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FACILITY FORM 602

N65-21336 (ACCESSION NUMBER)

(THRU) 1

38 (PAGES)

(CODE)

CR-57977 (NASA CR OR TMX OR AD NUMBER)

14 (CATEGORY)

GPO PRICE $ __________

OTS PRICE(S) $ __________

Hard copy (HC) __________

Microfiche (MF) __________

OPTICS TECHNOLOGY, INC.

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FINAL TECHNICAL REPORT

FIBER OPTICS SYSTEMS FOR PLANETARY SCAN SYSTEM

Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, California

This work was performed for the Jet Propulsion Laboratory, California Institute of Technology, sponsored by the National Aeronautics and Space Administration under Contract NAS7-100.

Contract No. 950586

Submitted By

OPTICS TECHNOLOGY, INC.
248 Harbor Boulevard
Belmont, California

January, 1965

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I. INTRODUCTION

This is the final report on JPL Contract No. 950586 entitled "Fiber Optics Systems for Planetary Scan System". The goals of this program were to provide a simple, reliable and lightweight optical sighting and tracking system for the Mariner B spacecraft. A quadratured silicon detector which fed a balanced bridge network provided the reference axes of the optical system and was supplied, complete with immediately associated circuitry, by JPL for incorporation into the final instrument.

It was a specific aim of this program to incorporate a fiber optics cone and a simple, readily available photographic lens into the final system to obviate the need for a large and expensive objective.

II. TECHNICAL DISCUSSION

A. Systems Specifications

At the outset of the program the broad specifications of the finished system were as follows:

Effective Focal Length	10 mm ± 0.5 mm
Effective F/ratio	F/0.7
Semi-Field Angle	25° ± 2°
Resolution at Output Plane	20 lp/mm
Geometric Distortion	± 5 per cent across full field
Transmission of Fiber Optics	Not less than 70 per cent

Transmission Range	0.5 - 1.1 microns
Overall Weight	1 lb, max.
Overall Length	6 inches, max.
Overall Diameter	2 inches, max.

A number of ancilliary specifications concerning materials, techniques, quality control and acceptance tests, etc., were also outlined as indicated in JPL Specification No. 31194. The sources for these specifications were the relevant portions of JPL Documents Nos. 20016, 20061, 30228, 30229, 30236, 30250, MC-3-120 and 32-150. Interface drawings were supplied by JPL and these governed some aspects of the basic system design.

B. System Design

1. General

An outline drawing of the overall system is shown in Figure 1. As can be seen, the entire optics are shielded by an outer cylinder to preserve thermal equilibrium. The main support member, which also contains the detector and printed circuitry associated with the bridge network, was designed and fabricated in accordance with drawings supplied by JPL.

2. Optical Design

The optical system design is shown in Figure 2. After a thorough survey of all available photographic lenses an F/2.3, 30 mm focal length Bausch & Lomb

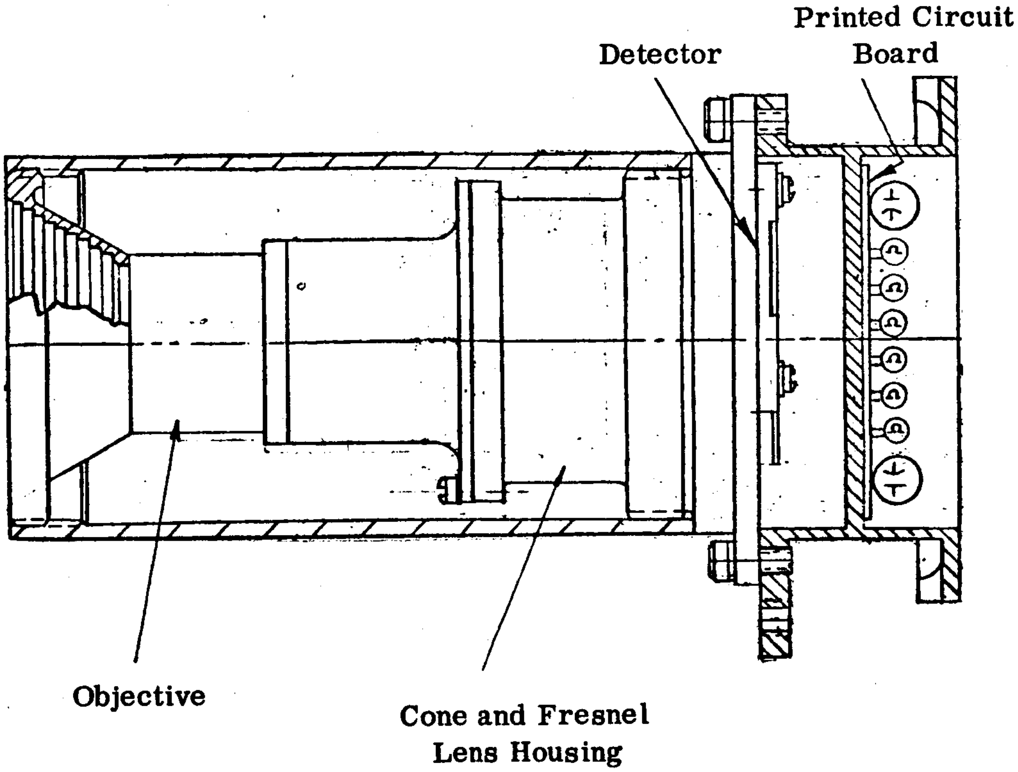

Figure 1 - Overall System Outline

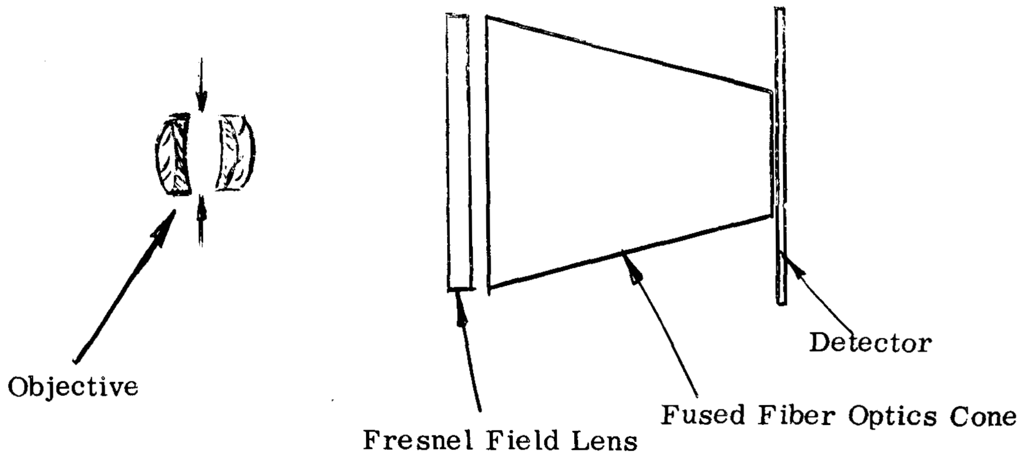

Figure 2 - Basic Optical System Design

"Baltar" was selected as being a most suitable objective. The basic design of this lens is shown in Figure 3 and it is seen to be based on the Gauss symmetrical doublet, a system which, because of its essentially concentric design, gives high speed, wide field angle and yet maintains high resolution over the field. This particular lens contains two cemented doublet components and it was necessary to separate these doublets prior to recementing with JPL approved cements for outer space environment. Separation was accomplished after removal of the doublets from their lens mounts by a cooling technique which proved to be 100 per cent effective. The initial breakage experienced with this technique was traced to slight tool marks which were made upon the lenses during their removal from their mounts. Recementing of the lenses was performed at Fairchild Camera and Instrument Corporation at 2718 Griffith Park Boulevard in Los Angeles who were, at the time, working on a similar, related JPL project.

The basic lens mount in which the "Baltar" was received was in the meantime stripped down while the lenses were being cemented and the iris diaphragm removed. The outer surface of the lens mount was reworked to remove unnecessary weight and markings while the internal parts were modified so that the doublets could be remounted after recementing. The final lens assembly is shown in Figure 4.

The use of a 30 mm focal length lens dictated the design of the fiber optics cone. For an effective focal length of 10 mm, a 3 : 1 cone ratio is required. It can be shown that, when fiber materials that are capable of giving a fiber N.A. of unity are used, a 3 : 1 cone will not be able to effectively capture the lower rim

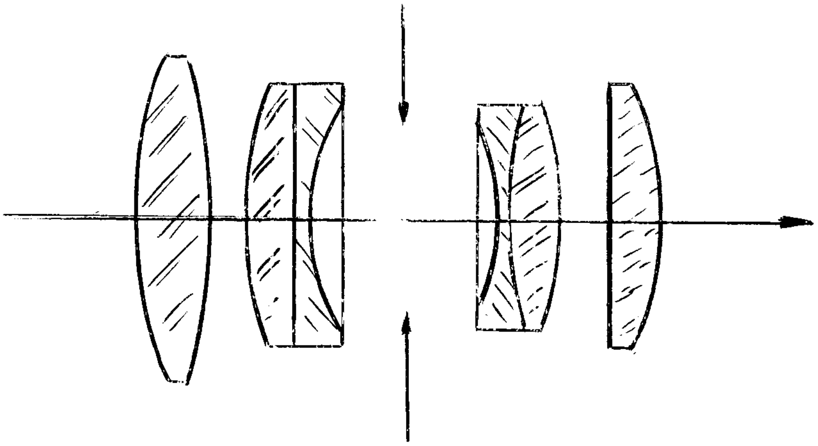

Figure 3 - Basic "Baltar" Design

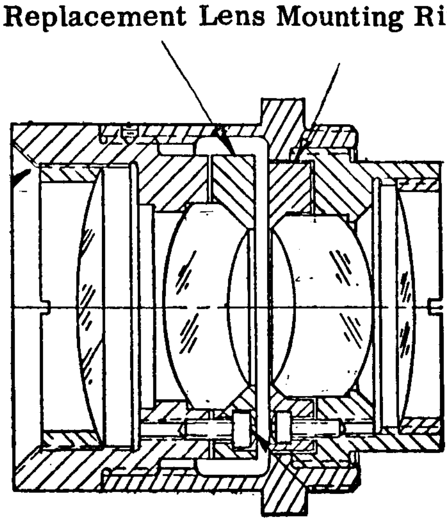

Figure 4 - Final Modified "Baltar" Assembly

ray from a 30mm F/2.3 lens. However, such a cone is easily capable of transmitting an F/2.3 input on-axis, and excessive vignetting for off-axis points could be reduced with a field lens of suitable characteristics.

