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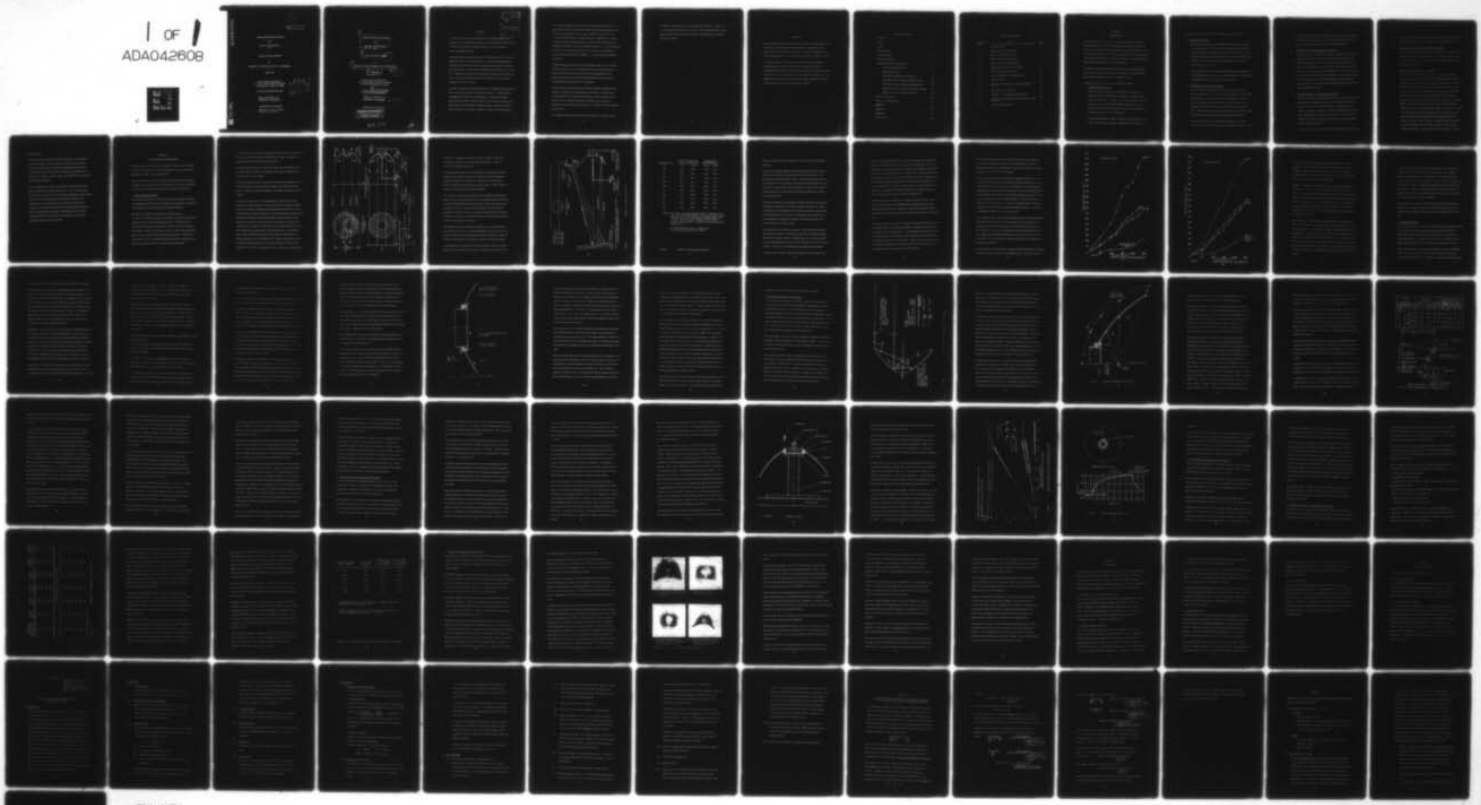

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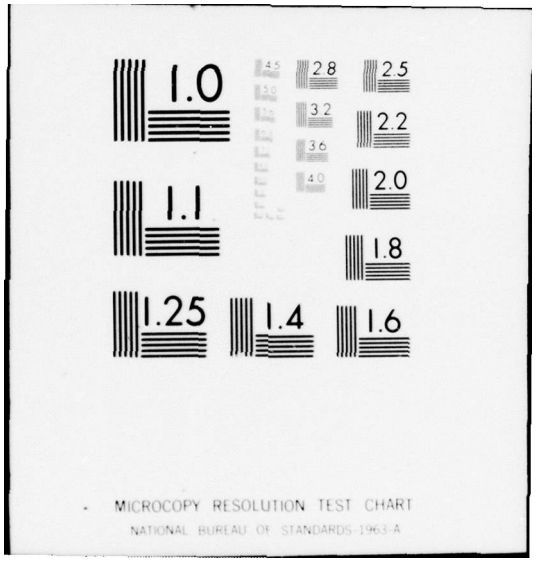
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IMPROVED REFLECTOR ASSEMBLY

FOR

AN/VSS-3 SEARCHLIGHT
(U)

FINAL TECHNICAL REPORT

BY

MARLOWE A. PICHEL AND DAVID O. CARPENTIER

APRIL 1974

NIGHT VISION LABORATORY
U.S. ARMY ELECTRONICS COMMAND
FORT BELVOIR, VIRGINIA 22060

CONTRACT DAAK02-73-C-0314

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SUMMARY

This report covers the activities undertaken and accomplished relative to the development of an improved reflector assembly for the AN/VSS-3 and AN/VSS-3A 1 Kilowatt, Xenon Short-Arc Searchlight Assembly. The work involved a number of interrelated activities.

Initial operational and performance tests were accomplished, using a Government supplied AN/VSS-3A Searchlight Assembly, to verify that certain performance degradation, which had been noted in previous production contracts involving the Searchlight Assembly, was the result of instabilities of the reflector mount, or hub, or of a "slippage" or movement of the electroformed reflector relative to the mount, or hub. Ray trace and re-image optical tests confirmed that such movement or "slippage" was, in fact, occurring.

A complete re-design of the reflector assembly was accomplished through sequential fabrication and test of modified versions of the components. Improved stability and gripping of the reflector was accomplished by a combination of changes including hub and retainer materials, quantity, size and torque requirements of the clamping bolts, the development of a lapping technique to improve the match of the hub and retainer to the reflector, together with other related improvements.

The resultant re-designed reflector assembly was then subjected to a multitude of operational tests including exposure to exaggerated flexures (simulating operational change from compact to spread beam modes), temperature extremes, and other factors intended to detect any remaining deficiencies. Additionally, in an effort to improve overall Searchlight performance as well as minimize production costs associated with extensive "tuning" and component matching. etc., during Searchlight manufacture, a more stringent series of tests was developed to make possible the detection and selection of reflectors capable of meeting an improved performance specification.

Complete drawings and specifications were developed to depict the new reflector/hub/retainer assembly, and new test procedures and criteria were developed. Six reflector assemblies conforming to the new drawings and specifications, were produced and tested to verify both the improved performance attainable and the increased stability and consistency of the new design.

During the course of production tests of Searchlight Assemblies employing the new reflectors, a previously undetected problem was discovered. Certain new tests revealed a tendency of the electroformed reflectors to suffer a permanent loss of performance due to residual deformation when exposed to high operational temperature while maintained in the spread beam, or deflected, mode for prolonged periods of time.

It is concluded that all original objectives of the program were fulfilled with the

development and documentation of an improved reflector assembly. Further work may be required to fully determine the cause of, and to develop effective corrective measures to prevent the degradation associated with high temperature, prolonged flexing of the reflector.

FOREWARD

The work performed and reported herein was a joint effort of the Electroforming and Illumination Systems Departments of Pichel Industries, Incorporated, and was performed under contract DAAK02-73-C-0314. The effort was sponsored by the Night Vision Laboratory, U.S. Army Electronics Command, Fort Belvoir, Virginia.

PII wishes to express its thanks and appreciation for the help and cooperation extended during the course of the contract by Mr. Donald E. Merritt, the Contracting Officer's Technical Representative, all personnel of DCASD, Pasadena, California, and technical personnel of Varo, Incorporated, Garland, Texas, who supplied valuable detailed technical information relative to problems of interface with the Searchlight Assembly under production conditions.

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SECTION I

INTRODUCTION

The basic purpose of the contract was to improve the SC-D-647010 Reflector Assembly utilized in the AN/VSS-3 Searchlight, and to develop improved test techniques to be utilized in acceptance testing of the reflector assembly to insure that future procurements will provide reflector assemblies which maximize searchlight performance and reliability while minimizing the cost associated with searchlight alignment and attainment of specified performance.

The program, as proposed and performed, consisted of a number of interrelated areas of activity. For purpose of clarity, these areas are listed independently below and are similarly delineated in the subsequent sections.

The specific areas of activity which were undertaken included:

1. Preliminary Reflector Testing:

   Test results and accompanying engineering data were developed from extensive testing of individual reflector assemblies. In order to obtain true comparative criteria, a number of units of the "old style," or presently specified reflector assembly #SC-D-647010, were tested so that their performance could be directly compared with that of the improved design as developed during the course of the program.

   The tests included standard "sphere of confusion" tests, "grid tests" (which pinpoint local anomolies), and other related tests with the reflectors sub-

jected to a variety of deflection modes, including severe "over-flexing."

2. Engineering and Design:

An engineering and design phase evaluated two versions of an improved hub/retainer configuration, which were intuitively and empirically developed to combine closer control of tolerances with a more stable and accurate physical configuration employing increased clamping forces to eliminate the observed slippage or deformation which sometimes occurred during the "flexed" or spread beam operational cycle.

A basic requirement of the new design was that complete interchangeability with the presently specified reflector assembly be maintained to eliminate any possible problems associated with retrofit or maintenance.

3. Development of Improved Test Techniques:

In conjunction with the above, an extensive study of new and improved optical testing techniques was undertaken which provided for "zonal mapping" and comparison of the entire active surface of the reflector. The results of these more stringent tests provided a basis for the determination of a more meaningful specification and for new reflector production "point source" tests. These tests should provide future reflector assembly acceptance criteria that has a meaningful relationship to ultimate searchlight performance.

It is a goal of the program that all reflector assemblies of the new and improved design, tested and accepted per the improved test techniques, when

properly installed in a Searchlight Assembly with other conforming components, will virtually guarantee attainment of all searchlight performance specifications relative to peak beam candlepower and beam holeing requirements.

4. Development of the Re-designed Reflector Assembly:

Experimental versions of the new hub and retainer configurations were produced and the performance and stability of each resultant reflector assembly was tested, both independently as a "reflector assembly only" (being subjected to deflections substantially greater than that to be experienced in actual operation) and as a functioning part of the searchlight system. This was accomplished by incorporation into the GFE Searchlight Assembly, where they were subjected to multiple flexings between compact and spread beam modes of operation, while exposed to all normally experienced operating temperatures as developed within the Searchlight housing.

5. Finalization of Design, Drawings and Specifications:

After all evolutionary design modifications and corrections had been completed and evaluated, the designs and specifications were finalized and drawings developed for the complete reflector assembly, including details of hub, retainer, and all other components. Final details regarding material specification, finishing treatments, assembly torque requirement, and other factors related to the repetitive production of high performance reflector assemblies were developed and documented.

It is intended that these resultant drawings and specifications will be the basis

for the development of a new Government Drawing Package and Procurement Specification which will result in substantially improved reflector quality.

6. Production and Test - 6 Deliverable Reflector Assemblies:

Six (6) complete reflector assemblies, fully representative of the new design and specification, were produced and tested. Five of the units were delivered to Fort Belvoir and one was retained at PII for additional final testing in the GFE Searchlight Assembly.

7. Possible New Reflector Performance Criteria:

During the course of final system testing, Varo, Incorporated of Garland, Texas, a prime contractor for the AN/VSS-3 Searchlight Assembly and a PII reflector customer, experienced certain degradation of performance of reflector assemblies which were identical to those produced during the course of this contract. Under virtually all operational and environmental conditions the Searchlights incorporating the re-designed Reflector Assemblies produced unusually high peak beam candlepower readings, (well in excess of 110 million PBCP), with "zero" beam holeing. However, under newly developed test conditions, when the mirrors were left in the flexed, or spread beam, condition for a prolonged period of time at high temperature, the peak beam candlepower was observed to have dropped drastically after the Searchlight was returned to its compact mode of operation. Repeated tests at Varo and at PII, in which the prolonged duration of flexing was again combined with high operational temperatures, produced similar results indicating that a problem

did indeed exist.

"Old style" or present specification reflector assemblies, including residual units which had been produced more than two years previously on another contract, exhibited the same deformation and degradation of performance when exposed to similar test conditions, indicating that the problem was not, in fact, new or related to a recent change in the characteristics of the electro-formed reflectors themselves.

It was concluded that the problem may have always existed with the present design configuration and material specifications, but that it had previously been masked by two factors. (1) The more obvious deformation and performance reduction previously experienced which was related to slippage of the reflector within the hub/retainer and, (2) the fact that the specific test conditions which apparently contributed to the newly discovered deformation, namely prolonged duration of exposure to high temperature in the flexed, spread beam mode, had never previously been applied in a manner which caused the deformation to become evident.

SECTION II

INVESTIGATION AND DISCUSSION

During the course of the program, certain phases of the activity were undertaken simultaneously where possible, while other phases were, of course, sequentially dependent on completion of the preceding effort.

The ensuing discussion of the work accomplished during the course of the program is presented, in the interest of better organization and conciseness, independently for each phase in the same general sequence as outlined in the Introduction.

1. Preliminary Reflector Testing

The test technique utilized for the independent testing of the reflector assemblies encompassed both a repeat of the initial acceptance test procedures, and additional tests associated with controlled flexing of the reflector assemblies.

Specifically, each reflector was subjected to the following tests.

