8550-04	-0	-0	-0
NORM. LOADS	JOINT 9	3.7161	21.788	-119.35	0	0	0
	JOINT 10	-6.6490	-9.6040	53.673	-0	-0	-0

************************************** STRESS CALCULATION 1053 **************************************

INPUT CONSTANTS

C1 = 1.7900
C2 = 1.7900
C3 = 1.7900
C4 = 1.7900
F1 = 1.2840
F2 = 2.2000
F3 = 2.2000

TYPE OF STRESS	JOINT 9	JOINT 10
AXIAL STRESS	48.961	21.582
IN-PLANE BENDING STRESS 1	-306.52	-137.84
IN-PLANE BENDING STRESS 2	306.52	137.84
NORMAL PLANE BENDING STRESS 1	0	0
NORMAL PLANE BENDING STRESS 2	-0	-0
TORSIONAL STRESS	0	-0
IN-PLANE SHEAR STRESS	8.1755	-14.628
NORMAL PLANE SHEAR STRESS	0	-0

MEMBER 10 11 (CURVED BAR) FREQUENCY 0

RADIUS OF CURVATURE = 58.125 INCLUDED ANGLE = 11.990 REFERENCE TEMPERATURE = 0

COORDINATES OF JOINT NO. 10	(55.280	, -17.962	,	0)	I JOINT
COORDINATES OF JOINT NO. 11	(50.338	, -29.062	,	0)	J JOINT
COORDINATES OF REFERENCE JOINT	(	0 ,	0 ,	0)	U JOINT

RESTRAINT CODES JOINT 10 (0 , 0 , 0 , 0 , 0 , 0) JOINT 11 (0 , 0 , 0 , 0 , 0 , 0)

YOUNGS MODULUS =	0.3000+08	TORSIONAL CONSTANT =	1.3940	DISTRIBUTED LOADS 1 =	-0.5800-01
SHEAR MODULUS =	0.1150+08	SHEAR CONSTANT 1 =	0	2 =	-0.8480
THERMAL COEFFICIENT -	0	SHEAR CONSTANT 2 =	0	3 =	0
CROSS SECTIONAL AREA =	0.4450	TEMPERATURE GRAD 1 =	0	4 =	0
MOMENT OF INERTIA 1 =	0.6970	TEMPERATURE GRAD 2 =	0	5 =	0
MOMENT OF INERTIA 2 =	0.6970	TEMPERATURE AVERAGE =	0	6 =	0
ROTATION OF AXIS =	0	WEIGHT DENSITY =	0.3220	WEIGHT OF MEMBER =	1.7442

** CALCULATIONS **

		DIRECTION 1	DIRECTION 2	DIRECTION 3	DIRECTION 4	DIRECTION 5	DIRECTION 6
MEMBER LOADS	JOINT 10	-3.3557	11.189	-53.673	0	-0	-0
	JOINT 11	6.9028	-1.4892	-30.212	-0	0	-0
NORM. DEFL.	JOINT 10	0.9780-03	-0.1389-02	0.8550-04	-0	-0	-0
	JOINT 11	-0.4570-03	-0.1449-02	0.9237-04	-0	-0	-0
NORM. LOADS	JOINT 10	6.6490	9.6040	-53.673	-0	-0	-0
	JOINT 11	-6.7226	2.1616	-30.212	-0	-0	-0