In calculating the design of this field lens, several basic parameters must be considered. It is sufficient for the field lens to divert the lower rim ray of the furthest off-axis point so that it lies within the cone of acceptance of the extreme peripheral fiber, as indicated in Figure 5. To bring the principal rays from the objective lens parallel to the optical axis of the system, a 30 mm focal length F/1 field lens is required. The use of an ordinary plano-convex lens would result in a component of considerable bulk and weight which, due to its thickness, would introduce a large amount of distortion and field curvature. Thus, rather than use a conventional lens, it was decided that a Fresnel lens would be more suitable.

In the fabrication of this lens, a master was designed and fabricated by the Bolsey Corporation, and initial experiments were made using a type approved plastic, called "Zerlon" which is manufactured by the Dow Chemical Corporation. A replication technique was tried using Zerlon dissolved in a number of solvents ranging from acetone to the ethers. Much difficulty was experienced with all of these solutions, due to the tendency for the liquid to first form a thick skin and then to trap bubbles beneath it. The experiments were discontinued after subsequent discussions with the Bolsey Corporation, who had in the meantime experimented with samples of Zerlon and felt that an adaptation of their present pressing techniques would allow them to fabricate the Fresnel lenses directly.

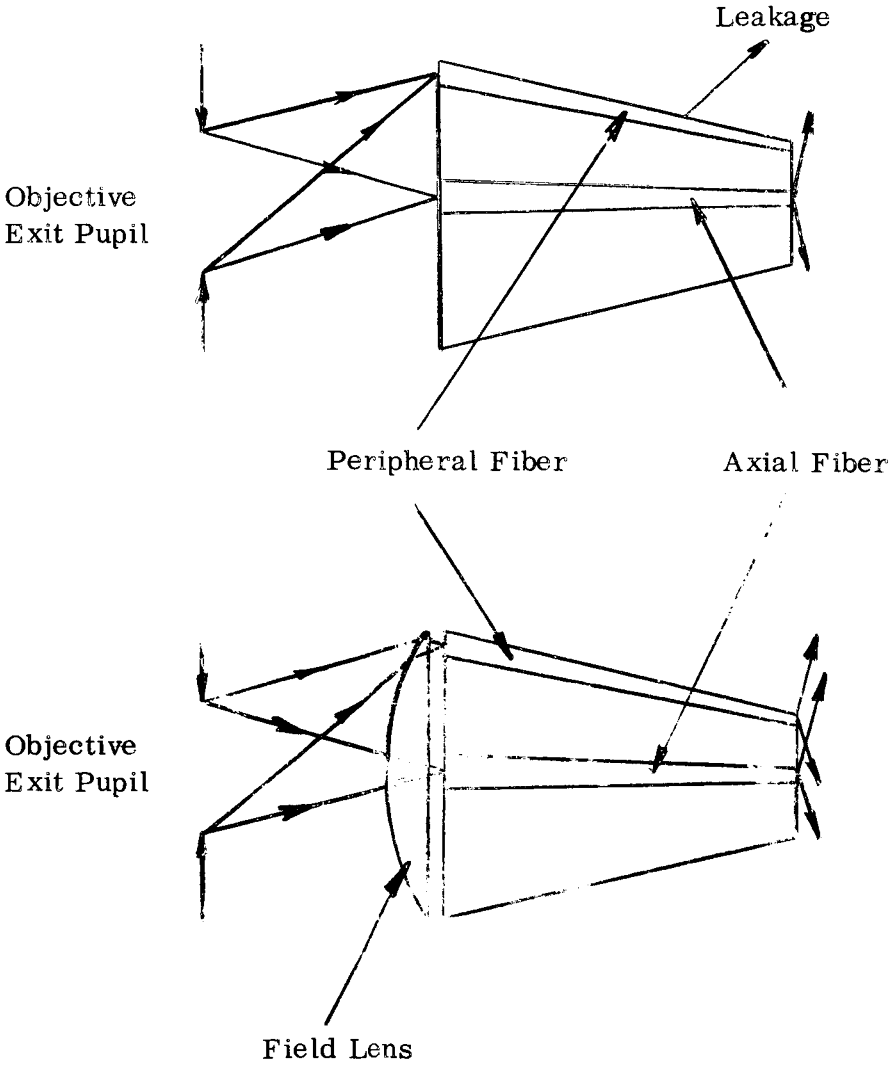

Figure 5 - Illustrating the Effect of Field Lenses When used in Conjunction with Fiber Optics Cones

Fresnel lenses of adequate quality were eventually received from Bolsey in time for incorporation into the first delivery model of the optical probe system.

The lenses were designed and fabricated to the following specifications:

1. Diameter (Active Area)	30 mm
2. Outside Diameter	32 mm
3. Thickness	1 mm
4. Focal Length	30 mm
5. Spherical Aberration	None

3. Cones

The heart of the overall system is the fiber optics cone and the major part of the developmental effort was directed toward the production of high quality components. While many difficulties were encountered in the fabrication of high quality cones, several items were eventually produced which were in fact capable of a higher resolution than initially outlined in the system specification.

Several methods for the production of conical elements were tried and, in all, it was found that a major problem was the elimination of air entrapments between the multiple fibers used in the fabrication of the final assembly. In general, in all the methods used, it was necessary to perform the final steps in the coning process at a temperature which is significantly higher than that at which the multiple fibers that form the assembly were produced. As a result, minor air entrapments within the multiple fiber, insignificant in themselves, could expand to many times their original size, thus causing major blemishes within the fiber optics cone. This effect was most serious in the first technique used for cone fabrication in which a pre-formed boule was taken and drawn down under heat to form a "double" cone as shown in Figure 6. The original boule had, in this case, been originally formed at low temperature and high pressure, resulting in a high quality optical component. However, the small air entrapments inadvertently contained within the boule are at a high pressure and, as soon as the glasses soften, could expand to many times their original size.

Various techniques were tried to eliminate this fault, including vacuum processing of the original boule; however, it was found that not only did atmospheric entrapments exist but there was a possibility of the formation of pockets of gases from gases that were dissolved in the glasses during their early formation as well as from gases absorbed on the surface of the fibers.

It was eventually found that a forming process in which the entire cone was fabricated under continuously drawn vacuum would lead to high quality cones; this is the method which is currently being used to produce these items. In this process, multiple fibers are assembled in a suitably pre-formed glass tube and heated in a cylindrical furnace mounted on a glass lathe. Fusion is initially performed by the combined action of heat and vacuum and is caused to occur progressively along the boule length so that the gases are driven out to the continuously evacuated portion of the glass tube. After fusion, coning is immediately effected by local heating in the center of the boule and the application of longitudinal tension. A slow annealing cycle completes the coning process.

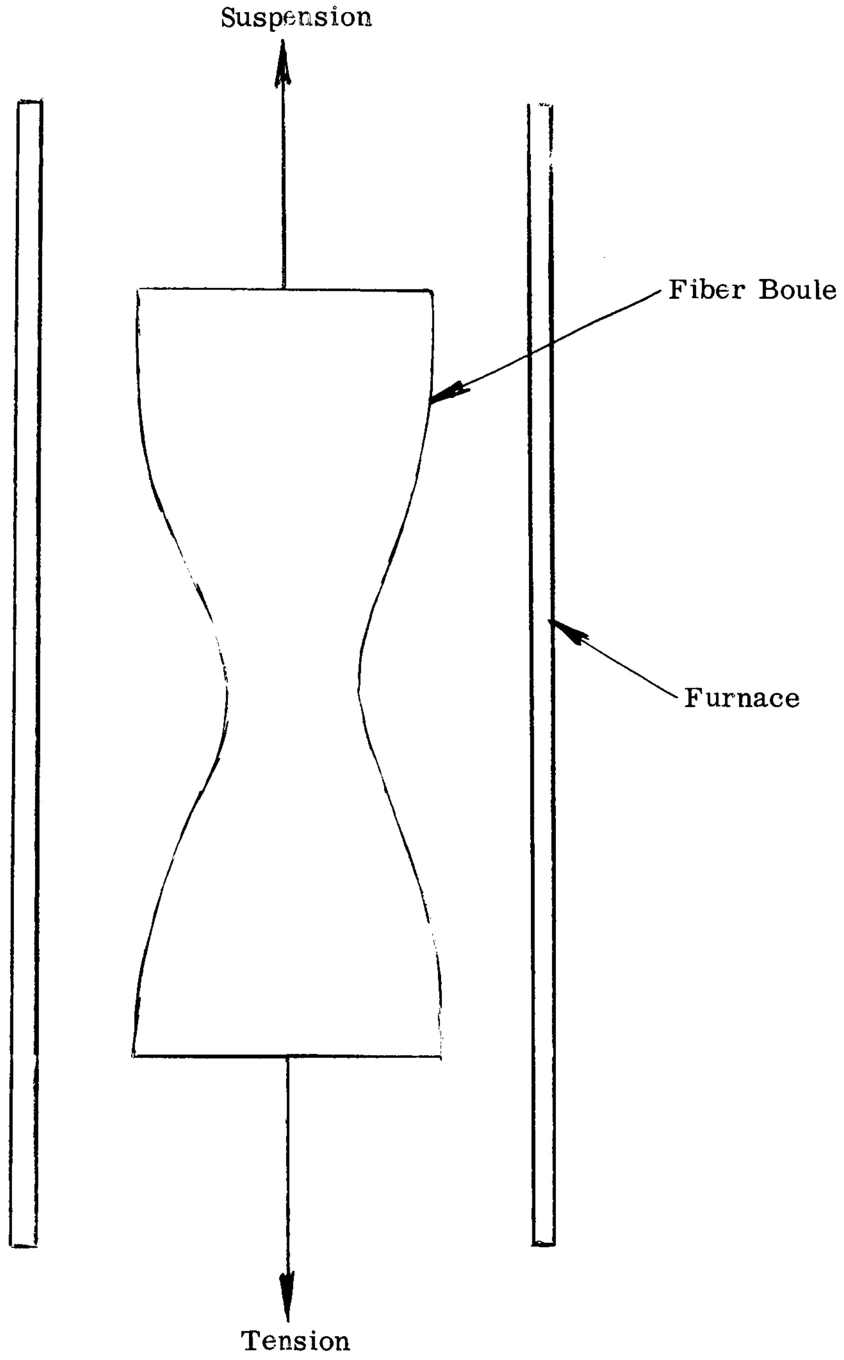

Figure 6 - Double Cone Fabrication from Pre-Formed Cylindrical Boule

4. Mechanical Design

There were several unusual features of the mechanical design necessitated by the use of fiber optics cones in the overall system. The techniques used for cone fabrication precluded a guarantee of either a specific length for each cone or exact concentricity between the input and output faces. Thus, it was necessary to design the system to allow for these features and each unit was, to some extent, custom-made to suit a particular fiber optics cone.