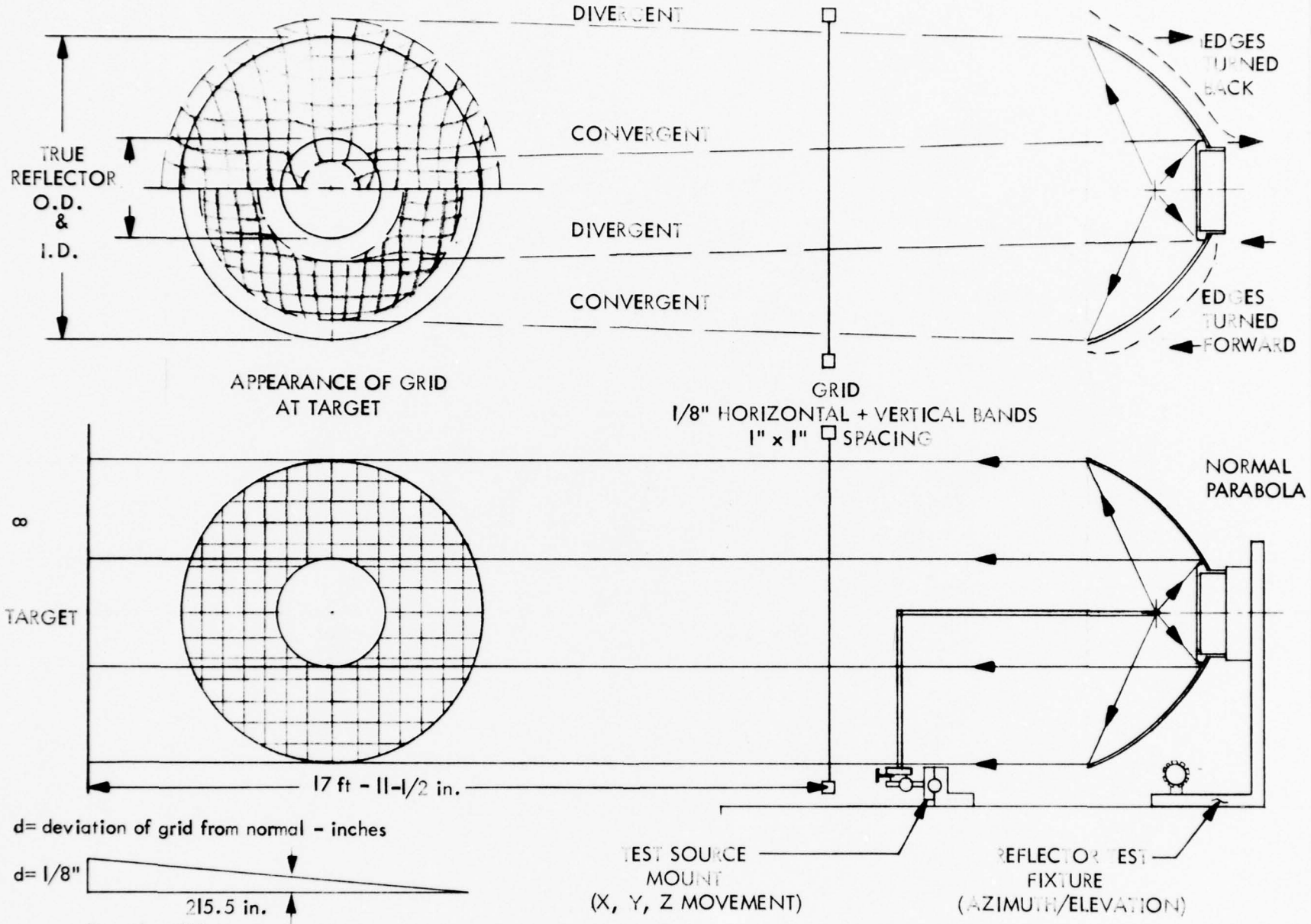
A. Grid Test - The Reflector assembly is positioned on a support structure which is capable of movement in both elevation and azimuth. A point light source is positioned on a manipulator which provides a capability of three axes adjustment (X-horizontal, Y-vertical, and Z-axial). A grid of 1/8 inch wide bands equally spaced at one inch intervals, both horizontally and vertically, is placed in front of the reflector so that the collimated light from the reflector is projected through the grid to a target area, where is is observed and/or photographed.

In this test, when proper focal point positioning of the point source is achieved, and when a true, undistorted, parabolic reflector surface is present, a shadow of the grid is projected to the target area without distortion.

If local anomalies or deviations of the reflector shape exist, the deviations cause the shadow pattern of the grid to be displaced on the target, showing the exact location and extent of any anomaly.

The degree of angular deviation of the reflector can easily be calculated from the observed displacement of the grid pattern as related to the distance from grid to target. A diagram of the grid test components, and related calculations are shown in Figure 1.

B. Sphere of Confusion Test - The standard sphere of confusion test is used to determine the overall integrated, or average, performance of a reflector assembly. In this test, the reflector and light source are positioned and utilized in a manner identical to that employed for the grid test, except that the grid is removed from the beam and instead of allowing the projected image to fall on a target for visual observation, the target is swung out of the way and the beam is directed onto the reflective face of a parabolic "collimating" mirror of high accuracy from which the rays are redirected to the focal point of the collimating mirror. An integrating sphere, having variable aperture plates, is positioned with the aperture at the theoretical focal point of the collimating mirror. Aperture plates having a variety of different entrance aperture diameters, which by calculation relate to various "spheres of confusion", allow determination of the overall accuracy of the reflector



$\text{Tan } 1' = \frac{.125}{215.5'} = 0°-2'$ Beam deviation, $= \pm 0°-1'$ reflector slope error

FIGURE 1 GRID TEST DIAGRAM

being tested. A diagram of the test set up is shown in Figure 2. The specific test procedure and criteria for calibration and determination of "sphere of confusion" is contained in Appendix A.

The two test procedures above serve to identify the overall preexisting condition or quality of each reflector assembly and to establish its relative performance capability as related to the specification. Application of these tests prior to flexing or searchlight operation provides a reference point or "base" condition for comparison and measurement of potential degradation.

Prior to initiation of this contract, a large number of reflector assemblies manufactured to, and in total compliance with, the existing drawings and specifications for the SC-D-647010 Reflector Assembly had been tested by the above described techniques. However, to provide an up-to-date basis for exact and specific comparisons, a series of re-tests was made utilizing standard reflector assemblies. A summary of the "sphere of confusion" performance rest results and accompanying "grid test" pictures is shown in Figure 3.

After establishing the base performance capabilities for each reflector assembly, each reflector was mounted in a modified searchlight frame assembly where it was subjected to flexing forces which duplicated the reflector deformation conditions produced by the mechanism of "spread beam" operation within the searchlight.

To accomplish this in a controlled and infinitely variable manner, the eccentric electric motor driven deflection mechanism was replaced by a mechanical, screw

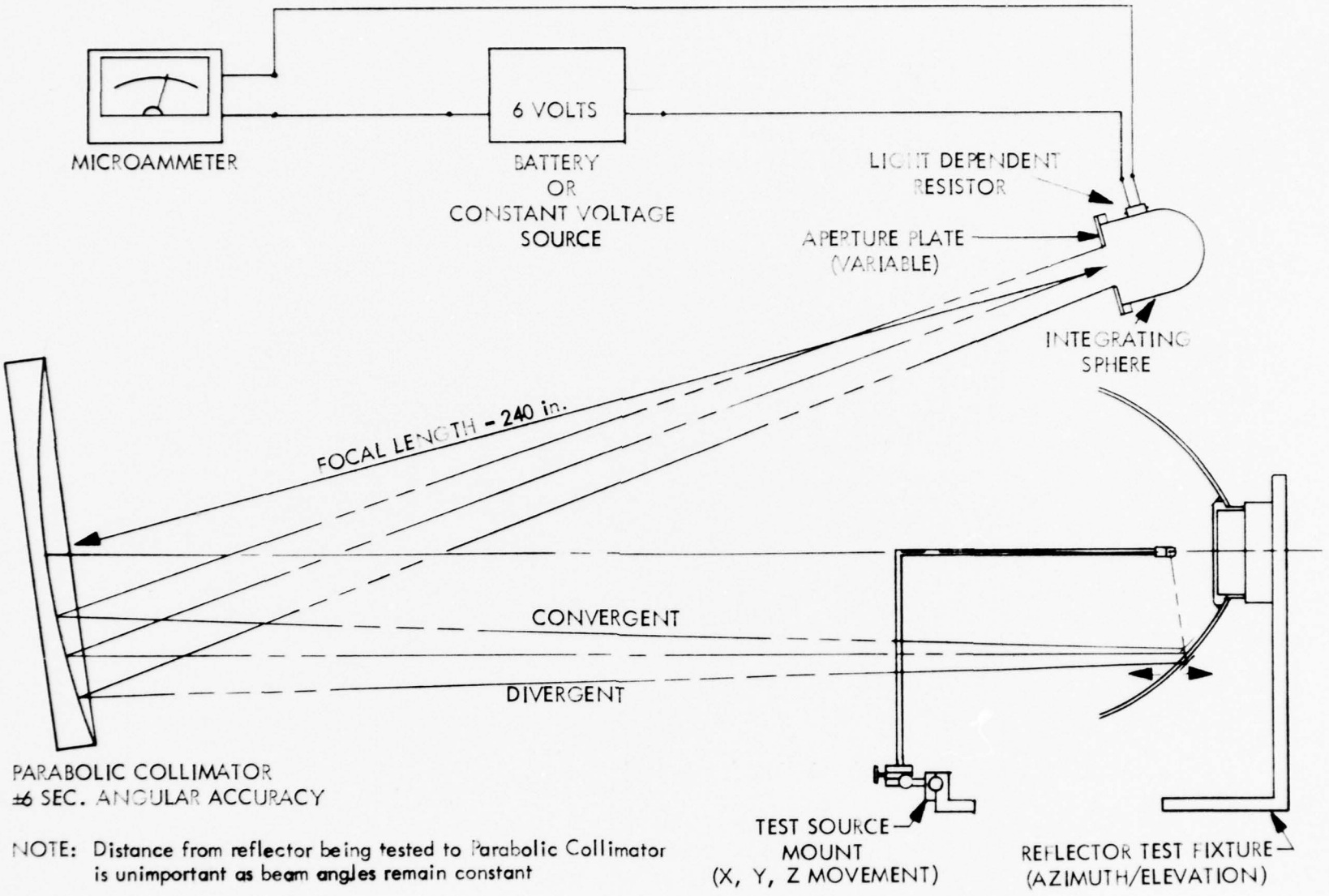


FIGURE 2 SPHERE OF CONFUSION TEST DIAGRAM

REFLECTOR SERIAL NO.	SPHERE OF CONFUSION PRIOR TO DEFLECTION		PERFORMANCE AFTER DEFLECTION	
	1 mm	.35 mm	1 mm	.35 mm
008	98.5	78.0	97.0	25.4
011	98.5	85.0	98.5	38.4
012	99.0	85.0	98.0	46.3
014*	99.2	91.2	89.0	9.7
018*	99.0	78.0	89.0	15.2
019	98.8	85.5	96.5	18.0
023	98.5	69.5	92.0	15.2
027	96.8	77.3	98.0	49.0
112	98.6	52.8	85.0	23.8
038	99.0	88.2	98.0	43.7

NOTE: 1) With .040 inch equivalent aperture (4.085 in.) virtually all of the beam energy can enter the aperture, even though the beam becomes badly distorted due to reflector movement between adaptor and retainer. This is not the case, however, when the 0.35 mm equivalent aperture (1.407 in.) is used as can be seen by the right-hand column.

2) All reflectors deflected .250 in. actuator travel.
*Residual deflection graph shown in Figure 4

FIGURE 3 SPHERE OF CONFUSION TEST RESULTS

driven actuator which provided a method for inducing specific and controllable deflection.

The test frame was also equipped with dial indicators mounted at the top and at either side of the reflector, approximately 1/8 inch from the outer rim of the reflector and normal to the reflector surface. The test mechanism was mounted on the standard mirror mount equipment, providing both azimuth and elevation movements in such a manner that the "grid" and "sphere of confusion" tests could be performed exactly in the same manner as previously described for normal static mirror assembly testing.

To determine the effect of varying degrees of reflector flexing on the performance and stability characteristics of the reflector assembly, the "base" test condition was repeated and the characteristics of the "grid" and "sphere of confusion" tests in the unflexed condition were recorded. The reflector was then distorted in an incremental manner by applying the deflection force through actuation of the screw mechanism in increments of .050".

After application of each deflecting increment, the dial indicators (which had been previously zeroed for the "base" test conditions of the undeflected reflector assembly) were read and recorded. The deflecting actuator was then backed off to remove the deflection force, and the reflector allowed to return to its "normal" condition. At this point, the dial indicators were again read and recorded.

If return to normal or "base" condition was complete, all dial indicators would

read zero and the "grid" and "sphere of confusion" tests would duplicate the "base" conditions. If residual deformation occurred to the mirror assembly, the amount of such deformation was registered by the dial indicators, and the effect on performance was detected by the "grid" and "sphere of confusion" tests. The residual deformation was indicated in the "grid" test by a distinct flattening of the disc of light projected by the reflector assembly and a displacement of the grid lines as projected from the vicinity of the bottom of the mirror where the deflection forces were applied. The performance, or percent of total energy contained within an aperture of a given size, was also observed to drop in the "sphere of confusion" test.

As noted, the amount of deflection was increased by multiples of .050" in each successive test sequence, with the deflecting force being totally removed after each deflection until a maximum deflection of .500" had been applied. Data was recorded for each deflection increment while flexed and after removal of the flexing force.

It should be noted that the definition of "degree of deflection" applies to the amount of movement of the push rod causing the deflection, rather than to the actual movement of the reflector rim itself (which is of a lesser degree and results from a transfer of the forward push rod force through the push pad mechanism to the reflector rim as an angular component of the forward force). Despite this lack of direct coupling, the amount of actual deflection of the rim of the mirror was found to be quite reproducible for any fixed increment of push rod movement.

When the Searchlight is assembled and adjusted, the amount of mirror deflection can be varied. Actual deflection results from the total possible movement (as produced by the drive motor cam) reduced by "free travel" between push mechanism and reflector. Such "free travel" is adjustable.

Although various figures had been supplied to PII regarding the amount of push rod or mirror deflection mechanism travel utilized in obtaining spread beam operational conditions, the deflection mechanism of the GFE Searchlight was re-measured and related calculations performed at PII to verify what the maximum possible deflection movement could be. Calculation of the cam and cam follower displacement, derived from actual measurement of the components resulted in a possible total travel of .272" minimum to .276" maximum. To determine the possible effect of clearances and "back lash", the mechanism was actually rotated and measured. It was determined that true resultant push rod movement was .270".

Since it has been stated by the technical personnel involved with searchlight assembly and test that the push mechanism is normally adjusted to provide a stroke of only approximately .200", and since the maximum possible deflection induced by the drive mechanism is .270", the test parameters which provided deflection movements up to .500" actually applied deflective forces more than double those which would be experienced in actual operation. Graphs showing the results of these deflection tests are shown in Figure 4.