** STRESS CALCULATION 1053 **

INPUT CONSTANTS	TYPE OF STRESS	JOINT 10	JOINT 11
C1 = 1.7900	AXIAL STRESS	21.582	-4.8576
C2 = 1.7900	IN-PLANE BENDING STRESS 1	-137.84	77.590
C3 = 1.7900	IN-PLANE BENDING STRESS 2	137.84	-77.590
C4 = 1.7900	NORMAL PLANE BENDING STRESS 1	-0	0
F1 = 1.2840	NORMAL PLANE BENDING STRESS 2	0	-0
F2 = 2.2000	TORSIONAL STRESS	-0	-0
F3 = 2.2000	IN-PLANE SHEAR STRESS	14.628	-14.790
	NORMAL PLANE SHEAR STRESS	-0	-0

```
                                MEMBER   11   12  ( CURVED  BAR )                        FREQUENCY          0

RADIUS OF CURVATURE  =  58.125              INCLUDED  ANGLE  =  12.001           REFERENCE TEMPERATURE =        0

               COORDINATES  OF  JOINT  NO.   11   (  50.338    , -29.062    ,           0 )    I  JOINT
               COORDINATES  OF  JOINT  NO.   12   (  43.195    , -38.893    ,           0 )    J  JOINT
               COORDINATES  OF  REFERENCE  JOINT  (         0 ,          0 ,           0 )    O  JOINT

        RESTRAINT  CODES      JOINT   11  ( 0 , 0 , 0 , 0 , 0 , 0 )     JOINT   12  ( 0 , 0 , 0 , 0 , 0 , 0 )

YOUNGS   MODULUS      =  0.3000+08        TORSIONAL  CONSTANT  =  1.3940         DISTRIBUTED  LOADS  1  = -0.8400-01
SHEAR    MODULUS      =  0.1150+08        SHEAR  CONSTANT   1  =          0                           2  = -0.7510
THERMAL  COEFFICIENT  =        0          SHEAR  CONSTANT   2  =          0                           3  =          0
CROSS SECTIONAL AREA  =  0.4450           TEMPERATURE  GRAD 1  =          0                           4  =          0
MOMENT OF INERTIA  1  =  0.6970           TEMPERATURE  GRAD 2  =          0                           5  =          0
MOMENT OF INERTIA  2  =  0.6970           TEMPERATURE AVERAGE  =          0                           6  =          0
ROTATION   OF   AXIS  =        0          WEIGHT  DENSITY      =  0.3220         WEIGHT  OF  MEMBER      =  1.7444

**************************************************** CALCULATIONS ******************************************************

                              DIRECTION 1     DIRECTION 2     DIRECTION 3     DIRECTION      DIRECTION 5     DIRECTION 6

MEMBER LOADS   JOINT   11    -6.9028          1.4892          30.212              0             -0              -0
               JOINT   12     11.441          6.4940         -98.633             -0              0              -0

NORM.  DEFL.   JOINT   11    -0.4570-03      -0.1449-02       0.9237-04          -0             -0              -0
               JOINT   12    -0.1668-02      -0.1210-02       0.[illegible]34-04          -0             -0              -0

NORM.  LOADS   JOINT   11     6.7226         -2.1617          30.212             -0             -0              -0
               JOINT   12    -4.1571         12.482          -98.633             -0             -0              -0

*********************************************** STRESS  CALCULATION  1053 **********************************************

         INPUT CONSTANTS                  TYPE  OF  STRESS                   JOINT   11      JOINT   12

         C1 =  1.7900                     AXIAL  STRESS                     -4.8577          -28.049
         C2 =  1.7900                     IN-PLANE  BENDING  STRESS 1        77.590           253.30
         C3 =  1.7900                     IN-PLANE  BENDING  STRESS 2       -77.590          -253.30
         C4 =  1.7900                     NORMAL PLANE BENDING STRESS 1          -0                 0
         F1 =  1.2840                     NORMAL PLANE BENDING STRESS 2           0                -0
         F2 =  2.2000                     TORSIONAL  STRESS                      -0                -0
         F3 =  2.2000                     IN-PLANE  SHEAR  STRESS            14.790           -9.1456
                                          NORMAL PLANE SHEAR STRESS              -0                -0
```

MEMBER 12 13 (CURVED BAR) FREQUENCY 0

RADIUS OF CURVATURE = 58.125 INCLUDED ANGLE = 12.000 REFERENCE TEMPERATURE = 0

COORDINATES OF JOINT NO. 12 (43.195 , -38.893 , 0) I JOINT
COORDINATES OF JOINT NO. 13 (34.165 , -47.024 , 0) J JOINT
COORDINATES OF REFERENCE JOINT (0 , 0 , 0) 0 JOINT

RESTRAINT CODES JOINT 12 (0 , 0 , 0 , 0 , 0 , 0) JOINT 13 (0 , 0 , 0 , 0 , 0 , 0)

YOUNGS MODULUS	= 0.3000+08	TORSIONAL CONSTANT	= 1.3340	DISTRIBUTED LOADS 1	= -0.1060
SHEAR MODULUS	= 0.1150+08	SHEAR CONSTANT 1	= 0	2	= -0.6210
THERMAL COEFFICIENT	= 0	SHEAR CONSTANT 2	= 0	3	= 0
CROSS SECTIONAL AREA	= 0.4450	TEMPERATURE GRAD 1	= 0	4	= 0
MOMENT OF INERTIA 1	= 0.6970	TEMPERATURE GRAD 2	= 0	5	= 0
MOMENT OF INERTIA 2	= 0.6970	TEMPERATURE AVERAGE	= 0	6	= 0
ROTATION OF AXIS	= 0	WEIGHT DENSITY	= 0.3220	WEIGHT OF MEMBER	= 1.7443