In addition to this feature, the cone housing, which was the most massive portion of the overall system, had to withstand vibrational, shock and thermal environmental tests according to the JPL specifications. The basic design of the cone housing is shown in Figure 7 which, while being the final unit design, differs in only very minor details from the initial design selected. Environmental tests performed on early units and fiber optics cones verified that the basic design was adequate and the final unit design was essentially identical.

Because the cones were not of standard configuration, each cone housing was made in conjunction with a specific cone. The detector mounting assembly was also designed to allow considerable latitude in position to compensate for any lack in concentricity between the faces of the cone.

The procedure for the assembly of this portion of the unit was to first position the detector in its yoke so that the etched cross on its surface was aligned with the yoke axis. Minor deviation in the perfection of the surface quadrature on the detector made this procedure necessary. Once located, the detector was cemented into place with a type approved cement. The second step was to align

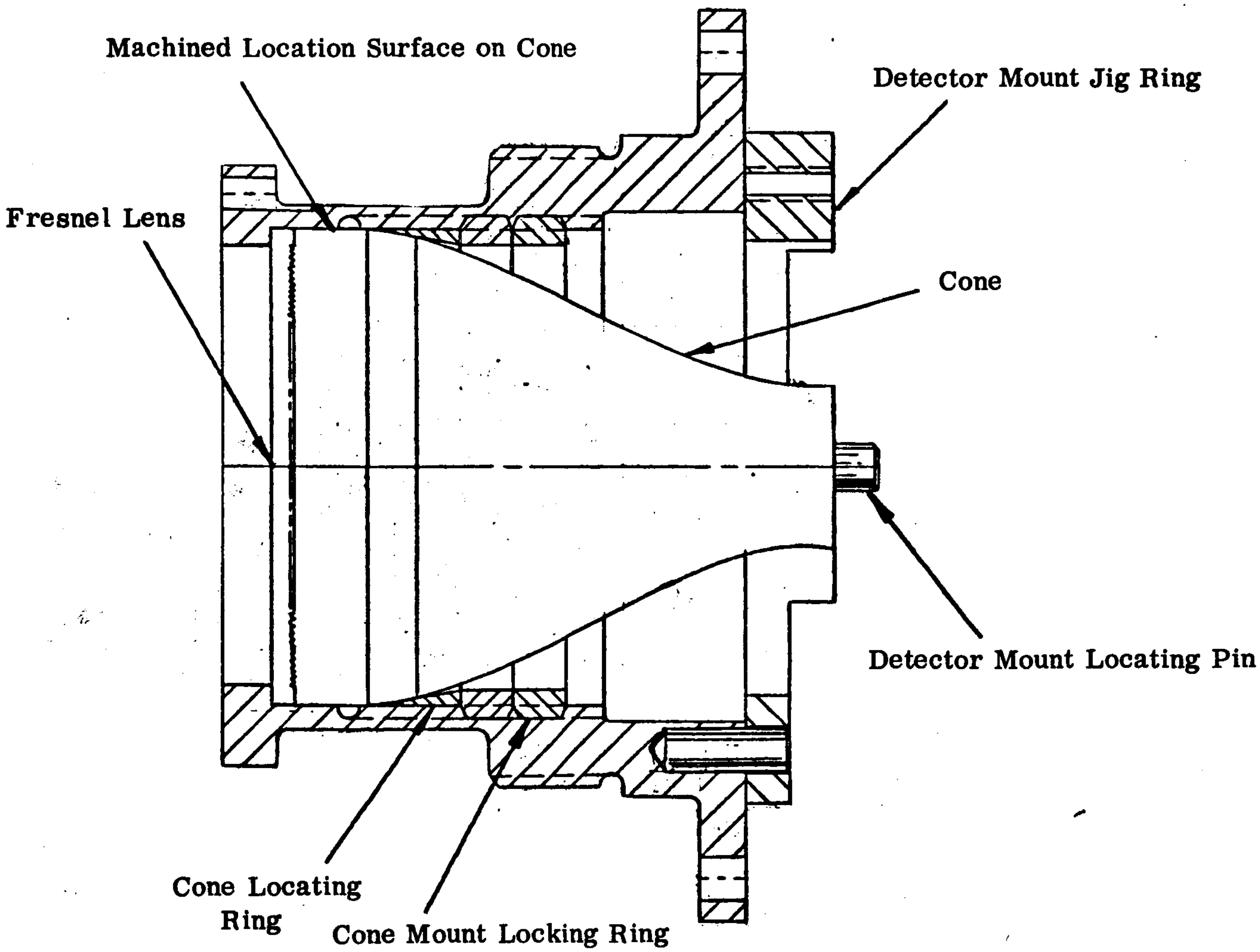

Figure 7 - Cone Housing Assembly

a master locating ring on the cone housing in such a way that its center was positioned with respect to the optical axis of the cone. A reticle which was placed over the input face of the cone provided this datum and the locating ring could be clamped and pinned into place. Once this was done, it was no longer possible to disassemble the unit without destroying the alignment. Apparatus used for this assembly is shown schematically in Figure 8 and pictorially in Figures 9, 10 and 11.

The remainder of the system assembly was entirely straightforward and followed standard type-approved procedures.

5. System Tests - Optical

The first system supplied to JPL has a low resolution cone; subsequent units were fitted with high resolution cones. With the exception of the first unit, each unit was nominally identical and, for the sake of brevity, a description of system tests on only one of these latter units is presented. Only in the first unit are significant deviations discernible and these are noted when applicable.

By and large, all the major specifications were met and in some cases exceeded. The required field angle, effective focal length, effective F/ratio, weight and physical dimensions were as requested and outlined in Section II.A, "Systems Specifications" in this report. The spectral transmission range of the entire unit also fell within the required limits although this measurement was based on the transmission of individual components rather than a completed system. Curves showing these individual transmissions are illustrated in