It should be noted that while certain of the original SC-D-647010 Reflector Assemblies showed little residual distortion at normal deflection levels, other units exhibited

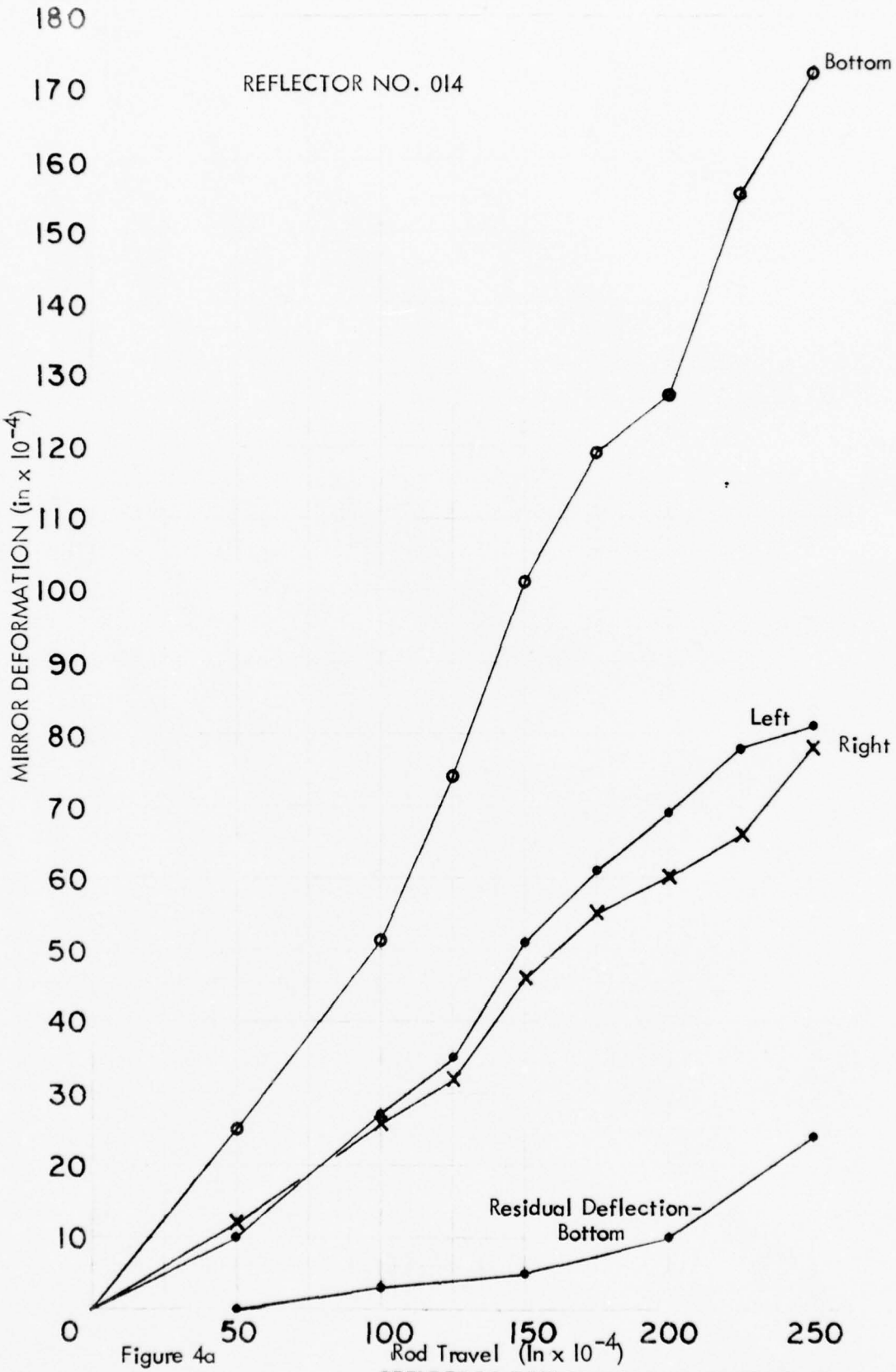


Figure 4a

REFLECTOR DEFLECTION MEASUREMENTS

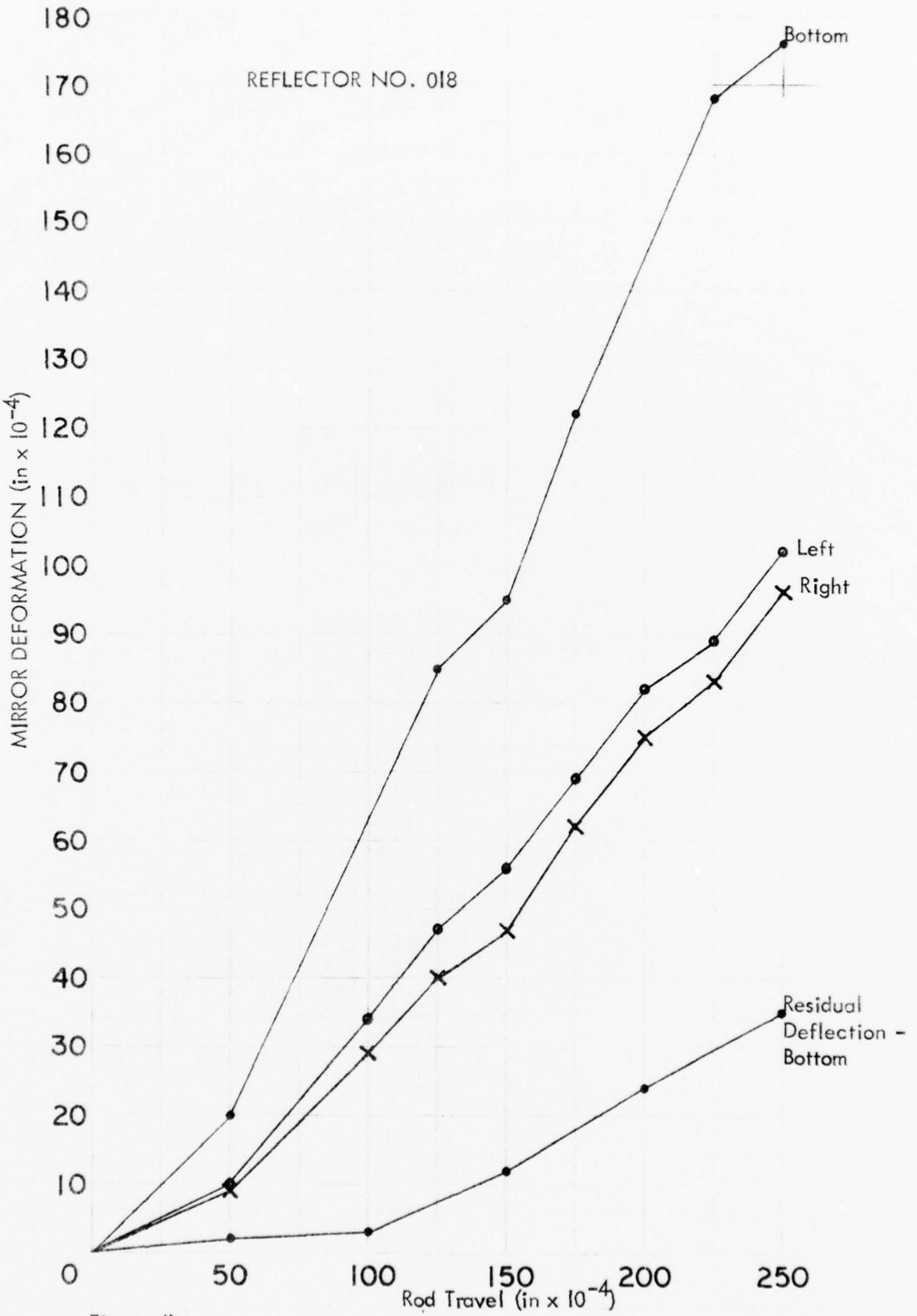


Figure 4b

REFLECTOR DEFLECTION MEASUREMENTS

severe residual deformation and accompanying loss of performance. Careful examination of all of the components, assembly procedures and torque values indicated no measurable difference between the "good" or "bad" reflector assemblies, leading to the conclusion that the "good" units were probably borderline, and that overall performance was unpredictable.

Normally, if the reflector is securely mounted in an unyielding manner at its inner periphery, a return to normal configuration after flexing does, in fact, occur. If, however, under the solidly applied force of the mechanically actuated push rod, the reflector slips or moves somewhat between the two clamping surfaces of the adaptor and retainer, then, when the deflecting force is removed there is no equal or opposing force available to drive the reflector back to its original configuration, and the deformed configuration is retained by the clamping action of the adaptor and retainer.

This characteristic "slippage" has been conclusively proven by simply loosening the screws which provide the clamping force between adaptor and retainer, allowing the mirror to return to its normal parabolic contour. When the screws are then re-tightened, the original, symmetrical, high performance beam characteristics are restored. In virtually each instance, this characteristic was repeated, leading to the firm conclusion that the mirrors were not bending or distorting as had previously been supposed, but were merely slipping within, and being retained in the slipped or distorted configuration by, the adaptor and retainer hardware of the reflector assembly.

A number of units of SC-D-647010 reflector assemblies were then installed in the GFE Searchlight and, after first allowing the searchlight to obtain stabilized internal operating temperatures, were subjected to a number of cycles between compact and spread beam modes of operation. In many, but not all, instances, the beam pattern was observed to degrade after repeated (up to 50 sequential) flexings. Such degradation resulted in an observable flattening of the bottom and general spreading of the projected beam shape after return to compact mode, accompanied by a marked reduction in peak beam candlepower.

The above tests served to further confirm the conclusion that the reflectors were indeed slipping, and that an improved hub/retainer configuration and overall reflector assembly re-design was required to gain the required stability and reliability.

2. Engineering and Design

Since it had previously been determined during the course of past reflector assembly and searchlight manufacturing programs, and was currently being verified in greater detail through duplicate tests and evaluation, that the prime cause for performance degradation was related to mirror movement or "slippage" within the adaptor/retainer assembly, certain corrective design approaches were obvious.

The most precise portion of the electroformed reflector is, of course, the parabolic reflective inner face. Because of this fact, logic dictates that mounting and uniform geometrical support of the reflector be accomplished relative to that precise

face, and that stability of the reflector be assured by the method of attachment.

In the previous or existing design for the SC-D-647010 reflector assembly, the "retainer," which serves to couple the reflector to the searchlight frame, is an extremely thin, flexible aluminum component. The "adaptor," which is positioned behind the reflector (and is used to clamp the reflector against the front retainer by means of eight (8) equally spaced No. 4-40 cap screws), is somewhat heavier and therefore more stable than the companion front retainer. This relationship allows any deviations induced by possible nonuniformities in the rear of the reflector element to produce a warping effect in the mirror, which cannot be corrected by the relatively unstable front retainer.

Additionally, since the coefficient of thermal expansion of the 6061-T6 aluminum alloy utilized in fabrication of the reflector adaptor and retainer components is nearly double that of the nickel utilized in the reflector (and the stainless steel clamping screws), an undesirable imbalance of movement and forces due to thermal expansion during temperature cycling can lead to stretching of the extremely inadequate No. 4-40 cap screws which accomplish the clamping and holding action, and to displacement of the mating curves of the components. Specific data regarding the thermal expansion interrelationships are shown in Appendix B.

A number of other undesirable factors also exist in the present design. Since the nickel reflector, particularly the smooth front face which is rhodium plated, is considerably harder than the aluminum adaptor and retainer materials, it is virtually

impossible for the front retainer to get a "bite," or grip on the reflector to prevent the undesirable slippage or movement. Additionally, the torque levels achievable with the 8 #4-40 clamping screws are such that only very limited gripping forces can be achieved.

Measurements of the flatness and/or roundness of the hub assembly, when the reflector (detached from the searchlight) was intentionally flexed an amount equal to that in the spread beam configuration, indicated that the reflector, and not the hub/retainer components, became the stronger or governing factor. When the mirror was flexed, the adaptor and retainer were deviated from their "as machined" configuration. In short, the entire adaptor/retainer assembly was determined to be inadequate.

The initial intuitive and logical redesign of the reflector mounting hardware included the following changes.

A. A general configuration redesign to provide direct support of the reflector by means of a more rigid hub which provides improved, more stable mating characteristics to the Searchlight.

B. A choice of steel for the hub material, rather than aluminum, for increased strength and to minimize the effect of differences of coefficient of thermal expansion between the bolts, hub, retainer and reflector in the final assembly.

C. A re-design of the retainer, to be positioned at the rear of the reflector, into a twin land, semi-flexible ring whose sole purpose is to provide a high degree of clamping force in such a manner that the reflector is held firmly against the hub

at the accurate reflector front surface interface, so that the hub contour governs, rather than the retainer ring.

D. An increase in the size of, and change in specification for, the assembly clamping screws to provide a higher torquing capability and increased clamping force.

Two similar but basically different configurations were initially evaluated. Configuration 1 provided for positioning of the clamping screws from the front side of the hub, through the reflector and into the retainer ring which was threaded to receive them. Configuration 2 reversed this positioning, with the clamping screws inserted from the rear, or retainer side, through the reflector and into the steel hub assembly.

Configuration 1 was calculated to have the least effect on mirror clamping force due to environmental temperature deviations since hub, bolts, and reflector would be closely matched in coefficient of thermal expansion, the bolts being retained in the aluminum ring to the rear. Ultimate torque levels attainable, however, would be less than those attainable with Configuration 2 due to the possible stripping of the threads in the aluminum retaining ring.

The reversed bolt position of Configuration 2, while subjecting the bolts to some degree of physical "working" or stress variation, due to the mismatch in coefficient of thermal expansion between the steel bolts and the aluminum retaining ring through which they must pass, may provide higher clamping forces through thread engagement of the steel bolt with the steel hub, which is a substantially stronger element than the aluminum retaining ring. Additionally, if the bolts are properly sized to

withstand the stress occasioned by the unbalanced thermal expansion of the aluminum retainer ring, greater clamping forces will be achieved because of the difference in thermal expansion when the Searchlight is at operating temperature, which was the condition under which previous slippages were found to occur. Re-stated, if the bolts are properly sized, the expansion coefficient differences which were previously found to be detrimental can become advantageous.

As an added feature, it was felt that positioning of the clamping screws at the rear of the reflector would preclude any possibility of inexperienced personnel from accidentally removing the mirror clamping screws, rather than the hub retaining screws, when working with or removing the reflector assembly from the Searchlight for any reason. Figure 5 shows the two configurations.

Both configurations of the new hub were detailed and initially fabricated, but, through discussions with the COTR it was decided to pursue Configuration 2, due to the apparent advantages listed above.

With the present drawings and specifications, each of the individual reflector assembly components is separately dimensioned and toleranced, so that additive tolerances can, and do, occur. While the focal length of the electroformed reflector is held to a reasonably close tolerance, $\pm$ .010 inches, when assembled to the retainer an additional tolerance build up of $\pm$ .015 is possible, allowing a total of $\pm$ .025 inches between the true point of attachment to the Searchlight and the actual best focal position of the reflector.