** CALCULATIONS ***

		DIRECTION 1	DIRECTION 2	DIRECTION 3	DIRECTION 4	DIRECTION 5	DIRECTION 6
MEMBER LOADS	JOINT 12	-11.441	-6.4941	98.633	0	-0	-0
	JOINT 13	16.187	12.500	-121.98	-0	0	-0
NORM. DEFL.	JOINT 12	-0.1668-02	-0.1210-02	0.5334-04	-0	-0	-0
	JOINT 13	-0.2133-02	-0.7810-03	-0.1369-04	-0	-0	-0
NORM. LOADS	JOINT 12	4.1570	-12.482	98.633	-0	-0	-0
	JOINT 13	0.5986	20.443	-121.98	-0	-0	-0

** STRESS CALCULATION 1053 **

INPUT CONSTANTS

C1 = 1.7900
C2 = 1.7900
C3 = 1.7900
C4 = 1.7900
F1 = 1.2840
F2 = 2.2000
F3 = 2.2000

TYPE OF STRESS	JOINT 12	JOINT 13
AXIAL STRESS	-28.049	-45.940
IN-PLANE BENDING STRESS 1	253.30	313.28
IN-PLANE BENDING STRESS 2	-253.30	-313.28
NORMAL PLANE BENDING STRESS 1	-0	0
NORMAL PLANE BENDING STRESS 2	0	-0
TORSIONAL STRESS	-0	-0
IN-PLANE SHEAR STRESS	9.1455	1.3169
NORMAL PLANE SHEAR STRESS	-0	-0

MEMBER 13 14 (CURVED BAR) FREQUENCY 0

RADIUS OF CURVATURE = 58.125 INCLUDED ANGLE = 12.00 REFERENCE TEMPERATURE = 0

COORDINATES OF JOINT NO. 13	(34.165	, -47.024	, 0)	I JOINT
COORDINATES OF JOINT NO. 14	(23.642	, -53.100	, 0)	J JOINT
COORDINATES OF REFERENCE JOINT	(0	, 0	, 0)	G JOINT

RESTRAINT CODES JOINT 13 (0 , 0 , 0 , 0 , 0 , 0) JOINT 14 (0 , 0 , 0 , 0 , 0 , 0)

YOUNGS MODULUS	= 0.3000+08	TORSIONAL CONSTANT	= 1.3940	DISTRIBUTED LOADS 1	= -0.1240
SHEAR MODULUS	= 0.1150+08	SHEAR CONSTANT 1	= 0	2	= -0.4650
THERMAL COEFFICIENT	= 0	SHEAR CONSTANT 2	= 0	3	= 0
CROSS SECTIONAL AREA	= 0.4450	TEMPERATURE GRAD 1	= 0	4	= 0
MOMENT OF INERTIA 1	= 0.6970	TEMPERATURE GRAD 2	= 0	5	= 0
MOMENT OF INERTIA 2	= 0.6970	TEMPERATURE AVERAGE	= 0	6	= 0
ROTATION OF AXIS	= 0	WEIGHT DENSITY	= 0.3220	WEIGHT OF MEMBER	= 1.7443

*** CALCULATIONS ***

		DIRECTION 1	DIRECTION 2	DIRECTION 3	DIRECTION 4	DIRECTION 5	DIRECTION 6
MEMBER LOADS	JOINT 13	-16.187	-12.500	121.98	0	-0	-0
	JOINT 14	20.327	16.631	-77.231	-0	0	-0
NORM. DEFL.	JOINT 13	-0.2133-02	-0.7810-03	-0.1369-04	-0	-0	-0
	JOINT 14	-0.1681-02	-0.3457-03	-0.7542-04	-	-0	-0
NORM. LOADS	JOINT 13	-0.5986	-20.443	121.98	-0	-0	-0
	JOINT 14	6.9249	25.334	-77.231	-0	-0	-0