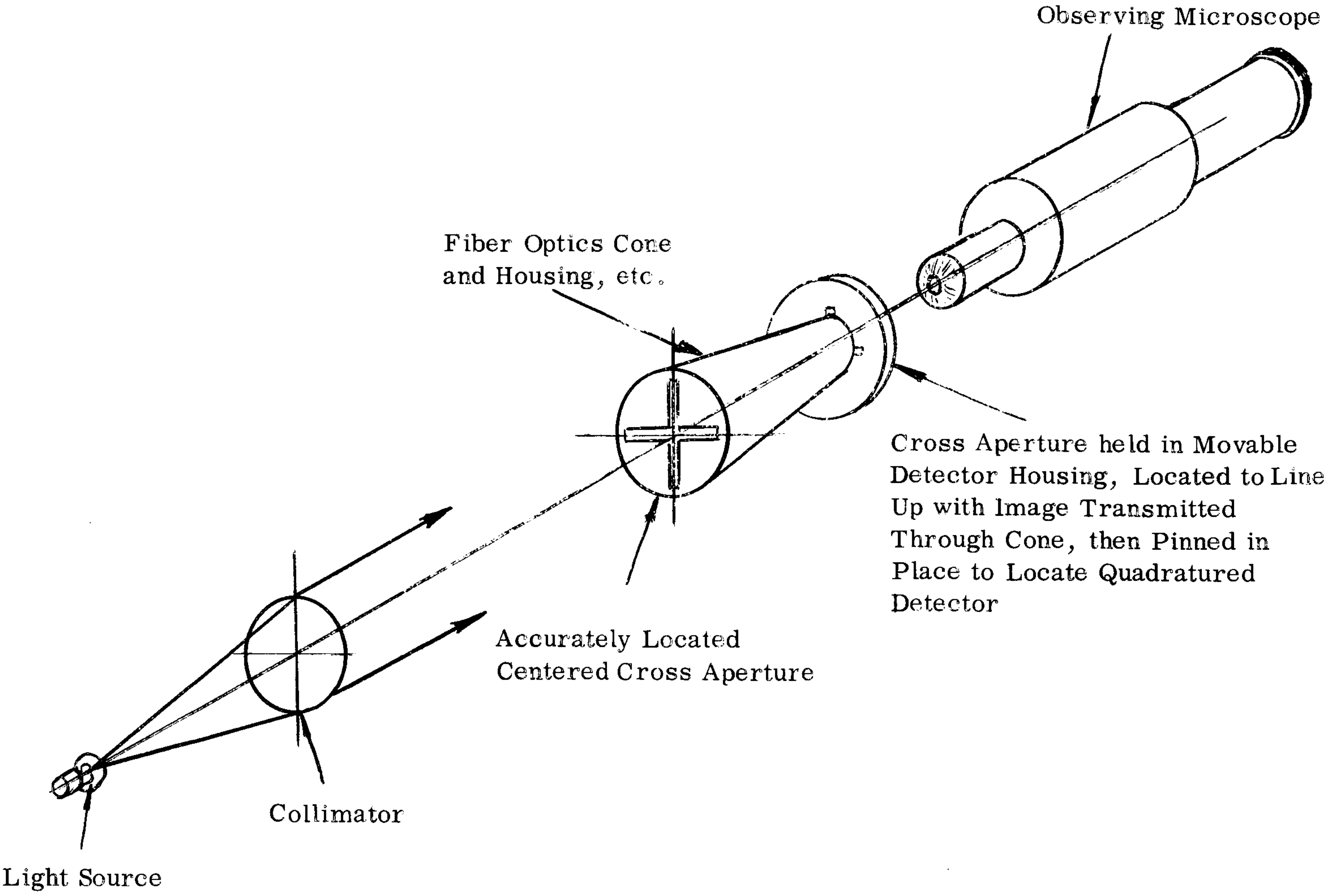

Figure 8 - Basic Alignment Procedure

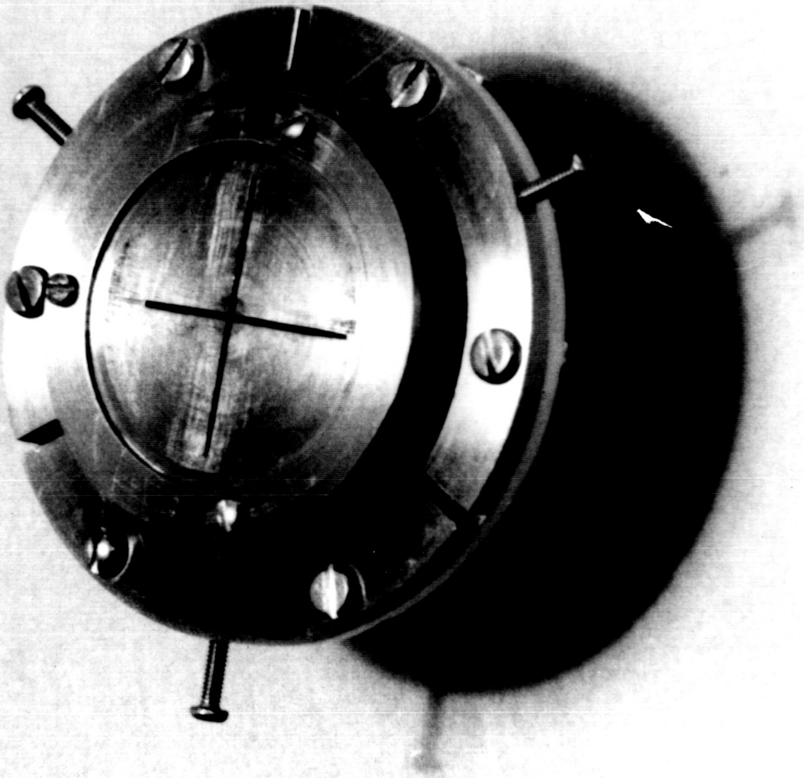

Figure 9 - Assembly Prior to Alignment

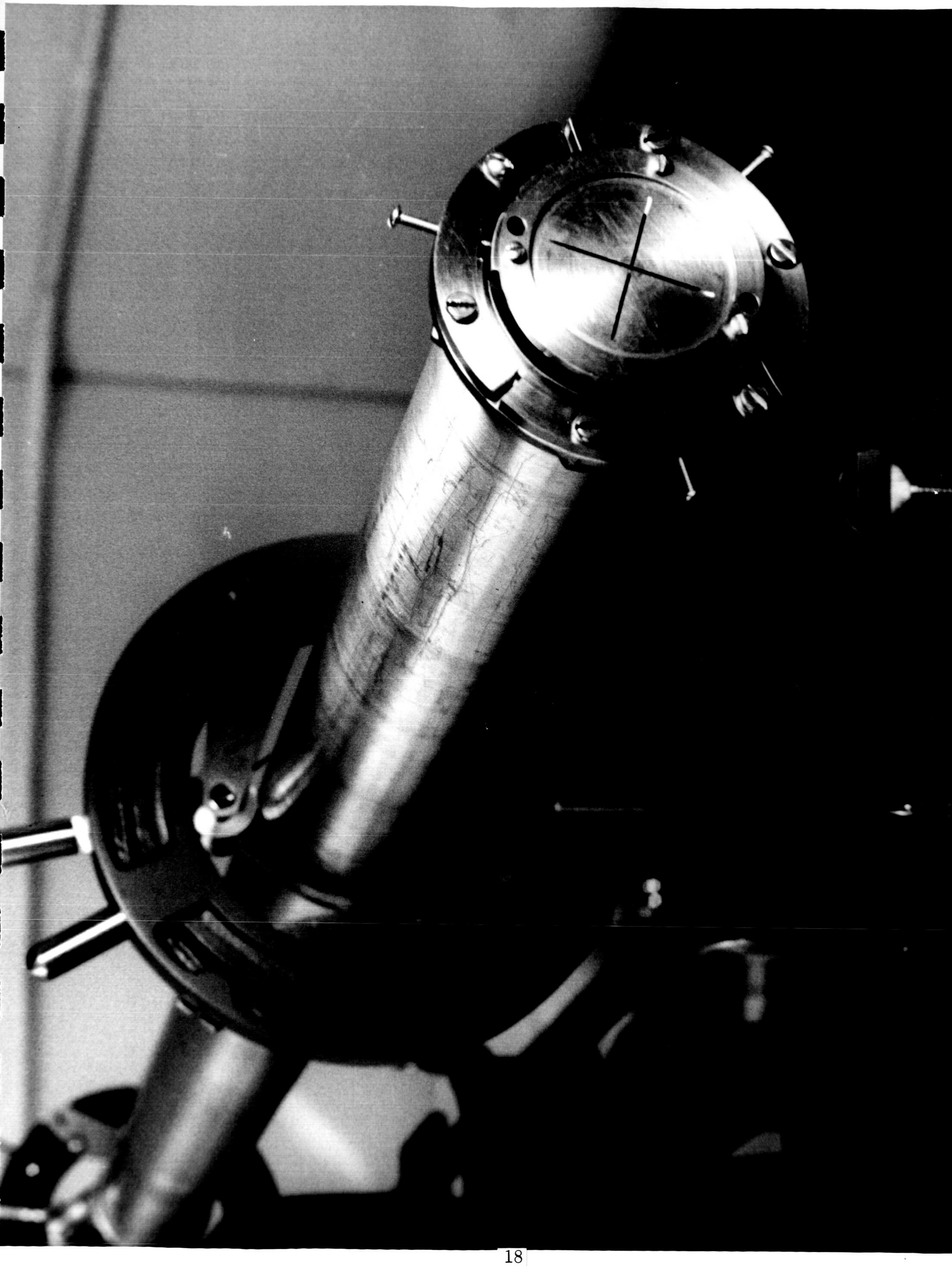

Figure 10 - Unit Assembled in Alignment Jig

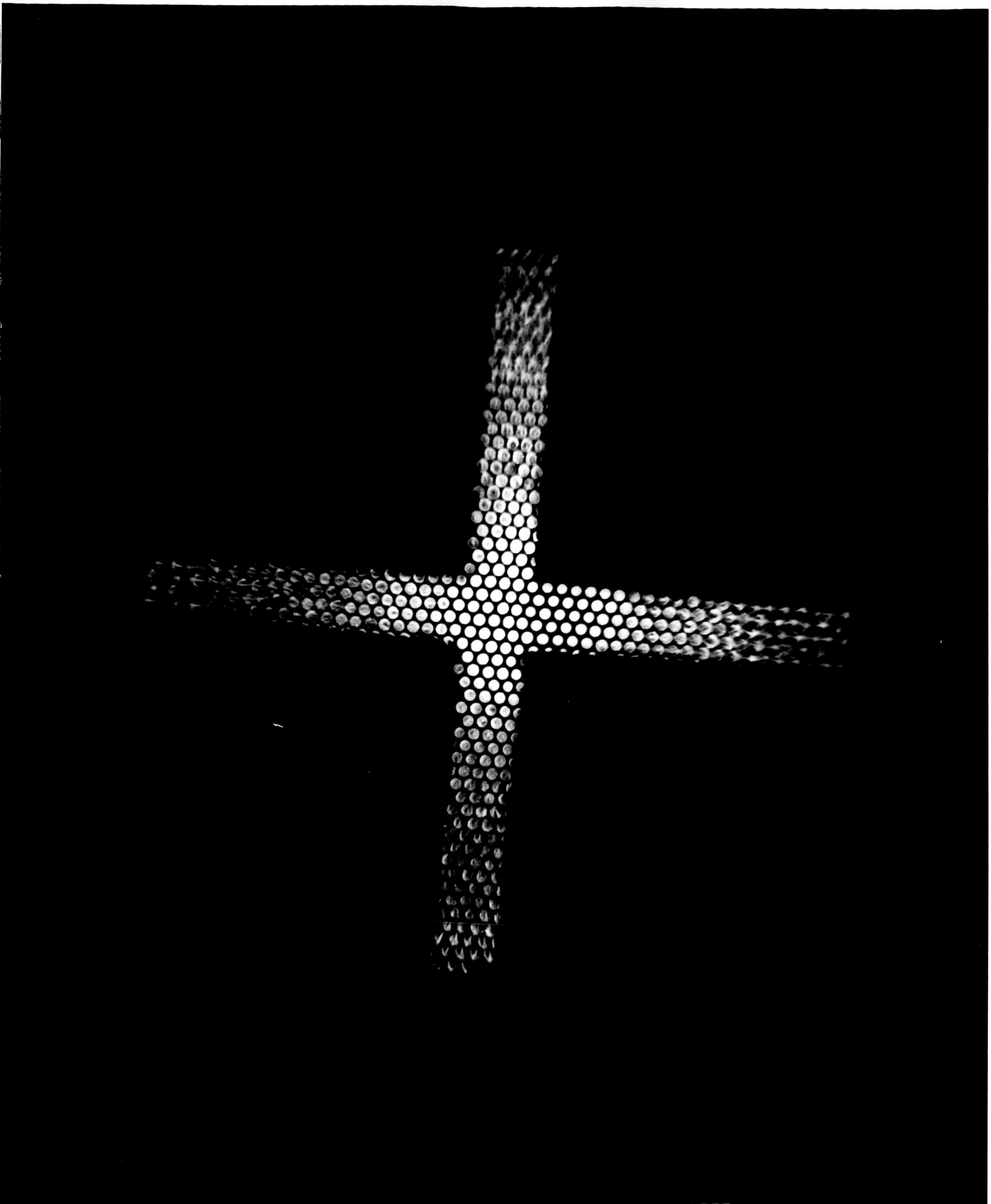

Figure 11 - Appearance at Output of Alignment Jig When Unit is Correctly Aligned

Figures 12, 13 and 14, and the computed overall system transmission is shown in Figure 15.

Vignetting curves for the objective alone and in combination with the cone and Fresnel lens are shown in Figure 16, where it can be seen that the cone/Fresnel lens combination does, in fact, eliminate the vignetting which is apparent in the cone alone. This particular measurement was not made on the first unit supplied to JPL as the necessary equipment was not at that time available; however, there were no visual indications of vignetting.

The resolution of the entire system was tested using standard NBS resolution charts. In the case of the later units, the overall system resolution was well within the required limits, while for the first unit it was considerably lower. This first unit had a cone fabricated from large fibers and was only capable of an overall resolution of about 3 line pairs per millimeter. Later units could resolve well in excess of 30 to 40 line pairs per millimeter.