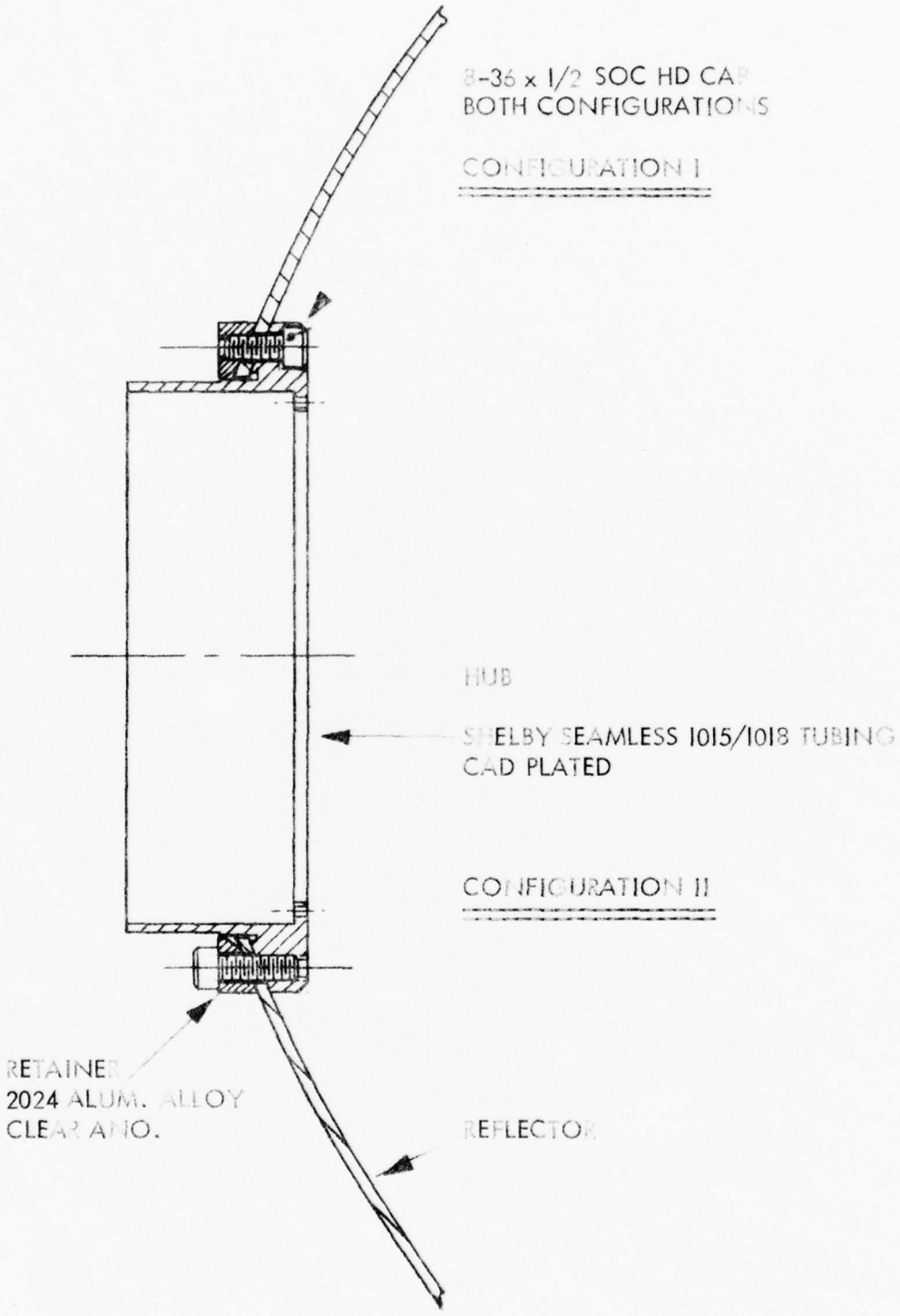


FIGURE 5 INITIAL REFLECTOR ASSEMBLY RE-DESIGN

Since the reflector assembly is purchased and utilized as a "complete assembly" it seems more reasonable that the dimension of real criticality is the actual distance from the point of attachment to the Searchlight to the "best" focus of the parabolic reflector. Where even relatively gross ($\pm$ .050 inches for instance) deviations of reflector focal length, if properly positioned relative to the arc source, would produce immeasurable differences in performance, it has been proven that minor deviations (on the order of $\pm$ .010 inches) in the relative position of arc "hot spot" to reflector "best focus" can produce marked changes in peak beam candlepower, beam holeing characteristics and total beam angle.

With these facts in mind, a reflector/hub assembly re-dimensioning was developed which first determines the average "best focal distance" of the reflectors being replicated from any given production tool. With proper application of electroforming replication techniques, utilizing adequate stress control, the reflector focal lengths are reproduced to a high degree of precision with deviations rarely exceeding .005 inches.

The new hub design dimensions and tolerances carefully control the distance from the hub/searchlight interface (Reference letter B of the hub design), with respect to the relative position of the paraboloidally curved section of the hub, which is the true position of attachment and control for the reflector face. With this dimension adequately controlled, repetitive positioning of the reflector assembly in the search-light to a high degree of accuracy on a totally interchangeable basis is achieved.

Initial tests of the new configuration, while indicating substantially increased gripping forces and generally improved performance over the previous design, still produced some "slippage" and minor performance loss related thereto under extreme flexing and temperature cycling conditions. To further increase the clamping force and maintain maximum uniformity, the number of clamping bolts was increased from 8 to 12, providing a 50% increase in clamping force.

During development of the new hub configuration, trace machining techniques were developed to provide a close match between the parabolic inner contour of the reflector and the mating face of the hub. It was determined by tes. and evaluation that hub contour errors of as little as .0001 to .0002 inches could produce visibly observable and measurable performance decreases due to distortion of the inner portion of the reflector by the hub. Continual tolerance tightening and evolutionary improvement of related tooling resulted in an improved match and reflector assembly performance, but a better technique to obtain "near perfect" contour matching of the two components was desired. Additionally, it was determined that it would be highly desirable to provide a substantially increased level of friction between the main hub and the hard, smooth face of the reflector to further minimize any tendency for the reflector to slip against the hub when subjected to spread beam mode deflection forces.

A production technique involving a relatively simple lapping process was evolved which accomplished both objectives. Exact "contour matching" was achieved together with a controlled roughening of the mating surfaces through a lapping

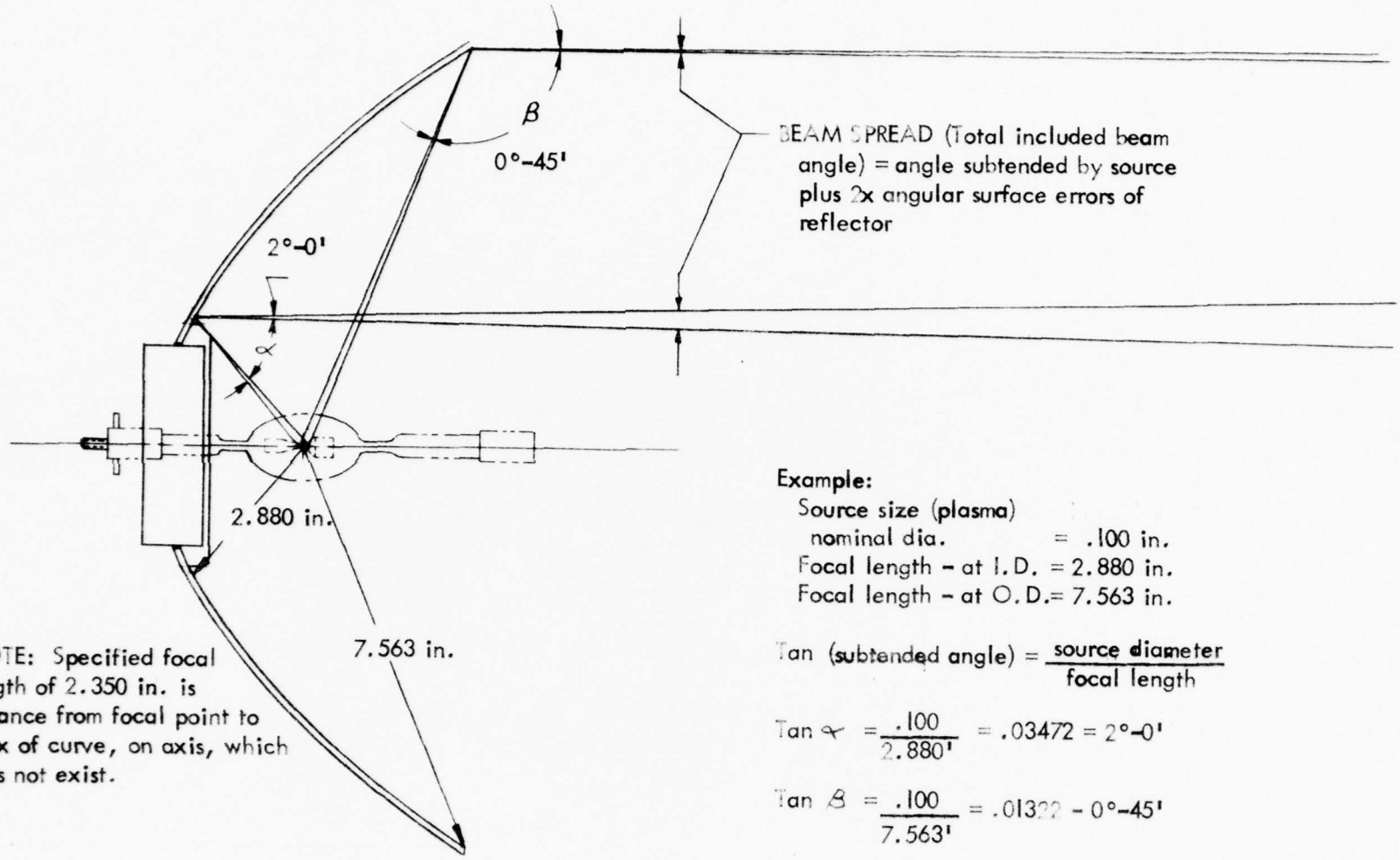
technique which will be described in more detail later in this report.

3. Development of Improved Test Techniques

One of the goals of the program was to develop improved test techniques which would enable more precise evaluation and judgment of the qualities of individual reflector assemblies during the course of production and for final acceptance. It was desired to develop test criteria that would have a specific relationship to actual searchlight performance, so that a meaningful specification could be evolved, which would, insofar as reflector performance was concerned, virtually guarantee attainment of all searchlight performance specifications relative to peak beam candlepower, beam holeing and general beam angle requirements.

The relatively deep, low f number reflector configuration utilized in the AN/VSS-3 Searchlight, although specified to have a focal length of 2.350", in fact, combines a multiplicity of actual focal lengths. Figure 6 illustrates the typical variations in focal lengths which occur.

Since the effective radiation source, or plasma ball, of the xenon short arc lamp is reasonably symmetrical and therefore exhibits the same general, overall dimensions when viewed from different angles, the actual beam spread varies as a result of reflection from different portions of the reflector, due to the varying focal lengths. Because of this variation, angular deviations, or anomalies, of the reflector near the rim, where focal lengths are longer, produce a different effect on performance than do similar deviations or anomalies near the center of the reflector.



BEAM SPREAD (Total included beam angle) = angle subtended by source plus 2x angular surface errors of reflector

Example:

Source size (plasma) nominal dia. = .100 in.
Focal length – at I.D. = 2.880 in.
Focal length – at O.D. = 7.563 in.

$$\text{Tan (subtended angle)} = \frac{\text{source diameter}}{\text{focal length}}$$

$$\text{Tan } \alpha = \frac{.100}{2.880'} = .03472 = 2°\text{-}0'$$

$$\text{Tan } \beta = \frac{.100}{7.563'} = .01322 - 0°\text{-}45'$$

NOTE: Specified focal length of 2.350 in. is distance from focal point to apex of curve, on axis, which does not exist.

FIGURE 6 FOCAL LENGTH AND BEAM ANGLE VARIATIONS

Similarly, test results obtained with the currently specified "sphere of confusion" test, in which a .040" sphere of confusion is specified, are somewhat meaningless, since the theory and formulas used to establish test parameters are based on the focal length as (traditionally) measured, along the axis of the reflector, and do not take into consideration actual focal distances.

To enable a more specific evaluation of the effect of the variable focal distances on circle of confusion test results, the reflector surface was arbitrarily divided into three zones. These zones were defined by dividing the total effective radiation angle of the source (as defined by the total solid angle subtended by the source between the rim and hub of the reflector) into three equal segments. Although the polar energy distribution of the xenon short arc lamp is not completely uniform, this division was arbitrarily chosen as a reasonably effective way of dividing the total beam energy into three zones, rather than by other techniques such as division of the reflector surface area, etc. Figure 7 illustrates this division of energy and the resultant projected sections of the reflector which relate to each zone.

A masking technique was evolved, whereby each of the zones could be masked individually, or in conjunction with other zones, to allow the characteristics of each individual zone to be independently evaluated relative to the sphere of confusion test. As was expected, angular deviations occurring in any of the three zones produced the same general degree of beam deviation at the aperture of the integrating sphere, but the accuracy of measurement of the effect of such deviations or anomalies was progressively masked as the zonal tests progressed from rim to

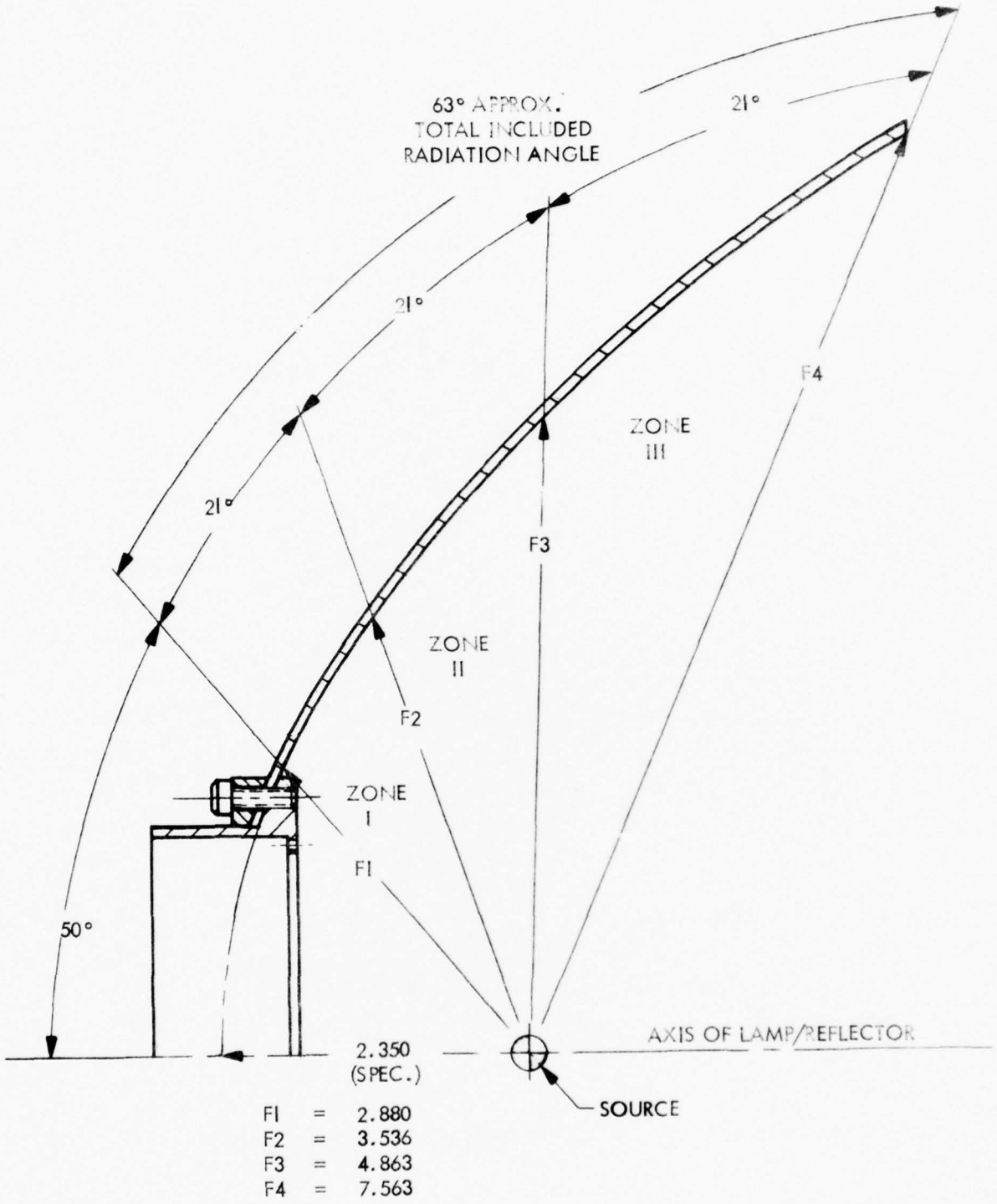


FIGURE 7 DIVISION OF REFLECTOR INTO 3 ZONES

center of the reflector due to the increase in magnification factor of the test source, which is not considered at all in the existing test procedures.