** STRESS CALCULATION 1053 ***

INPUT CONSTANTS	TYPE OF STRESS	JOINT 13	JOINT 14
C1 = 1.7900	AXIAL STRESS	-45.945	-56.930
C2 = 1.7900	IN-PLANE BENDING STRESS 1	313.28	198.34
C3 = 1.7900	IN-PLANE BENDING STRESS 2	-313.28	-198.34
C4 = 1.7900	NORMAL PLANE BENDING STRESS 1	-0	0
F1 = 1.2840	NORMAL PLANE BENDING STRESS 2	0	-0
F2 = 2.2000	TORSIONAL STRESS	-0	-0
F3 = 2.2000	IN-PLANE SHEAR STRESS	-1.3169	15.235
	NORMAL PLANE SHEAR STRESS	-0	-0

MEMBER 14 15 (CURVED BAR) FREQUENCY 0

RADIUS OF CURVATURE = 58.125 INCLUDED ANGLE = 12.000 REFERENCE TEMPERATURE = 0

COORDINATES OF JOINT NO. 14 (23.642 , -53.100 , 0) I JOINT
COORDINATES OF JOINT NO. 15 (12.085 , -56.855 , 0) J JOINT
COORDINATES OF REFERENCE JOINT (0 , 0 , 0) O JOINT

RESTRAINT CODES JOINT 14 (0 , 0 , 0 , 0 , 0 , 0) JOINT 15 (0 , 0 , 0 , 0 , 0 , 0)

YOUNGS MODULUS =	0.3000+08	TORSIONAL CONSTANT =	1.3940	DISTRIBUTED LOADS 1 =	-0.1360
SHEAR MODULUS =	0.1150+08	SHEAR CONSTANT 1 =	0	2 =	-0.2870
THERMAL COEFFICIENT =	0	SHEAR CONSTANT 2 =	0	3 =	0
CROSS SECTIONAL AREA =	0.4450	TEMPERATURE GRAD 1 =	0	4 =	0
MOMENT OF INERTIA 1 =	0.6970	TEMPERATURE GRAD 2 =	0	5 =	0
MOMENT OF INERTIA 2 =	0.6970	TEMPERATURE AVERAGE =	0	6 =	0
ROTATION OF AXIS =	0	WEIGHT DENSITY =	0.3200	WEIGHT OF MEMBER =	1.7444

•• CALCULATIONS ••

			DIRECTION 1	DIRECTION 2	DIRECTION 3	DIRECTION 4	DIRECTION 5	DIRECTION 6
MEMBER LOADS	JOINT	14	-20.327	-16.631	77.231	0	-0	-0
	JOINT	15	23.133	19.280	50.160	-0	0	-0
NORM. DEFL.	JOINT	14	-0.1681-02	-0.3457-03	-0.7542-04	-0	-0	-0
	JOINT	15	-0.6543-03	-0.7362-04	-0.8751-04	-0	-0	-0
NORM. LOADS	JOINT	14	-6.9249	-25.334	77.231	-0	-0	-0
	JOINT	15	14.049	26.636	50.160	-0	-0	-0

•• STRESS CALCULATION 1053 ••

INPUT CONSTANTS	TYPE OF STRESS	JOINT 14	JOINT 15
C1 = 1.7900	AXIAL STRESS	-56.930	-50.857
C2 = 1.7900	IN-PLANE BENDING STRESS 1	198.34	-128.82
C3 = 1.7900	IN-PLANE BENDING STRESS 2	-198.34	128.82
C4 = 1.7900	NORMAL PLANE BENDING STRESS 1	-0	0
F1 = 1.2840	NORMAL PLANE BENDING STRESS 2	0	-0
F2 = 2.2000	TORSIONAL STRESS	-0	-0
F3 = 2.2000	IN-PLANE SHEAR STRESS	-15.235	30.908
	NORMAL PLANE SHEAR STRESS	-0	-0

MEMBER 15 16 (CURVED BAR) FREQUENCY 0

RADIUS OF CURVATURE = 58.125 INCLUDED ANGLE = 12.000 REFERENCE TEMPERATURE = 0

COORDINATES OF JOINT NO. 15 (12.085 , -56.855 , 0) I JOINT
COORDINATES OF JOINT NO. 16 (0 , -58.125 , 0) J JOINT
COORDINATES OF REFERENCE JOINT (0 , 0 , 0) 0 JOINT

RESTRAINT CODES JOINT 15 (0 , 0 , 0 , 0 , 0 , 0) JOINT 16 (0 , 0 , 0 , 0 , 0 , 0)