The overall system transmission which determines the effective T/stop was measured on the same apparatus as was used for vignetting measurements. It was found that, due to minor irregularities within the individual cones, the transmission measurements varied both from cone to cone and within cones themselves. As soon as the image size upon the input face of the cone exceeded several fiber diameters (fiber diameter $\simeq$ 7 microns) the effect of the irregularities became less noticeable and integrated transmission measurements varied from about 45 to 55 per cent. As a result of this somewhat lower than anticipated cone transmission, the system T/stop was somewhat in excess of unity and ranged from

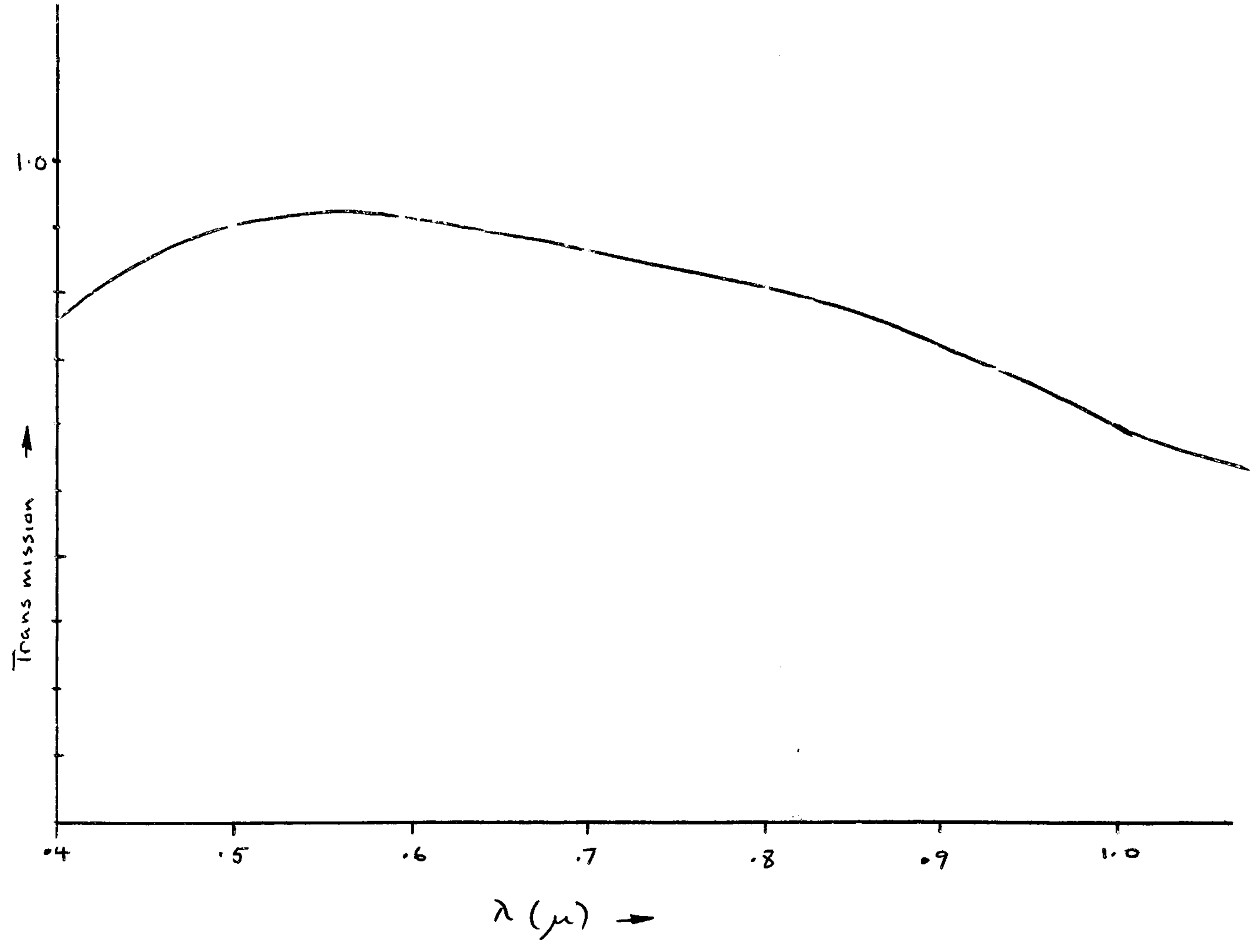

Figure 12 - Measured Transmission of "Baltar" Lens
(Includes Reflection Losses)

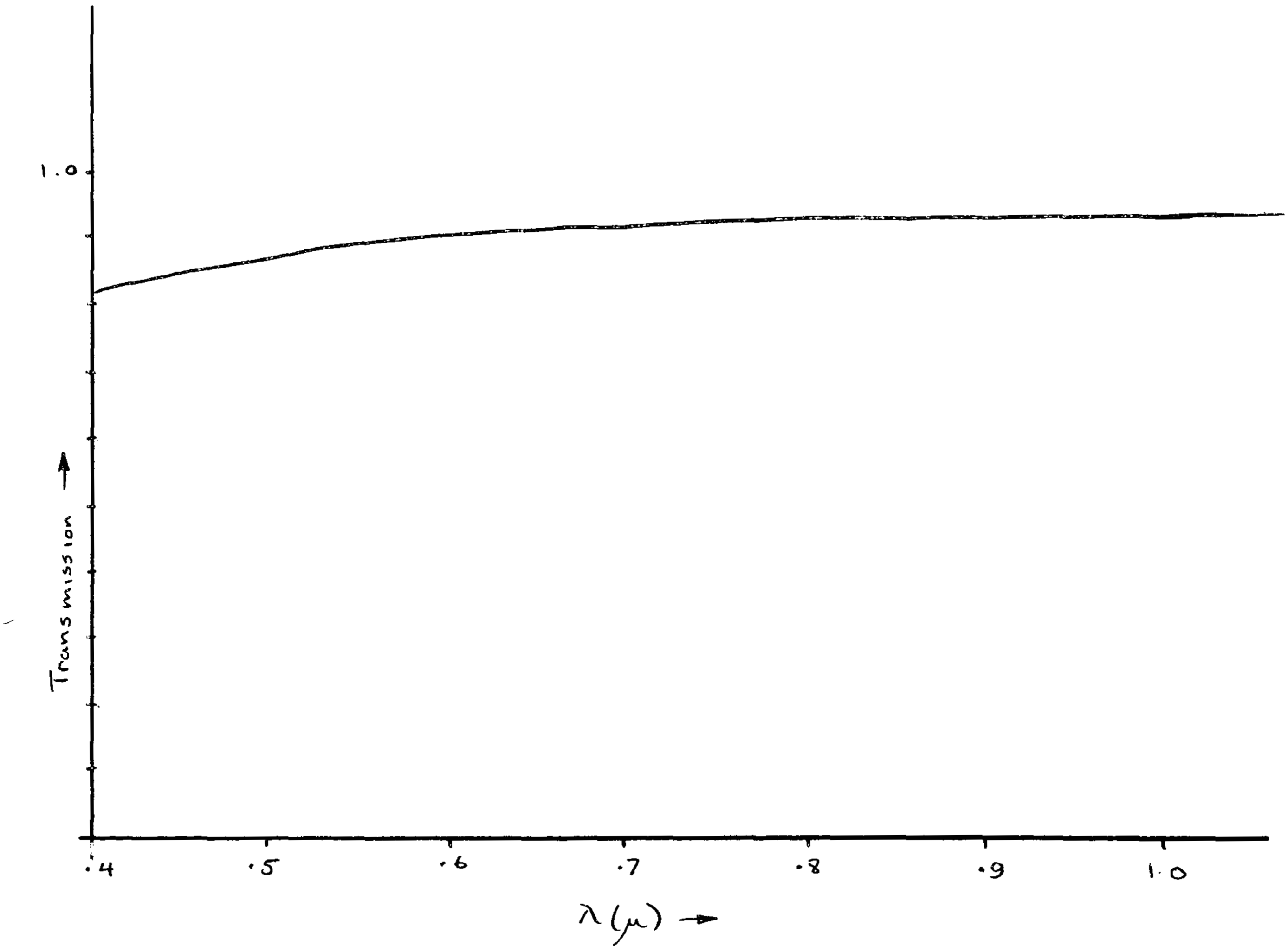

Figure 13 - Measured Transmission of Fresnel Lenses
(Includes Reflection Losses)