The specified test procedure, in defining the allowable aperture size through which 90% of the energy must pass for acceptance, apparently assumes that the ".040 in. equivalent sphere of confusion" is a meaningful measurement of the cumulative maximum allowable geometric deviations of the reflector resulting from "point source" ray tracing techniques. In fact, the test source is not infinitely small, but has measurable dimensions (which in themselves are not symmetrical due to the coiled filament characteristics of the test lamp).

The mathematics involved with determining test aperture size are based on a magnification factor which is the ratio of the focal length of the parabolic collimating mirror divided by the focal length of the mirror assembly being tested. However, the filament dimensions of the test source are also magnified by this same ratio. Per the specification, the magnification factor (derived by dividing the 240 in. focal length of the parabolic collimating mirror by the 2.350 in. focal length of the subject reflector) is 102.13. If the specified factor is used, the .040 in. sphere of confusion results in an "equivalent" aperture of 4.085 inches, through which 90% or more of the energy from the reflector being tested must pass. The average dimensions of the filament of the test source are .012 in. in diameter x .030 in. long. When multiplied by the magnification factor these dimensions become 1.226 in. x 3.064 in. respectively, which when compared to the test aperture diameter of 4.085 in. variously occupy from 30% up to a maximum of

75% of the total aperture diameter. These are unreal numbers, however, since that portion of the reflector along the axis, which by calculation produces the magnification factor of 102.13 does not, in fact, exist. (See Figures 6 and 7).

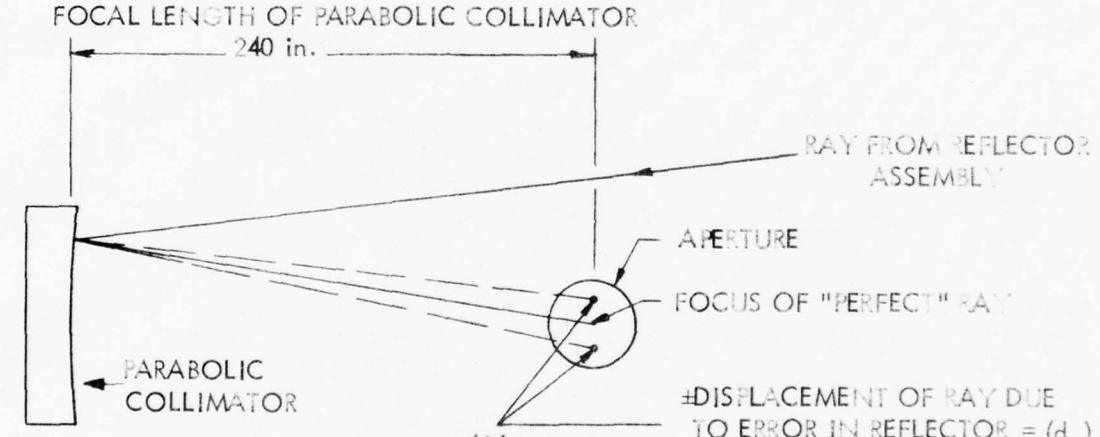
It becomes obvious then that even with a geometrically perfect reflector, the size of the re-imaged point source filament, since it is not constant, actually allows for greater angular reflector errors to be present in those portions of the reflector which are "seeing" the smaller portions of the filament where the test aperture size is only 30% occupied by the re-imaged filament, than for those portions of the reflector which "see" the long dimension of the filament, whose projected re-image occupies 75% of the test aperture.

This anomaly of the test procedure itself can actually permit a slightly astigmatic reflector whose projected flash pattern is not round, but oval, to test very nearly as good as a more accurate, round reflector, if the orientation of the non-symmetrical filament and the distortion of the reflector are in the proper relationship to one another.

The greatest test inaccuracy occurs, however, not due to the above factors, although the same ratio of source length to width applies, but to the variety of actual focal distances which occur, and which directly relate to magnification of the source size.

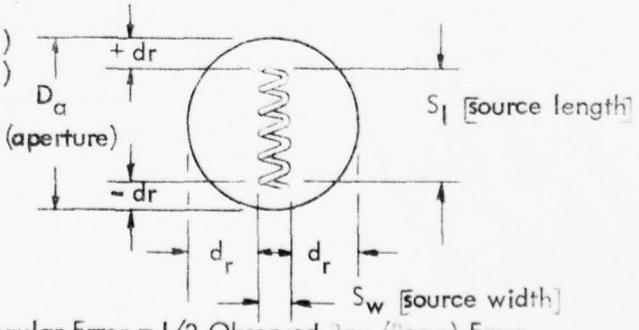
If the sphere of confusion test is applied as presently specified, progressively larger reflective errors, from center to rim of reflector, can occur without the test detecting them. Figure 8 illustrates, and lists in tabular form, the actual variations in

Reflector Focal Lengths			Magnification		Reflector Error Allowable with Present .040 Test Spec. Aperture (4.085 in.-Source)	
Location	Zone	Inches	Factor (X)	.012" W x .030"L "Point Source"	Width: inches - angle	Length: inches - angle
Spec. (axis)	All	2.350	102.13	1.226 x 3.064	2.859 ±10 $\frac{1}{4}$'	1.021 ±3 $\frac{3}{4}$'
f1	1	2.880	83.33	1.000 x 2.500	3.085 ±11'	1.585 ±5 $\frac{3}{4}$'
f2	2	3.536	67.87	.814 x 2.036	3.271 ±11 $\frac{3}{4}$'	2.049 ±7 $\frac{1}{3}$'
f3	3	4.863	49.35	.592 x 1.480	3.493 ±12 $\frac{1}{2}$'	2.605 ±9 $\frac{1}{3}$'
f4		7.563	31.73	.381 x .952	3.704 ±13 $\frac{1}{4}$'	3.133 ±11 $\frac{1}{4}$'



ANGULAR DEVIATION: $\text{Tan} \propto = \frac{o\ (dr)}{a\ (240\ \text{in.})}$

D_a = Diameter of aperture (in.)
S_l = Length of source (in.)
S_w = Width of source (in.)
$d_r = \pm 1/2\ (D_a - S_l)$
or $\pm 1/2\ (D_a - S_w)$



Reflector Angular Error = 1/2 Observed Ray (Beam) Error

FIGURE 8 SOURCE MAGNIFICATION VS. REFLECTOR ERRORS

magnification of the test source, as reproduced at the plane of the test aperture, for the various focal lengths actually occurring at the beginning and end of each of the three zones.

If the actual size of the test source is not taken into account, and the source is considered to be infinitely small, then the entire aperture diameter of 4.085 in. would represent the total allowable excursion of rays due to mirror errors, or inaccuracies. If this were the case, the total allowable angular beam deviation would be approximately $\pm$ 30 minutes (total included beam angle of 1°) and would be representative of reflector surface accuracy permitting errors, or deviations from a true parabola, up to $\pm$ 15 minutes of angle (slope error). Since the specification for searchlight operation in the compact mode requires that 90% of the peak beam energy be contained within a total beam spread of 1°, $\pm$ $1/4^{\circ}$, and since the minimum beam angle subtended by the 1 kilowatt xenon source (assuming perfect reflector geometry) is approximately $3/4^{\circ}$ minimum, (with the majority of the beam subtending a larger angle, see Figure 6), it becomes apparent that the test source size must be taken into account, and that reflector slope errors of $\pm$ 15 minutes ($1/4^{\circ}$) cannot be tolerated.

Figure 8 also lists the reflector angular errors which, when combined with the magnified source size resulting from the various focal lengths listed, could result from the use of a test aperture of 4.085 in. diameter. It can be seen that, for these conditions, allowable reflector errors run from $\pm$ 3-3/4 minutes to $\pm$ 13-1/4 minutes of angular slope error.

Previous searchlight performance tests, utilizing reflectors of a variety of angular accuracies, have indicated that adequate peak beam candlepower readings are difficult to achieve, and a severe tendency for beam holeing exists, when the angular error of the reflector surface exceeds approximately $\pm$ 5 minutes of arc slope deviation. This figure is exceeded, when utilizing the .040 in. sphere of confusion equivalent test aperture for all focal lengths existent within the active reflector surface. For these reasons, it was determined that the test aperture size must be reduced.

A series of test apertures were produced having a variety of aperture diameters which represented the short, average, and long focal lengths for each zone chosen. Utilizing reflectors of known performance in a searchlight, comparative point source "sphere of confusion" test results were obtained with the various diameter apertures combined with zonal masking of the reflector, matching the zone being tested to the proper aperture size (as derived from the magnification factor resulting from the actual focal length involved for that zone).

The results of these tests indicated that a specific quality, or accuracy, of reflector could definitely be identified through application of these test techniques. Reflectors so chosen did, in fact, exhibit substantially higher peak beam candlepower and less beam holeing than reflectors chosen only by the presently specified test procedures, utilizing the single 4.085 in. diameter aperture.

One serious disadvantage existed, however, relative to the use of the multiple aperture plates and reflector masking techniques. The time required for acquisition

and recording of valid test data, for both in-process testing and final acceptance testing, increased by many orders of magnitude. It was decided that a simpler test technique which would retain the advantages of the multiple aperture and mask test procedures was required.

Through empirical comparison of performance readings obtained using the multiple aperture/zonal masking technique with readings obtained with various aperture sizes, but without reflector masking, it was determined that reflectors of approximately comparable quality and performance could be detected and chosen utilizing only two aperture sizes, and without the requirement for zonal masking.

Due to the non-symmetrical nature of the point source filament, absolute definition of "allowable reflector slope error" is difficult. However, it was determined that a test aperture of 2.010 in. diameter, (equivalent to a .5 millimeter sphere of confusion, slightly smaller than 1/2 of the present specification), with an acceptance requirement of a minimum of 90% of total energy, provided a meaningful criteria for the selection of reflectors which would meet or exceed all searchlight performance requirements. Additionally, a second, and smaller, test aperture having a diameter of 1.407 in., (equivalent to a .35 millimeter sphere of confusion), with an acceptance criteria of 80% minimum, provided an overall angular tolerance control which would further limit reflector angular deviations and serve as an "above average quality" indicator.

The use of this smaller test aperture appears to further insure that reflector angular deviations remain small enough that undesirable beam holeing in the spread beam

mode is limited to well below 5%. In fact, reflectors which successfully passed the two aperture tests described above, when tested in a searchlight, exhibited virtually no measurable beam holeing, and provided average peak beam candlepower readings of over 110 million.

Other tests were also considered and evaluated, such as an integrated performance test based on a combination of total energy returned through an aperture of a given diameter related to total luminance of the test source. Such a test could effectively integrate reflector angular accuracy with reflectivity values. However, due to the complexity of calibration requirements, requirement for compensating for reflectivity values of the collimating mirror, etc., coupled with the fact that the previously described tests appeared capable of selecting reflectors which would substantially out perform the searchlight specifications, further activities related to the development of other more complex tests were discontinued.

4. Development of the Re-designed Reflector Assembly

As noted in the Engineering and Design discussion of this section, the chosen Configuration 2 re-design was progressively "de-bugged" and finalized. The usual tooling, technique, vendor education and inspection criteria problems occurred and were resolved as each problem was identified.

Initial difficulties in hub fabrication were associated with obtaining the required near perfect contour match to the replica reflectors which were produced from the new parabolic electroforming tooling. Initial attempts to produce the matching hub contour utilizing a template made by tape controlled milling techniques

resulted in a "mismatch" which was severe enough to produce extensive distortion of the center of the reflector. Eventually, a tracer template fabrication technique was evolved through replication of the replica reflector itself. Even with this more precise approach, certain problems remained.

It was determined that normal "chucking" techniques employed to grip the steel tubing during machining of the hub imparted enough distortion that, when the hub was released from the chuck, excessive run out resulted. A series of special holding tools were evolved to insure concentricity, perpendicularity and flatness, as required, in the end product hub.

Searchlight interface testing performed at Varo, Incorporated brought to light a problem of tolerancing and quality control associated with the inside diameter of the hub (Drawing reference dimension A), the flatness and perpendicularity of the attachment face, (reference plane B), and a requirement for control of radius at the interface corner between the two, both on the hub and on the searchlight frame itself.

Before these areas were modified and toleranced, on both hub and searchlight, reflector deformation upon assembly to the searchlight, evidenced by ovality of the projected beam and severe loss of performance, was found to be quite severe. The problem was traced to inaccuracies in machining and/or final dimension and tolerance, existent in both the reflector hub and the searchlight frame. Of prime concern, was a tendency of the searchlight frame to become somewhat oval after milling of the side slot required for infrared filter activation. This problem was

solved by a change in machining techniques and jigging by the searchlight prime contractor. Concurrently, PII undertook a re-tolerancing and modification of tooling and machining techniques to assure adherence to the new requirements for the hub. Precise inspection tools were also procured to insure that the newly added tolerances were held.