YOUNGS MODULUS =	0.3000+08	TORSIONAL CONSTANT =	1.3343	DISTRIBUTED LOADS 1 =	-0.1430
SHEAR MODULUS =	0.1150+08	SHEAR CONSTANT 1 =	0	2 =	-0.9700-01
THERMAL COEFFICIENT =	0	SHEAR CONSTANT 2 =	0	3 =	0
CROSS SECTIONAL AREA =	0.4450	TEMPERATURE GRAD 1 =	0	4 =	0
MOMENT OF INERTIA 1 =	0.6970	TEMPERATURE GRAD 2 =	0	5 =	0
MOMENT OF INERTIA 2 =	0.6970	TEMPERATURE AVERAGE =	0	6 =	0
ROTATION OF AXIS =	0	WEIGHT DENSITY =	0.3220	WEIGHT OF MEMBER =	1.7444

** CALCULATIONS **

		DIRECTION 1	DIRECTION 2	DIRECTION 3	DIRECTION 4	DIRECTION 5	DIRECTION 6
MEMBER LOADS	JOINT 15	-23.133	-19.280	-50.160	0	-0	-0
	JOINT 16	24.124	21.131	264.83	0	-0	0
NORM. DEFL.	JOINT 15	-0.6543-03	-0.7362-04	-0.8751-04	0	0	0
	JOINT 16	0	0	0	0	0	0
NORM. LOADS	JOINT 15	-14.049	-26.636	-50.160	-0	-0	-0
	JOINT 16	21.131	24.124	264.83	0	0	0

** STRESS CALCULATION 1053 **

INPUT CONSTANTS	TYPE OF STRESS	JOINT 15	JOINT 16
C1 = 1.7900	AXIAL STRESS	-50.357	-54.211
C2 = 1.7900	IN-PLANE BENDING STRESS 1	-128.82	-680.13
C3 = 1.7900	IN-PLANE BENDING STRESS 2	128.82	680.13
C4 = 1.7900	NORMAL PLANE BENDING STRESS 1	-0	-0
F1 = 1.2840	NORMAL PLANE BENDING STRESS 2	0	0
F2 = 2.2000	TORSIONAL STRESS	-0	0
F3 = 2.2000	IN-PLANE SHEAR STRESS	-30.708	46.489
	NORMAL PLANE SHEAR STRESS	-0	0

** DEFLECTIONS **

JOINT	DIRECTION 1	DIRECTION 2	DIRECTION 3	DIRECTION 4	DIRECTION 5	DIRECTION 6
1	0.	-9.1534-04	0.	-0.	0.	-0.
2	3.1566-05	-7.1263-04	3.2207-05	-0.	-0.	-0.
3	1.9207-04	-2.3137-04	4.7139-05	-0.	-0.	-0.
4	4.4399-04	2.1976-04	3.2295-05	-0.	-0.	-0.
5	5.1661-04	3.3237-04	-1.5735-05	0.	0.	0.
6	0.	0.	-8.7655-05	0.	0.	0.
7	-1.1453-03	-5.5320-04	-1.0322-04	0.	-0.	0.
8	-2.0476-03	-7.9392-04	-4.3141-05	-0.	0.	-0.
9	-2.0990-03	-8.3548-04	3.3395-05	0.	0.	0.
10	-1.3593-03	-1.0187-03	8.5496-05	0.	-0.	-0.
11	-3.2852-04	-1.4830-03	9.2368-05	0.	0.	-0.
12	4.2959-04	-2.0152-03	5.3344-05	0.	-0.	-0.
13	6.2210-04	-2.1850-03	-1.3687-05	0.	0.	-0.
14	3.6793-04	-1.6764-03	-7.5417-05	0.	0.	-0.
15	6.4033-05	-6.5533-04	-8.7508-05	0.	0.	-0.
16	0.	0.	0.	0.	0.	0.