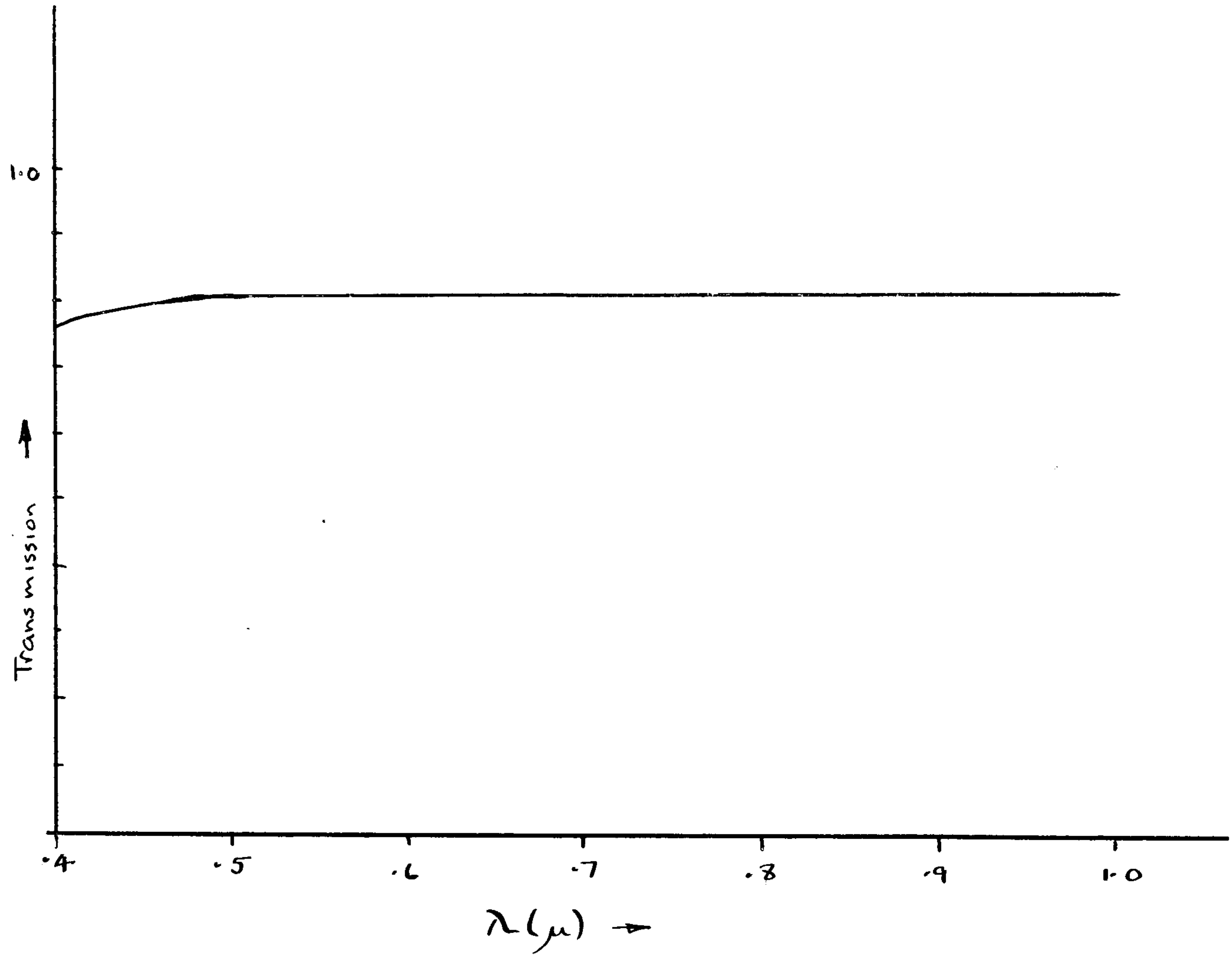

Figure 14 - Measured Transmission of Fiber Optics
Core Glass (Includes Fresnel Reflection Losses)

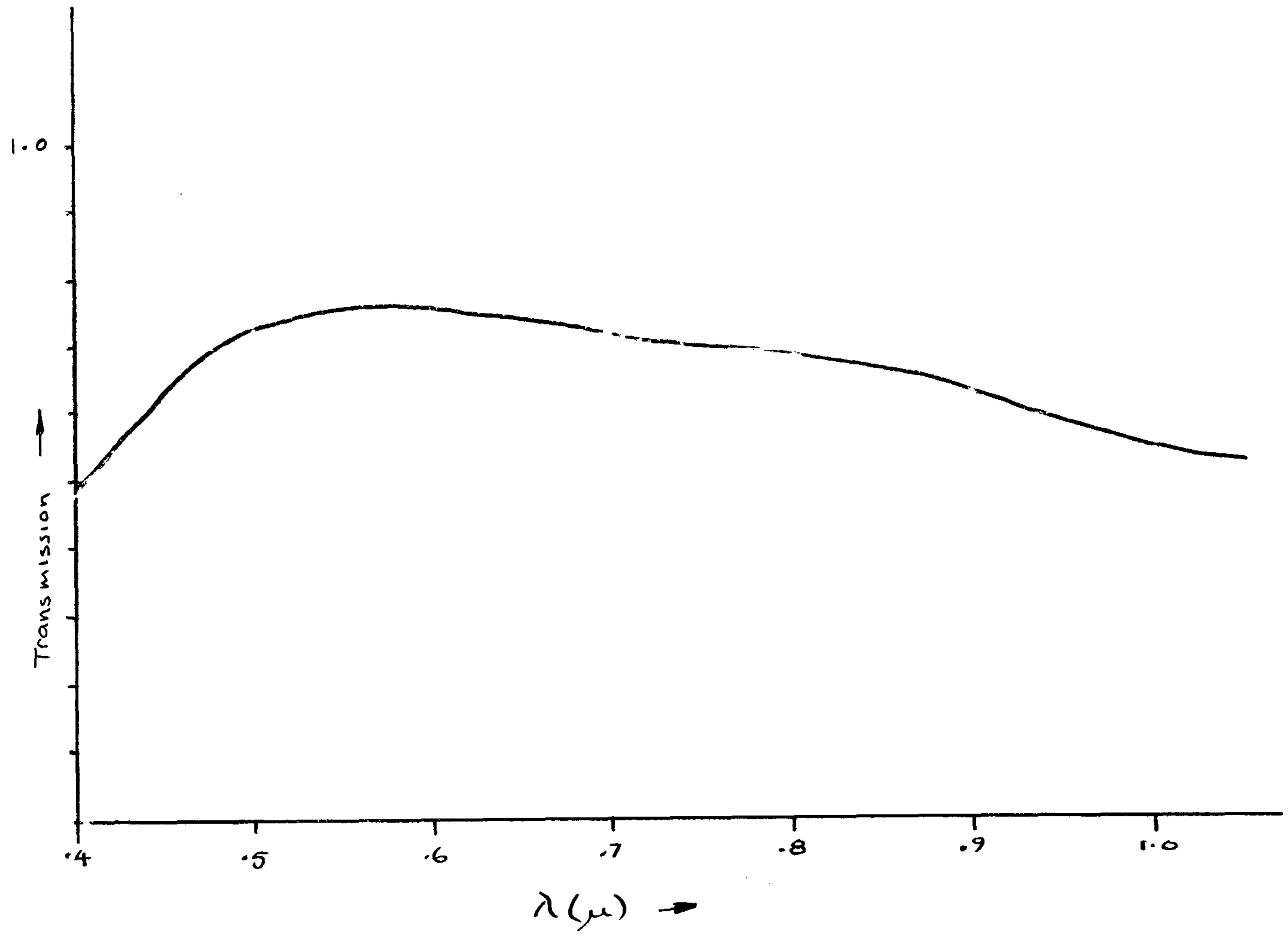

Figure 15 - Transmission of Overall System (Computed and Including Losses for each Component)

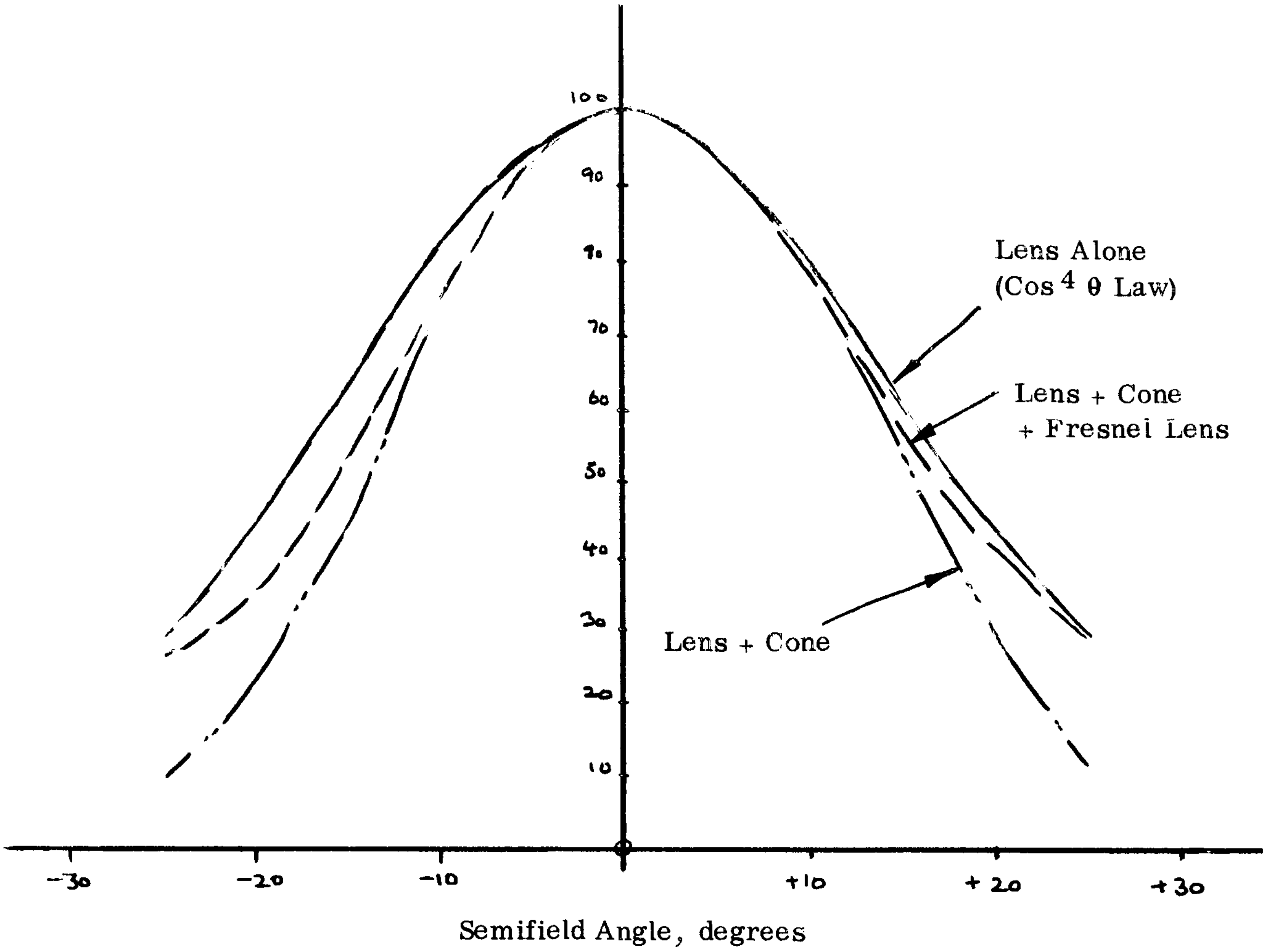

Figure 16 - Typical Measured Vignetting Curves (Normalized to 100 Percent)

1.1 for the first unit to a low of 1.4 for one of the subsequent units.

6. System Tests - Mechanical and Environmental

Most of the tests other than optical tests were performed at JPL by their personnel. Vibration, shock and thermal tests were performed on the various components, both optical and mechanical, early in the program and as a result dictated many of the design features. Detailed results of these tests are not presented in this report.

7. Assembly of Unit

The various stages in the construction and assembly can best be visualized by reference to photographs taken at various stages. Figure 17 shows an "exploded" view of the Fresnel field lens, cone and cone housing unit and indicates the sequence of assembly for these items. The cone and Fresnel lens are held in place by means of a locating ring followed by a clamping ring also shown in Figure 17. In the final unit, the clamping ring is locked into place by a second ring and adhesive cement, thus ensuring a vibration resistant assembly.