As previously mentioned, although the eight (8)-bolt version of Configuration 2 provided substantially better support and increased reflector gripping relative to the original design, some slippage, and resultant residual deformation, was experienced by both PII and the prime searchlight contractor after the units were subjected to multiple flexing cycles at operational temperatures. The change to a 12-bolt configuration, however, accompanied by a hub/reflector lapping technique to improve the fit and increase coefficient of friction at the hub/reflector interface totally eliminated any further "slipping" or reflector movement problems.

During the development and finalization of the new hub/retainer configuration, certain mirror assemblies, when tested on the optical range, evidenced two related defects. One problem was observed as a slightly oval, or out-of-round flash pattern, and the second as a localized distortion at the I. D. of the reflector at twelve distinct points adjacent to the clamping screws. In earlier versions, the oval flash pattern had been traceable directly to an out-of-round hub condition which had resulted from the deflective forces of lathe chucking, prior to the development of the new holding tools. In later instances, however, careful measurement of the hub indicated no such gross machining defect, yet periodically, slightly oval flash patterns were detected.

The problem was eventaully isolated as relating to the method of tightening and torquing of the reflector clamping bolts. A bolt tightening sequence, and torquing procedure, was experimentally developed which, when combined with the final contour lapping, eliminated the problem, and neither of the above mentioned hub related defects recurred.

It was found to be important, however, to insure that the hub was held in an undistorted manner during the lapping of the hub to the reflector, and during subsequent assembly of the hub, reflector and retainer. Since the reflector is basically a flexible element, it is extremely important that it be held in a normal, nondistorted condition during the lapping operation and, conversely, that during assembly, the hub, which will become the final governing element, be maintained in an undistorted condition. Special assembly tooling is shown in Figure 9. The assembly tool is constructed in such a manner that the pressure plate and hub seat duplicate the dimensioning and tolerances of the point of attachment to the searchlight. When the hub is placed on the hub seat and the pressure plate and retaining nut added and tightened, flatness of the hub mounting surface (reference plane B) is assured. As a periodic check of the accuracy of the hub/reflector lapping procedure, a blueing technique is utilized to assess the degree of fit between the hub and the reflector in the normal, unstressed condition. If a 100% contact is evident, it can be assumed that the lapping procedures were satisfactory.

After careful inspection to insure that all potential burrs, which may be residual from the drilling or elox hole cutting processes, and other possible foreign materials

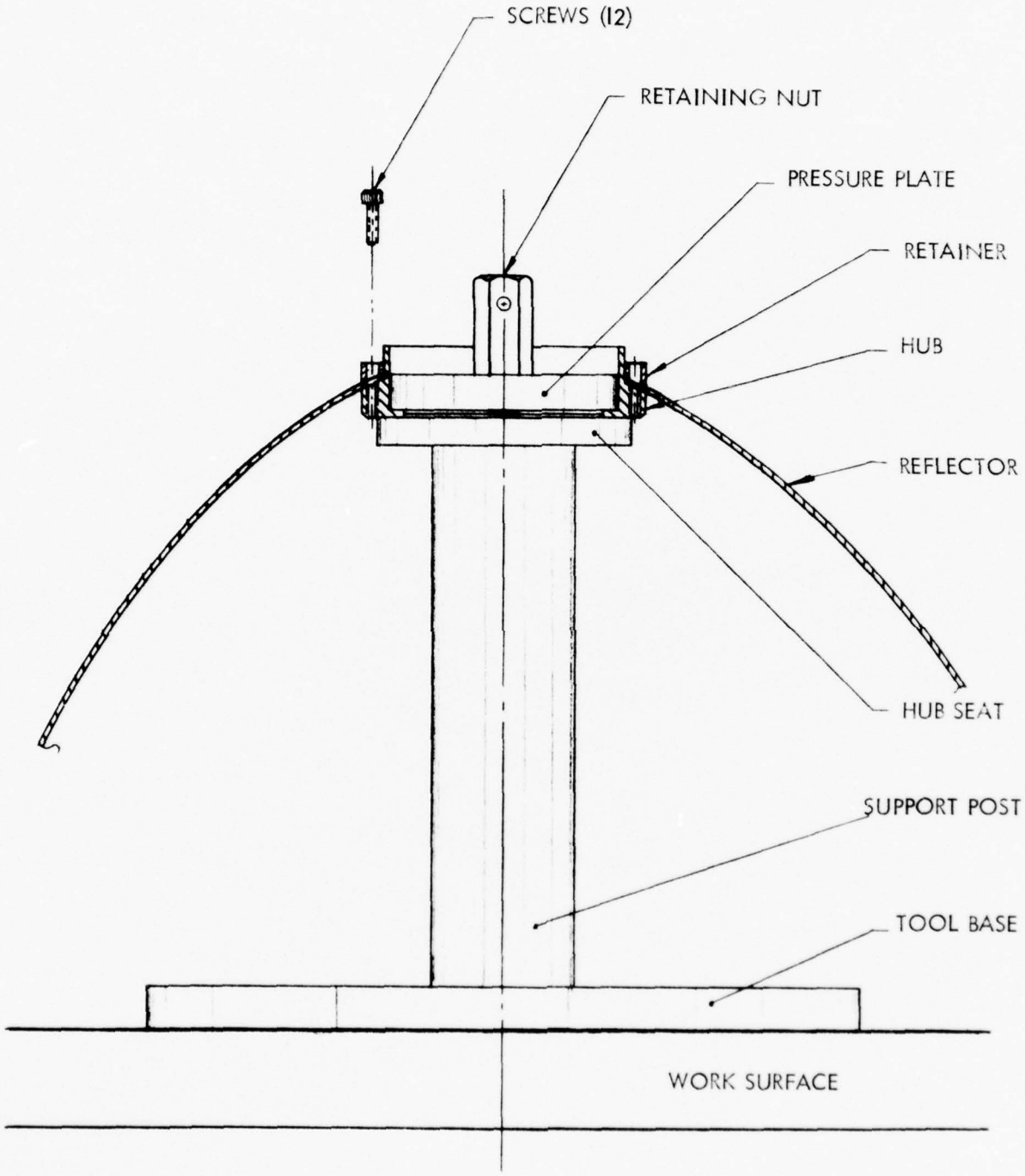


FIGURE 9 ASSEMBLY TOOLING

have been removed, the reflector is positioned on the hub, the retainer is added and the bolt tightening procedure accomplished.

Final qualification tests included the new static grid and circle of confusion tests, followed by 100% over-flexing in the modified searchlight/test fixture as well as multiple flexings in the searchlight at operational temperatures. Figure 10 shows the varying degrees of deflection which the re-designed units were subjected to, the minimal residual deflection and the virtually nonexistent performance degradation that resulted.

In order to provide the most severe test conditions possible in the searchlight, the mirror deflection linkage was adjusted to its maximum, or until it just contacted the reflector when in the compact mode. Then, upon actuation, the reflector was subjected to the full travel, or stroke, of the actuating cam. As previously noted, this represented a travel of between .260 and .270 inches, substantially more than that required to produce the specified beam angle for the spread beam mode.

To assure that no bending or movement relative to the hub was occurring, each mirror was retested prior to installation in the GFE Searchlight. The searchlight was then turned on, adjusted to its rated power and allowed to operate for approximately two hours, or until a reflector/hub temperature of at least 200° F. was attained. The reflector heating cycle is shown in Figure 11. Temperatures were measured by means of a thermocouple attached at the rear of the reflector under one of the reflector clamping screw heads. After the reflector had attained a temperature of over 200° F., it was subjected to 50 complete cycles between compact and spread

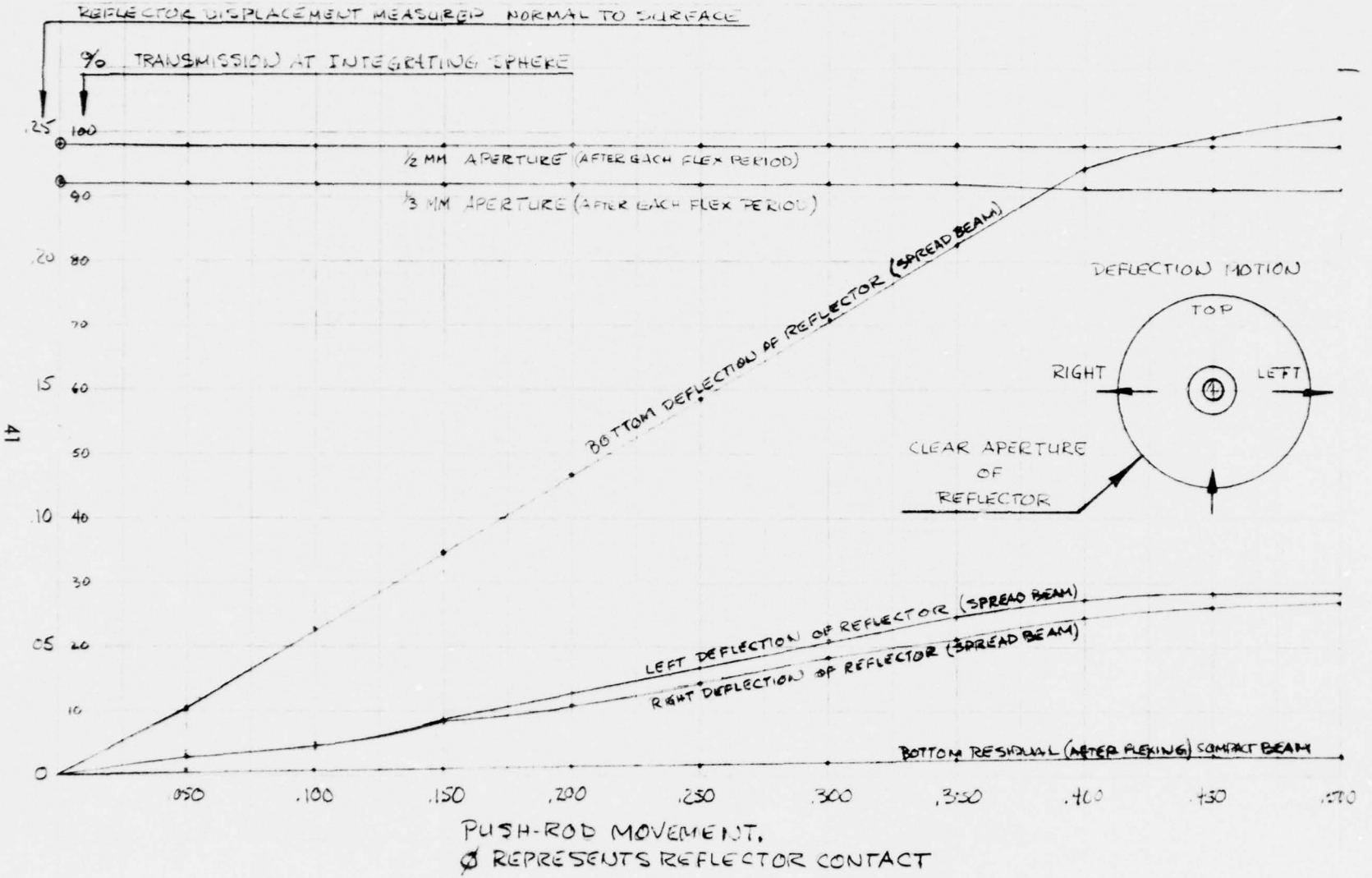


FIGURE 10 DEFLECTION VS PERFORMANCE, RE-DESIGNED REFLECTOR ASS'Y

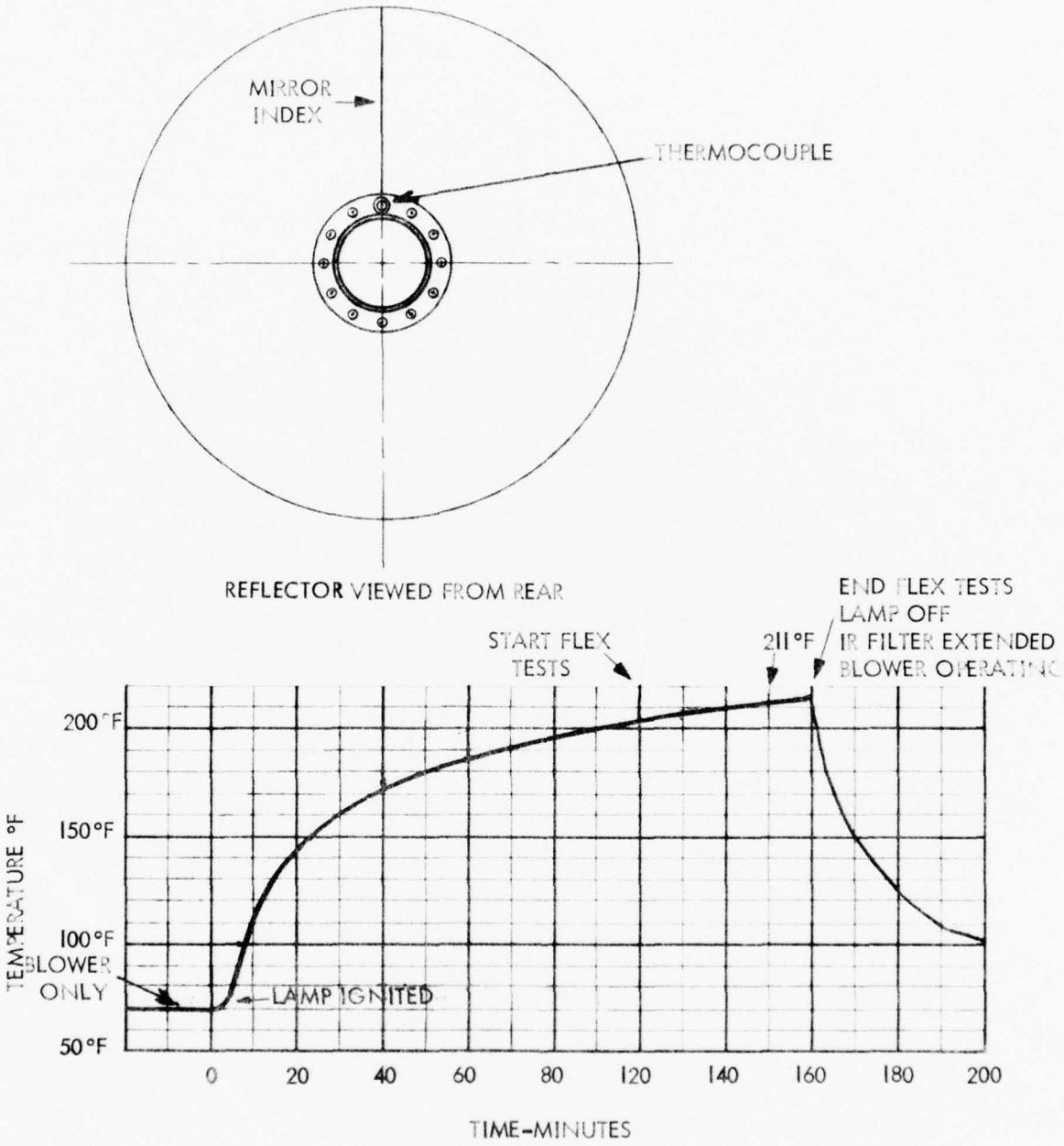


FIGURE 11 REFLECTOR/RETAINER TEMPERATURE

beam mode.