SUMMATION OF FORCES

JOINT	DIRECTION 1	DIRECTION 2	DIRECTION 3	DIRECTION 4	DIRECTION 5	DIRECTION 6
1	-4.3116+00	2.8610-06	-6.0547+01	0.	0.	0.
2	-9.6560-06	1.9073-06	1.9073-05	0.	0.	0.
3	3.8594-06	-5.2452-06	-2.1027-05	0.	0.	0.
4	4.1723-06	-2.7418-06	-1.2399-05	0.	0.	0.
5	4.1723-06	5.3644-06	-4.7684-06	0.	0.	0.
6	-1.9812+01	7.6522+01	-9.5367-06	0.	0.	0.
7	-4.2915-06	8.1062-05	3.5477-04	0.	0.	0.
8	-2.2173-05	7.6294-06	1.2589-04	0.	0.	0.
9	5.2452-06	8.1062-05	3.4332-05	0.	0.	0.
10	-1.9312-05	-2.6226-06	-2.3842-05	0.	0.	0.
11	-1.4305-05	-6.4373-06	-4.1962-05	0.	0.	0.
12	2.2650-05	-3.2306-05	5.7220-06	0.	0.	0.
13	-3.6955-05	-6.1989-06	-6.4850-05	0.	0.	0.
14	-2.9325-05	-1.4305-05	-1.8501-04	0.	0.	0.
15	8.8215-06	9.0599-06	2.2888-05	0.	0.	0.
16	2.4124+01	2.1131+01	2.6483+02	0.	0.	0.

TOTAL WEIGHT OF STRUCTURE = 26.165

REACTION CHECK

$\Sigma R = 2(76.522) + 2(21.131) = 195.306$ lbs

WEIGHT OF TORUS = 52.33 lbs

WEIGHT OF MIRROR = 143.345 lbs

W_{TOTAL} = 195.675 lbs

OK

00013 LINES OUTPUT.

$$**BRUNNER 557044P7306M12 143654 TIME 13266 DATE 03/31/65 $$

APPENDIX N

MATERIALS, SPECIAL TOOLING

AND

TEST EQUIPMENT

BLANK PAGE

MATERIALS

Item Description	Source
9-1/2 Foot Concentrator Shipping Fixture & Torus Ring	Cryochem. Engineering & Fabrication Co., Boyertown, Pa.
Epoxy Resins	MMM Company Newark Chemical Co. Newark, New Jersey
	Ciba Corporation Fair Lawn, New Jersey
Epoxy Catalyst	Union Carbide & Carbon Co. Moorestown, New Jersey
Epoxy Dye	Mathison Chemical Co. East Rutherford, New Jersey
Epoxy Wetting Agent	General Electric Co. Waterford, New York
Epoxy Filler	Tamms Industries Philadelphia, Pa.
NOPCO Foam H-110-for bonding nickel master & backup structure	NOPCO Chemical Co. North Arlington, New Jersey
Fairoprene Cement 4678 for Sealing backup structure surface	E.I. Dupont Denemours Wilmington, Del.
Strippable lacquer for protection of mirror and master	MMM Company Bristol, Pa.
French Polishing Cotton	International GE Company Paris, France
Lithium Aluminum Hydride for Al. Mirror Electroform	Metal Hydrides Inc. Beverly, Mass.
Anhydrous Ether for Al. Mirror Electroform	Scientific Glass Co.
Epoxy Bondmaster for Torus to Mirror Bonding	Adhesive Products Div. Pittsburgh Plate Glass Bloomfield, New Jersey

Mold & Cover Primers & Sealers

Item Description	Source
Pentamide #815	Ciba Products Summit, New Jersey
Araldite #571	Ciba Corporation Philadelphia, Pa.
Cabosil	Cabat Corporation Boston, Mass.

SPECIAL TOOLING OR EQUIPMENT

Spincasting Table, Drive & Speed Control Mechanism	Described in Reference 2-1
Standby Equipment	Described in Reference 2-1
Overhead Workway	Described in Reference 2-1
Metering & Mixing Equipment	Described in Reference 2-1
Aluminum Torus Ring (30")	Chalmers & Kubeck Philadelphia, Pa.
Schmidt Stress Cell	GE Proprietary Development
Osram 75 Watt Point Light Source	Peck Laboratories Berkeley, Calif.
76X2091 MM Convex Lens	Edmond Scientific Co. Barrington, New Jersey
Ramsdem Eyepiece	"
Eyepiece Adapter	"
Cross Hair Reticle 10 MM 100 divisions	"

SUBCONTRACTOR

Nickel Master and Nickel Mirror Electroforming Vendor	Bart Manufacturing Co. Newark, New Jersey
Mirror Coating Vendor	Liberty Mirror Division Brackenridge, Pa.
Kanigen Electroless Coating for 30" Ni master	Greenwald Plating Co. Chicago, Ill.