The fully fitted cone housing is shown assembled to the lens barrel and lens in Figure 18 and 19, and the unit is ready to be aligned as previously described.

After alignment the pre-assembled detector and detector mount are added to the unit. Figure 20 shows the detector mounted and aligned within its yoke, while Figure 21 shows the detector assembled in position on the cone housing.

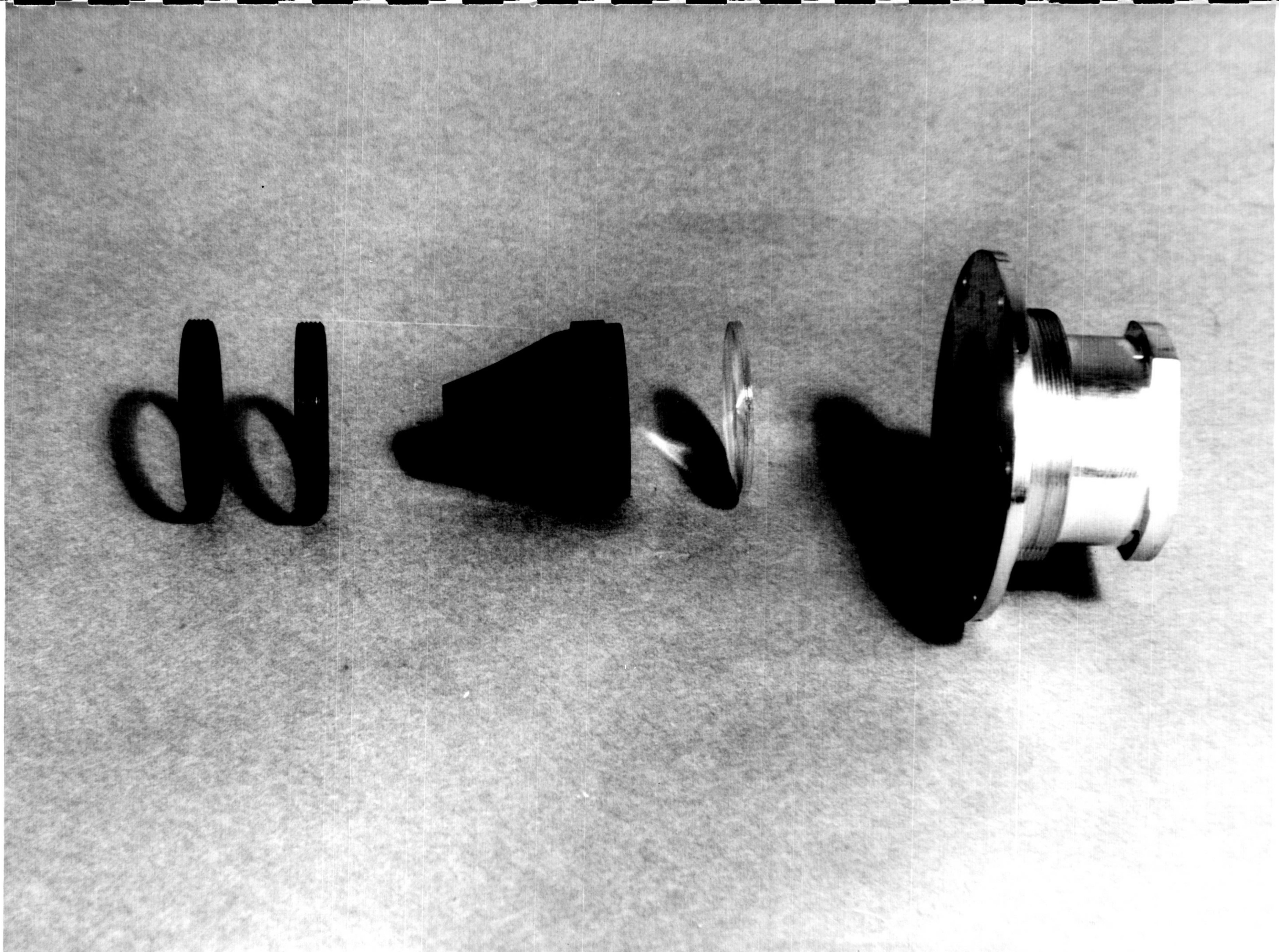

Figure 17 - Exploded View of Cone Housing Assembly
Showing Cone, Fresnel Lens and Locking Rings