At the completion of the operational tests, the peak beam candlepower of the searchlight was again measured and compared to the values obtained prior to operational flexing. Subsequently, the reflector assembly was removed from the searchlight and subjected to grid and circle of confusion tests. When no measurable degradation was observed, either in searchlight operation or in individual reflector assembly tests, the reflector assembly was considered to be stable and satisfactory.

5. Finalization of Design, Drawings and Specifications

During the course of the program, as each corrective measure was investigated and implemented, corresponding design, drawing and specification changes were made and documented to reflect the current status, as it existed.

Upon completion of all test and evaluation phases, and after thorough evaluation of all inputs made by both the COTR and Varo, Incorporated, (who had been conducting simultaneous evaluation in the course of their searchlight production), the new reflector assembly design was frozen.

A revised set of drawings was prepared to depict the reflector assembly and its components per the requirements of Exhibit A of the contract, No. A001, CLIN 0001.

It was desired by the COTR, that the new drawing package be totally inclusive, i.e.: in addition to complete description of all components, dimensions and tolerances, that it contain all necessary specifications for materials, finishes etc. so a separate specification would not be required. Additionally, it was desired that the new test

and acceptance specifications be included in the drawing package, rather than in a separate set of specifications which require reference to a number of different documents to determine overall procedures and acceptance test requirements.

PII has followed this desired approach in assemblying all of the drawings, specifications and related test and acceptance procedures in a single package. Because of the loss of legibility occasioned by the reduction of D-size drawings to report-size dimensions, the drawing package has not been reduced in size for incorporation in the body of the report, but is presented separately. To facilitate comparison to the new specifications and procedures relating to optical testing and related acceptance criteria, a compilation of the pertinent portions of each cited specification or document relating to optical testing procedures and acceptance criteria, per the existing drawings and specifications, is presented in Appendix C, together with related comments.

As previously noted, it is intended that these resultant drawings, specifications and procedures will provide a sound basis for the development of a new government drawing package and procurement specification which will result in substantially improved reflector quality.

6. Production and Test - 6 Deliverable Reflector Assemblies

Prior to initiation of this program, PII had produced new master optical tooling for the replication by electroforming of reflectors having a size and geometry conforming to the requirements of the SC-D-647010 reflector assembly. This new master optical

tooling had been produced with the objective of achieving an accuracy of parabolic contour and surface finish two to three times better than that which had previously been available. Optical tests confirmed that the new tooling was, in fact, capable of achieving these desired goals of increased accuracy.

Upon completion of the evolutionary design and development of the re-designed reflector assembly as previously described, six complete reflector assemblies were produced, as required by CLIN 0002, which embodied all aspects of the new design and fabrication techniques.

These six reflector assemblies, identified with PII serial numbers 37-14, 37-29, 37-72, 37-77, 37-78, and 37-79, were subjected to the following tests.

1. Projected grid tests, with photographs.
2. Revised sphere of confusion tests.
3. Deflection tests, out of searchlight, in .050 in. increments up to .500 in. total deflection (actuator travel).
4. Deflection while operating in searchlight at 200° F. or above, 50 complete cycles (compact mode to spread mode to compact mode).
5. Repeat of grid and sphere of confusion tests.
6. Focal point location, per the new specification.

The performance of all six reflector assemblies as related to the degradation, or rather, lack of degradation, when subjected to the progressive deflection tests, was quite similar. As an example, Figure 12 presents, in tabular form, deflection and performance data for reflector assembly number 37-77.

PUSH-ROD DISPLACEMENT BEYOND INITIAL MIRROR CONTACT	MAXIMUM BOTTOM DEFLECTION	MAXIMUM RIGHT DEFLECTION	MAXIMUM LEFT DEFLECTION	RESIDUAL BOTTOM DEFLECTION	.5 mm SPHERE OF CONFUSION %	.35 mm SPHERE OF CONFUSION %
.050	.0265	.0070	.0075	.0020	98.5	92.0
.100	.0560	.0115	.0106	.0022	98.2	92.0
.150	.0862	.0210	.0206	.0035	98.0	92.0
.200	.1162	.0272	.0320	.0044	98.0	92.0
PROBABLE MAXIMUM DEFLECTION STROKE						
.250	.1466	.0360	.0425	.0044	98.0	92.0
.300	.1777	.0446	.0523	.0056	98.0	92.0
.350	.2066	.0533	.0615	.0063	98.0	92.0
.400	.2366	.0625	.0694	.0078	98.0	91.5
.450	.2497	.0655	.0705	.0082	98.0	91.5
.500	.2559	.0670	.0711	.0079	98.0	91.5

NOTE: All dimensions are in inches.

FIGURE 12 DEFLECTION VS. PERFORMANCE, REFLECTOR #37-77

The dimensions listed for "maximum bottom deflection" relate to the actual amount of movement, measured in inches, of the bottom rim of the reflector in a direction normal to the reflector surface, resulting from the noted push rod, or deflection mechanism travel. The corresponding (but opposite direction) deflection of the right and left-hand sides of the mirror is also noted, as is the residual bottom deflection which remained after removal of the deflection force after each progressive .050 in. deflection movement. Percent transmission or "sphere of confusion" performance test results are also shown for the .35 and .5 millimeter equivalent aperture plates. These tests were performed after the progressive deflection tests, but prior to searchlight operational tests.

It should be noted that the residual bottom deflection resulting after "normal maximum" deflection of .200 in. of push rod travel was only approximately .0044 inches, and did not result in any meaningful reduction in reflector performance. Even after severe overdeflection of .500 in. of push rod travel, the residual bottom deflection amounted to only approximately .008 inches and with a performance drop of 0.5 percent.

Reflector number 37-77 was of exceptionally high performance. With a reflector of this quality, the beam or image at the integrating sphere aperture has been noted to be substantially smaller than the actual aperture dimension. For this reason, minor beam displacements caused by the .004 to .008 in. residual bottom deflection remain within the overall aperture dimension, and little or no performance loss is measured. With reflectors whose initial performance is not quite so good, and

whose re-imaged energy just falls within the aperture dimension, a similar residual bottom deflection has been observed to result in a greater measured loss of performance, as much as two or three percent. This can be explained by the fact that, when the energy bundle just falls within the aperture dimension prior to deflection, the slight displacement of the re-imaged beam, resulting from the residual deflection, causes a portion of the beam to fall outside of the aperture dimension, resulting in a measurable performance drop.

Figure No. 13 lists the percent transmission, or "sphere of confusion performance" for both aperture plate sizes (.5 millimeter and .35 millimeter), and focal point location for each of the six deliverable reflector assemblies after completion of all tests listed above.

Verification of all test results and final inspection of other aspects of the reflector assemblies in accordance with PII Drawing No. 876-001 was made at the PII facility in Pasadena by the COTR. One unit, serial number 37-77 was "shipped in place" and retained at PII for further testing in the GFE Searchlight Assembly. The other five reflector assemblies were shipped directly to Ft. Belvoir per Section H-2, sub-paragraph B of the referenced contract immediately after completion of testing and acceptance at PII.

After completion of subsequent searchlight tests, reflector assembly serial number 37-77 was shipped to Ft. Belvoir, Virginia, together with all government furnished equipment (searchlight, controls, cables and related items) which had been furnished to PII for use during performance of contract.

REFLECTOR ASSEMBLY SERIAL NUMBER	**FOCAL POINT LOCATION (in.)	PERFORMANCE @ .5 mm SPHERE OF CONFUSION %	PERFORMANCE @ .35 mm SPHERE OF CONFUSION %
37-14	1.751	98.5	92.0
37-29	1.750	97.5	91.75
37-72	1.752	98.2	92.2
*37-77	1.747	97.9	91.2
37-78	1.749	98.0	89.5
37-79	1.743	97.0	89.0

* Unit retained at PII for further searchlight testing. Shipped to Night Vision Laboratory with return of all other G.F.E.

** Measured dimension from "best focus" to point of attachment to searchlight assembly. Specified nominal dimension is: 1.750 inches.

FIGURE 13 FINAL TEST RESULTS FOR 6 DELIVERABLE REFLECTOR ASSEMBLIES

7. Possible New Reflector Performance Criteria

During the course of qualification and production tests of the AN/VSS-3 Searchlight Assembly at Varo, Incorporated, searchlight performance degradation was experienced which was traced to a deformation, or flattening, of the bottom portion of a new reflector assembly.

The reflector assemblies which were being incorporated in production searchlights at Varo, were similar in all respects to the improved reflector assemblies as developed during the course of this program. During the extensive developmental testing at PII, after the reflector "slipping" problems were resolved, no residual reflector deformation was observed as a result of any of the tests described.

The reflector assembly in question, and all other similar reflector assemblies of the new design configuration, had been producing peak beam candlepower readings well in excess of 100 million PBCP with near "zero" beam holeing when subjected to normal operational tests by Varo. However, it was learned, a new test condition had been applied, apparently for the first time.

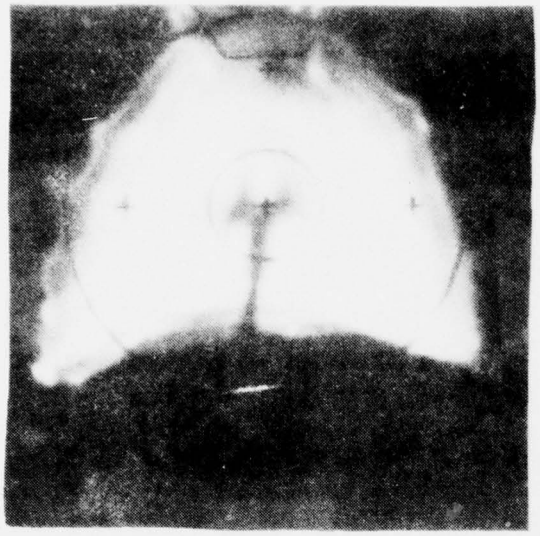
During the course of this newly developed qualification test, the reflector assembly was left in its flexed, or spread beam configuration, condition for a prolonged period of time at elevated temperatures. Normally, because of system design and sequencing, the reflector mechanism returns the reflector to the unflexed, compact beam mode. After being subjected to this new test condition, the reflector assembly was re-tested and found to have suffered severe performance degradation relative to peak beam candlepower. The visual flash pattern, as observed on a target, had also degraded

from a tight round pattern to one having an obviously flat bottom.

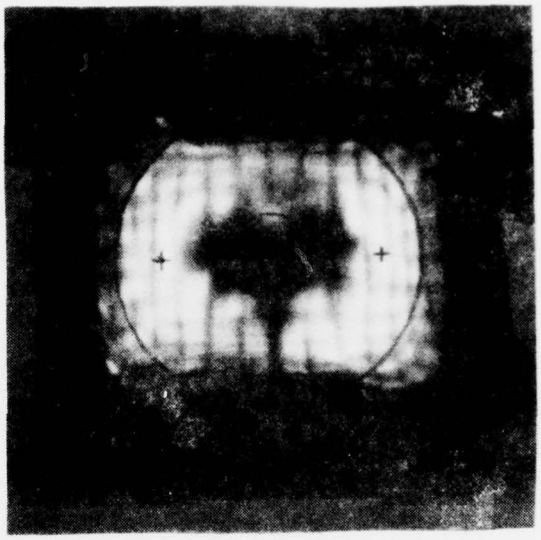
It was first thought that this reflector assembly, which had apparently taken a "permanent set" must have been subjected, accidentally, to some extreme environmental condition such as over-temperature, shock, or an unknown combination of conditions which had produced the degraded condition.

The deformed mirror was returned to PII where the degradation was immediately confirmed by application of projected grid and sphere of confusion tests. A photograph of the projected grid test of this reflector (serial number 37-49) as returned from Varo, is shown in Figure 14 a, which clearly shows the severe deformation which existed. Repeated tests at Varo with other new reflector assemblies produced similar results.

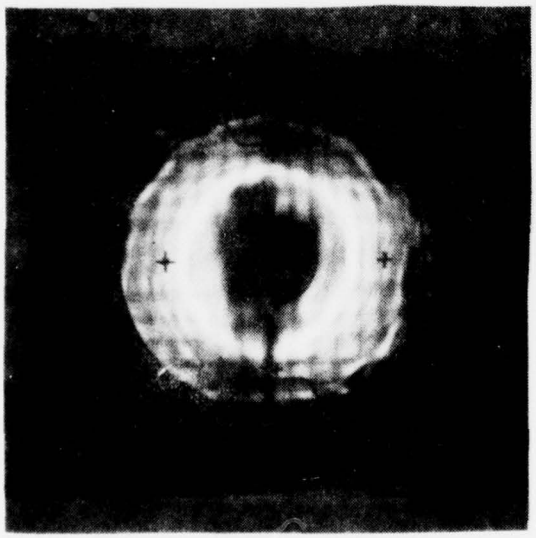
Comparable test conditions were simulated at PII by operating the searchlight in the infrared mode while partially restricting the air to the heat exchange system, causing the reflector temperature (which was monitored by a thermocouple as previously noted) to rise to approximately 210 to 215° F. The reflector assembly was then actuated to the spread beam, or deflected, configuration and allowed to remain in the deflected mode for progressive periods of time. After each approximate half-hour increment, the searchlight was returned to the compact mode and the appearance of the projected beam observed on the target. During approximately the first hour of operation no visual deformation was observed. At approximately one-and-one-half hours, however, a slight flattening of the image at the bottom was noticed. At the end of two-and-a-half hours a definite flat had developed at the bottom of the beam, and after five



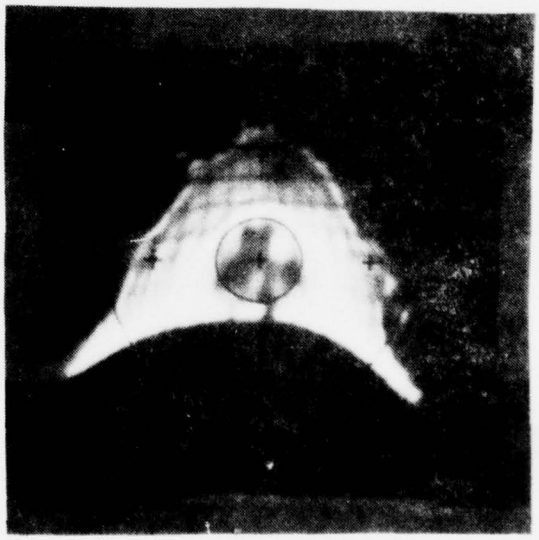
a. Reflector Assembly #37-99 As Returned From Varo, Inc.



b. Reflector Assembly #37-99



c. "Old Style" Reflector Assembly #43-165 Prior to "High Temperature", Prolonged Deflection Test



d. "Old Style" Reflector Assembly #43-165 After "High Temperature" Prolonged Deflection Test.