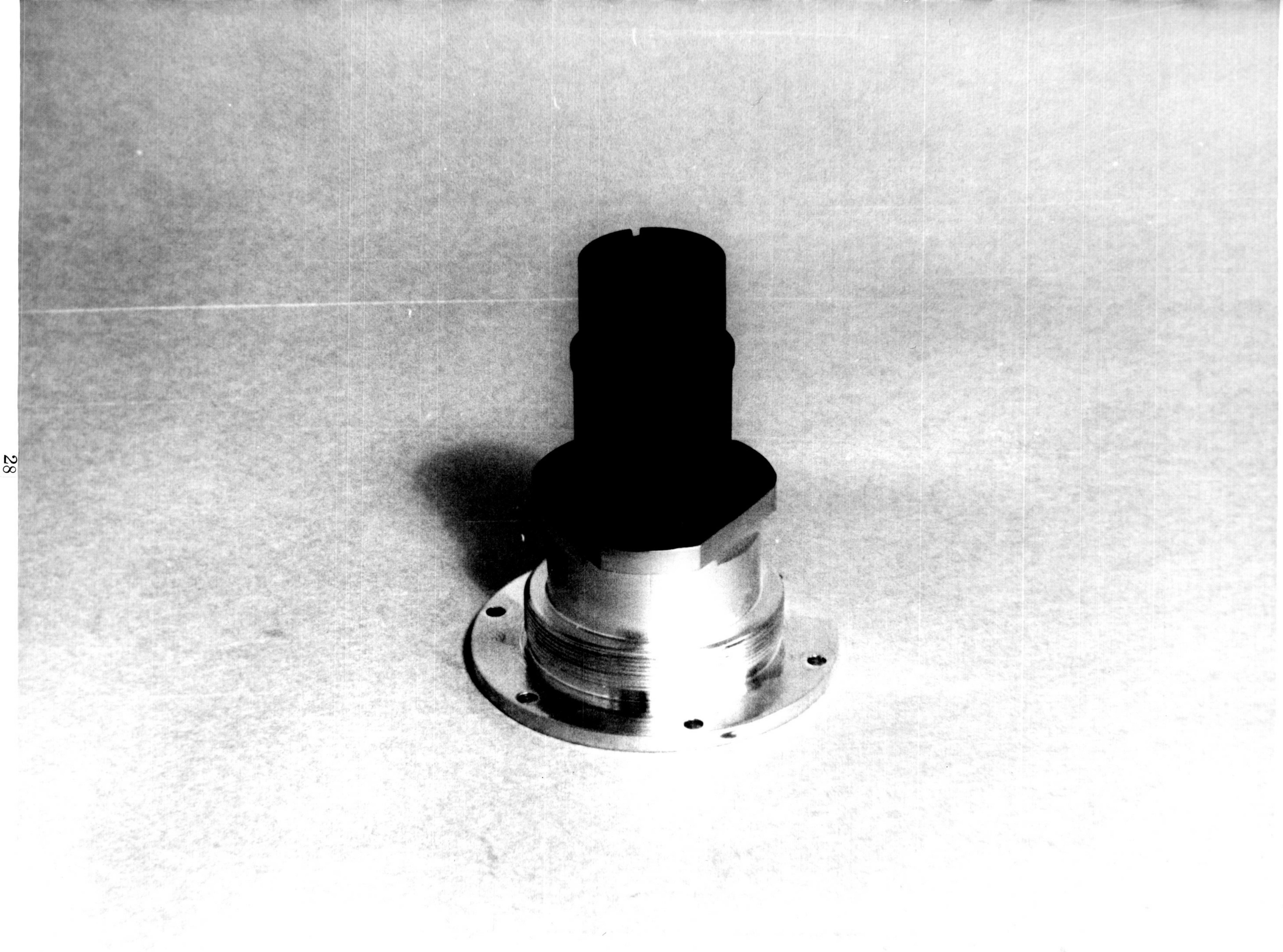

Figure 18 - Cone and Lens Assembly

Figure 19 - Cone-Lens Assembly After Alignment
and Prior to Detector Mounting

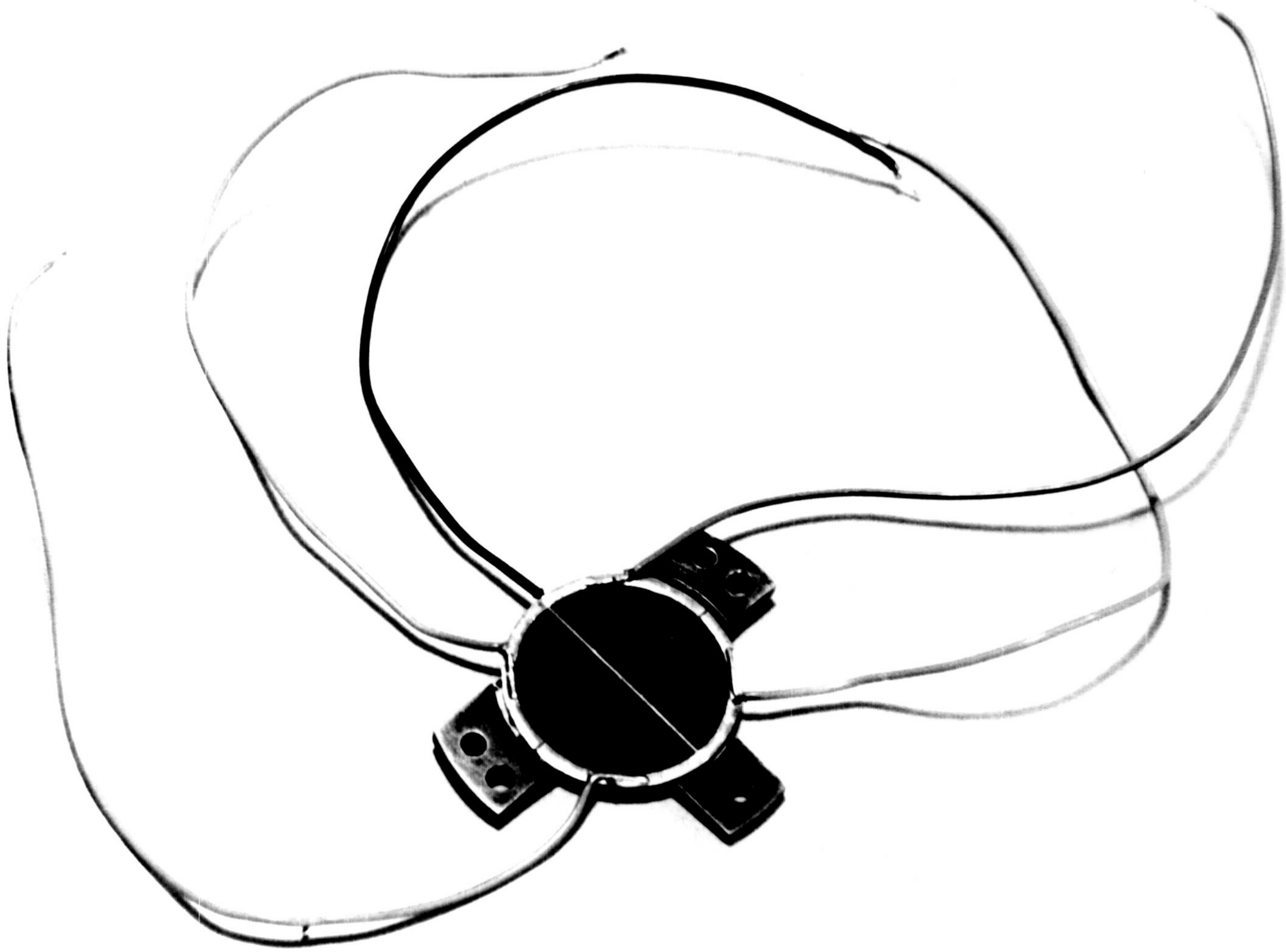

Figure 20 - Detector Unit and Mount

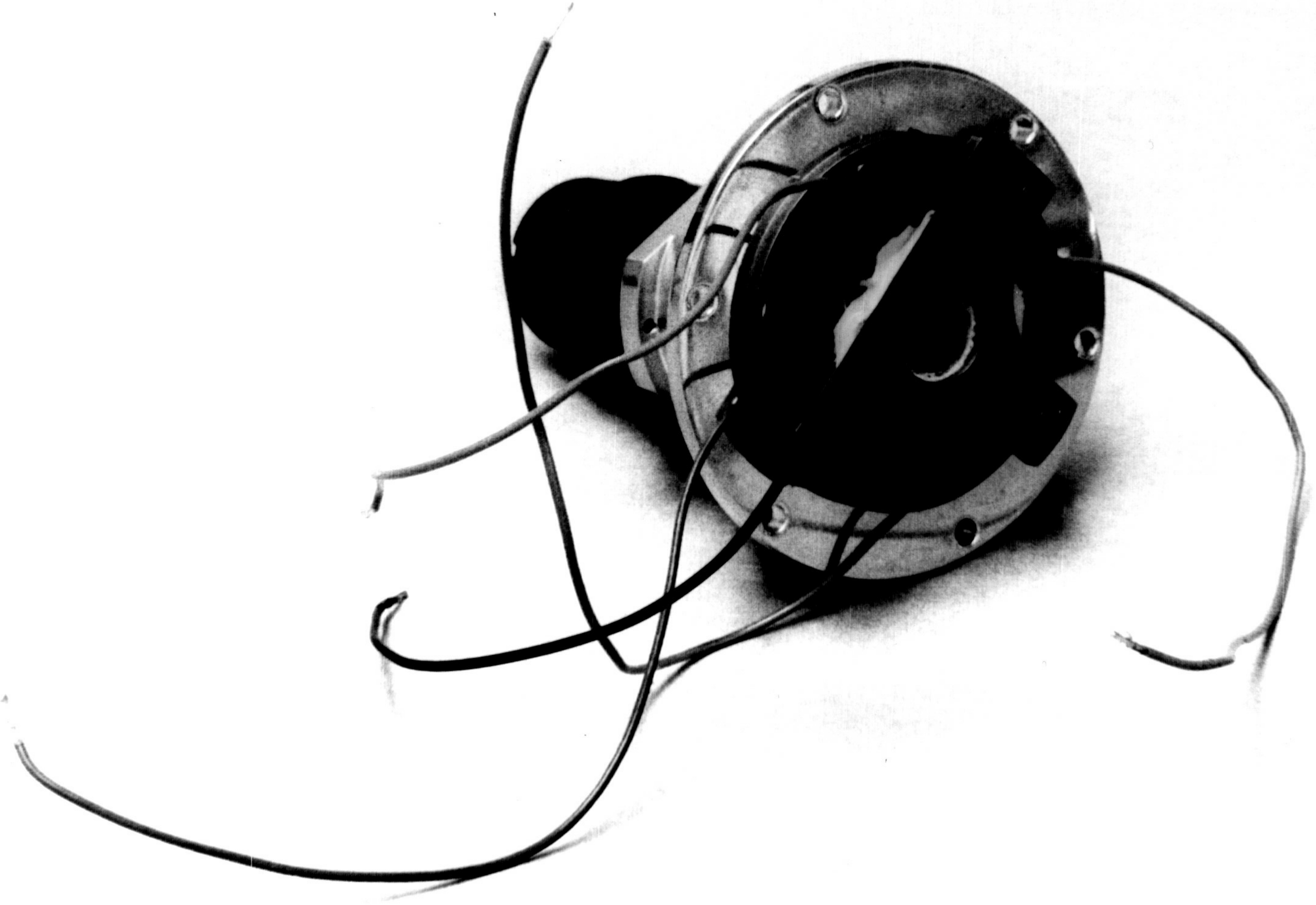

Figure 21 - Cone and Lens Assembly with Detector Assembly Unit in Place

Figure 22 - Complete Unit after Gold-Plating, Showing Thermal Shield

The final detail of assembly is the final cleaning, locking of moveable parts and fitting of the gold plated thermal barrier shield which also serves as a lens hood, providing some measure of protection against scattered light and micrometeorites as well as establishing uniform thermal radiative properties. The final complete assembly is shown in Figure 22.

III. SUMMARY AND CONCLUSION

A brief outline of the basic fabricational and design problems met and solved during the course of developmental work on a Mariner B space probe tracking system has been given. Major areas of effort have been described and relevant performance data given. In all aspects except one, the overall system transmission (and, hence, the T/stop) specifications have been met or exceeded. Later work has indicated that system transmission could have been improved at the expense of cone resolution, which was significantly higher than required in the later units supplied, in which case all specifications would have been met.

Respectfully submitted,

OPTICS TECHNOLOGY, INC.

Capellaro

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Fiber Optics Section

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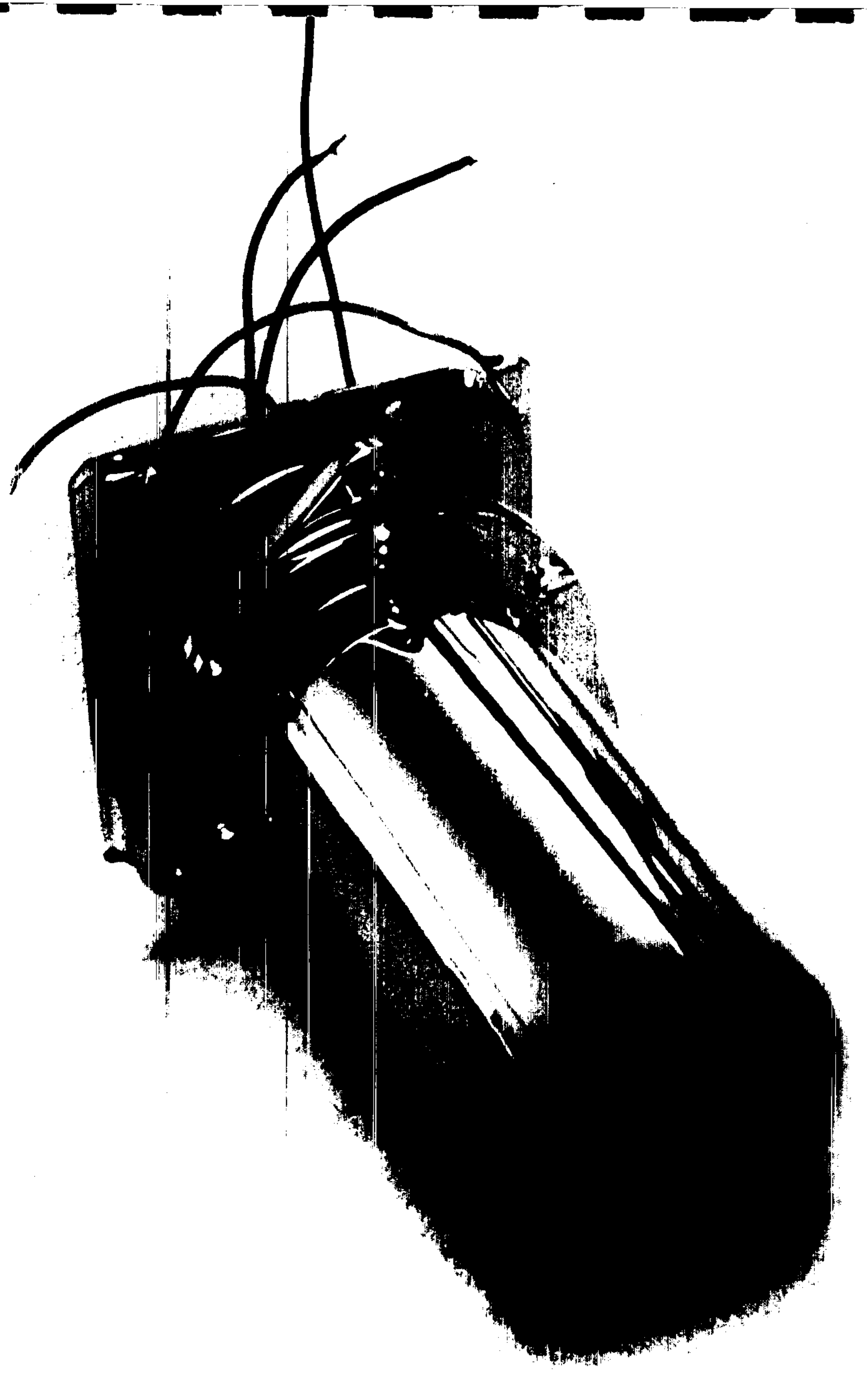

Figure 22 - Complete Unit after Gold-Plating, Showing Thermal Shield