FIGURE 14 PROJECTED GRID TEST PHOTOS

hours of operation in the flexed condition the flattening and distortion was clearly evident.

The projected grid photograph, Figure 14 b, shows reflector number 37-99 after undergoing a deflection duration of two-and-one-half hours. Flattening at the bottom of the picture is that which was induced by the prolonged high temperature deflection at PII. The flattening at the top of the picture is that which was previously induced by operation under the test conditions imposed at Varo, Inc. It can be seen that the type and extent of degradation is nearly identical.

Careful examination of the deformed reflectors confirmed that, unlike all previously experienced deformations in which reflector movement relative to the adaptor/retainer components had been the prime cause for degradation, these reflectors had not slipped, or moved within the hub in any way, but had, in fact, taken a permanent set or bend in the area of the mechanical deflector.

It was also noted that, with the passage of time, the deformation tended to lessen and, after a few days, had almost entirely disappeared.

Additional reflector assemblies were tested, both at Varo, Incorporated, and at PII under these newly developed environmental conditions of elevated temperature and prolonged deformation, and in each case the reflectors retained a certain degree of "permanent set."

In an effort to determine if the characteristics of the electroformed nickel had changed, a number of SC-D-647010 reflector assemblies that had been produced

more than two years previously were re-tested under the new conditions. The "old style" reflectors exhibited exactly the same characteristics, taking on a pronounced deformation in the area where the deflective forces were applied. Figures 14 c and d show a projected grid test of one of the old style reflector assemblies, number 43-165, both before and after the high temperature - prolonged deflection tests.

These tests indicated conclusively that the characteristics of the electroformed nickel utilized in the formation of the reflectors had not changed during the current production run, and that the earlier production reflectors appeared just as susceptible to this type of deformation as the more recent versions.

A number of reflector assemblies of both "old style" prior production and current versions were subjected to prolonged periods (overnight in some cases) of spread beam mode deflection but at ambient temperature, nominally 72 to 75° F. Only slight residual deformation and loss of performance was experienced under these conditions.

Although 210 to 220° F. would not normally be considered a "high temperature" condition, it became apparent that prolonged deformation at these temperatures did produce severe residual deformation of the reflector itself.

Preliminary discussions with metallurgists and representatives of International Nickel Corporation indicate that the problem may be due to the "cold creep" characteristics of certain metals. It has long been known that certain types of stainless steel, and

many "pure metals" are subject to "cold creep" deformation in that they will exhibit changed dimensional characteristics when subjected to deforming forces for prolonged periods of time. Additionally, elevated temperatures, even though not necessarily extreme, tend to speed up this deformation tendency.

It has been suggested that fabrication of the electroformed reflectors utilizing a nickel/cobalt alloy may provide the necessary changes or restructuring of the grain condition of the electrodeposited metal in such a way that this "pure metal cold creep" tendency will be minimized or eliminated.

It appears that the potential for deformation under these conditions has apparently always existed in the 1 KW electroformed reflectors. Due to previous test and evaluation procedures, however, it appears that the combination of conditions which cause permanent deflection had either not previously been encountered, or the tendency for such deformation had been masked by the more pronounced, and readily detectable "slippage" of the reflector within the adaptor/retainer.

Considerably more evaluation, of both a theoretical and empirical nature, will be required before the exact cause of this deformation can be totally identified. At that time it may be possible, through variations in electroforming technology or materials, to produce a reflector having all the advantages of the currently developed units but which will overcome this recently experienced problem.

SECTION III

CONCLUSIONS

Evaluation and analysis of all activities undertaken and data or information developed during the course of the program leads to a number of conclusions. The reader may, in some instances, form different opinions or reach other or modified conclusions based on his own interpretation of the information presented. However, the conclusions presented herein are considered basic, and the logical result of the overall effort.

1. Present Design - SC-D-647010 Reflector Assembly

The testing program undertaken conclusively verified the suspected instability of the presently specified reflector assembly under certain deflection mode conditions. Reflector "slippage" within the adaptor/retainer components was proven beyond a doubt. Analysis of material properties and thermal expansion characteristic of the various components indicated that the overall design incorporated a number of undesirable conditions. A re-design was totally justified.

2. Re-Designed Reflector Assembly

The re-designed reflector assembly evolved from a combination of theoretical, intuitive, and empirical activities which, after thorough "de-bugging" appeared to provide effective answers to virtually all previous problems. The new design incorporated a substantially stronger basic hub assembly with improved interface dimensions and tolerances as related to point of attachment to the searchlight assembly. The new hub/retainer configuration also provided a substantially more rigid assembly

with reflector clamping forces substantially increased to eliminate the previously observed slipping under all test and/or operational conditions.

Tooling and fabrication techniques evolved which, together with the improved master optical tooling, provided markedly increased reflector assembly accuracy and performance. The new material combinations should substantially increase stability relative to differences in thermal expansion characteristics.

Incorporation in searchlight production of reflector assemblies which conform to the new design and fabrication concepts has conclusively verified that marked increases in peak beam candlepower and beam uniformity (minimization or elimination of previously experienced beam holeing in the spread beam mode) has, in fact, been a direct result of the re-design.

3. Improved Optical Tests

Detailed and conclusive information has been gained through application of zonal test techniques which conclusively indicates that the prior performance specification and test techniques were inadequate to guarantee selection of high performance reflectors. Additionally, shortcomings of the presently specified optical testing procedures, particularly as related to the test illumination source itself, became obvious and changes or corrective measures were investigated and evaluated.

It was conclusively demonstrated that a relatively simple and inexpensive testing technique, if properly coupled with a tightened specification for optical performance, can provide an effective means for the selection of high quality reflectors on both

an in-process basis and for final acceptance. Such improved reflectors will, when properly installed in a searchlight assembly in a combination with other conforming components, virtually guarantee attainment of all searchlight optical and/or performance specifications.

4. Unresolved Instability

The recently detected residual deformation associated with prolonged periods of spread beam mode operation at elevated temperatures is apparently a new, previously undetected problem. No immediate or readily apparent answer exists regarding either the exact cause for, or solution to the problem. Possibly, insufficient testing and evaluation was undertaken or accomplished when achievement of beam spread through reflector deformation was initially suggested, or during the ensuing years of production and production testing by the various contractors who produced the AN/VSS-3 Searchlight Assembly.

SECTION IV

RECOMMENDATIONS

It is recommended that the following actions be taken:

1. Drawings and Specifications

The revised reflector assembly drawings and specifications should be incorporated into a new Government drawing package and procurement specification so that future procurements may benefit from the improved performance. Simplified searchlight assembly and alignment should result from the higher quality reflector assemblies.

2. Evaluation of Remaining Instability

The recently detected residual deformation, which results from sustained exposure of the reflector assembly to elevated temperature while in the spread beam configuration, should be further evaluated. A variety of modifications to the basic nickel electroforming technology are possible which may provide substantial improvement in stability and resistance to the observed deformation. Physical properties, grain structure and other parameters can be modified. Additives and alloying (such as the suggested nickel/cobalt combination) can be investigated. Although no "guarantees" can be made, in all likelihood the problem can be eliminated or at least minimized by such an investigation.

APPENDIX A

PII Procedure No. 236
Prepared by: B. Sojka
Approved by:
Date: December 3, 1968
Rev. No. A Date: 8/2/73
Page 1 of 8

PROCEDURE FOR SPHERE OF CONFUSION TEST (INTEGRATING SPHERE)

1.0 DESCRIPTION

This test is fundamentally a magnified re-image test with an integrating device. The purpose of the re-image test is to measure the overall geometric accuracy of the reflector being tested. The test is accomplished by placing a light source at the focal point of the mirror to be tested and projecting an essentially collimated beam onto a long focal length parabolic mirror of astronomical accuracy. The beam is adjusted to refocus at the focal point of the precision collimator mirror. Geometric errors in the test specimen are magnified by the ratio of the focal length of the precision collimator mirror to the focal length of the test specimen. The resultant magnified sphere of confusion at the focal point of the precision mirror can then be measured. This observed re-image size, when divided by the magnification factor, results in a measure of the sphere of confusion of the mirror being tested. The integrating sphere is used as a go-no-go gauge to eliminate the necessity of physically measuring the area or size of each re-image. By changing the aperture sizes, the percentage of energy passed by any given aperture can be determined.

2.0 EQUIPMENT

2.1 Collimating Mirror

23.375-inch hexagonal mirror with a 240-inch $\pm$ 2% focal length. Aluminized front surface. Surface accuracy better than 12-arc seconds.

2.2 Collimator Mirror Mount and Flash Screen

Mount for positioning of mirror provides capability for elevation adjustment. A preliminary alignment target is located concentric with the optical axis of the collimator mirror, and is hinged so that it can be swung out of the way during re-image testing.

2.3 Integrating Sphere

This unit consists of a 6-inch diameter by 6-inch long cylinder terminating in a 6-inch diameter hemisphere. Removable aperture plates are provided which are sized by the following formula:

$$D = \frac{FL_1}{FL_2} \times d$$

D = Diameter of aperture plate.

FL_1 = Focal length of collimator mirror (240").

FL_2 = Focal length of reflector being tested.

d = Circle of confusion "requirement" or "specification" for mirror being tested.

A light dependent resistor (LDR) is mounted in one wall of the integrating sphere so that it is only exposed to the opposite wall in a manner that

no light entering the orifice can directly impinge on it. The entire inside of the sphere is painted with 3-M Velvet Coating 100 series air dry enamel white, #101-A10. The aperture plates are painted on both sides with 3-M Velvet Coating 100 series air dry black, #101-C10. The unit is mounted at the focus of the collimating mirror (240") and is adjustable horizontally (x axis) and vertically (y axis).

2.4 Test Reflector Mount

A mounting device is provided to support the subject mirror during test. This mount provides for angular azimuth and elevation adjustments.

2.5 Lamp and Mounting

The source lamp is a Bausch & Lomb Type 71-71-44, 2.5-volt unit which is mounted on a support arm which is provided with x, y, and z axis adjustments.

2.6 Lamp Circuit

The lamp circuit consists of a controlled power supply in series with the lamp.

2.7 L.D.R. Circuit

The L.D.R. is connected in series with a 6-volt D.C. regulated power supply (or battery), and a microammeter having an accuracy of 1/2% and 400 ohms terminal resistance in all ranges, with ranges of 0-20, 0-50, 0-100, 0-200, 0-500, and 0-1000, micoramperes.

3.0 CALIBRATION

3.1 Aperture Plate Size Determination

The diameter of the aperture to be utilized to test any given reflector is determined as follows: (Examples given are for the 2.2 KW, M-60 Searchlight Reflector).

a) Determination of "Magnification Factor." (M.F.) - Divide the focal length of the collimator by the focal length of the reflector to be tested.

Example: $\frac{\text{f.l. of collimator - - - 240 in.}}{\text{f.l. of subject reflector - 6.870 in.}} = 34.934 \text{ (M.F.)}$

Note: If a focal length tolerance is permitted, the magnification factor should also be calculated to reflect the extremes permitted by the tolerance.

b) Aperture Calculation

To determine the size of the aperture, multiply the specified "sphere of confusion" by the magnification factor.

Example: Specification: 1 mm sphere of confusion

1 mm = .03937 in. M.F. = 34.934

.03937 x 34.934 = 1.375 in. aperture

3.2 Calibration of L.D.R. Circuit

It is important that, for the testing of any subject reflector, the L.D.R. is operating in a linear range for the average light being returned to the integrating sphere by the collimator mirror. This is determined as follows:

a) Set up the reflector to be tested and position and adjust the test source (operating at 2.5 volts, nominal), so that all the reflected energy is re-imaged into the integrating sphere. No aperture plates are used at this time.

b) Turn on the L.D.R. circuit and select a range on the microammeter which will give maximum deflection. The reading should be between 80 and 100% of full scale. This represents approximately the "100% point" for this particular test series.

c) Check the master calibration of the L.D.R. circuit to be sure that the reading at the "100% point" falls well within the linear response region for the L.D.R. or, if not, that accurate calibration data are available for the intensity region to be utilized (normally $\pm$ 25% of the 100% point reading).

If neither of the above conditions can be met, the integrating sphere must be re-calibrated for the intensity area of interest.

4.0 TEST PROCEDURE

4.1 Mount the subject reflector on the optical test fixture.

4.2 Place the Micro manipulator and test light source on the parallel aligning bar and position it so that it is approximately at the focal point of the subject reflector. Turn on the light source power supply and set the voltage to 2.5 volts.

4.3 Lower the "flash" screen and align the projected image of the subject reflector to provide the "best visual image" on the target screen. Center on target and adjust both light source and reflector mount to maximize concentricity of projected beam.

4.4 Raise the screen and fasten in raised position.

4.5 Position white "target" plate at aperture of integrating sphere.

4.6 Make fine adjustments of the x, y, and z movements of the lamp mount Micro manipulator, the x and y movements of the integrating sphere mount and the azimuth and elevation movements of the mirror mount to obtain the smallest, centered re-image on the target.

4.7 Remove the target plate from the integrating sphere. Turn the microammeter switch clockwise until a reading of 80 to 100% of full scale is obtained. (Note: This setting or range may be varied depending on the mirror being tested and other test conditions).

4.8 Wait one (1) minute for the microammeter to stabilize. Adjust light source supply voltage until microammeter reads full scale. This is the 100% reading.

4.9 Position proper aperture plate at entrance to integrating sphere.

4.10 Make fine adjustments of the x, y, and z movements of the lamp mount micromanipulator and the x and y movements of the integrating sphere

mount to obtain the highest reading on the micromanipulator.

Note: After the alignment steps of 4.6, these final alignment procedures require only extremely slight adjustments, usually only of the z axis (focal distance) adjustment of the lamp manipulator and the x and y movements of the integrating sphere.

The smallest visual re-image, with the least amount of light showing around the edges of the test aperture usually produces the highest reading on the microammeter. However, this is not always the case, and minor adjustments are required to obtain the highest possible reading on the microammeter.

BE PRECISE - it is not possible to obtain a reading higher than the quality of the reflector being tested will permit, but it is possible to obtain lower readings through careless alignment.

4.11 Remove the aperture plate and readjust the test source lamp voltage, if necessary, to 100% of full scale.

4.12 Replace the test aperture plate.

4.13 Repeat Step 4.10.

4.14 Using the upper 1 to 10 scale, multiply the reading by 10. Record the reading. This is the "percent performance" for the aperture used.

Note: As an alternate method, rather than adjusting the lamp voltage

to obtain a "no aperture plate" reading of 100% as in Step 4.8, simply record the "no aperture plate" reading (with the test source lamp voltage set at 2.5 volts) as the "preliminary 100% reading." Perform Steps 4.9 and 4.10. Remove test aperture plate and recheck the 100% reading and record as the "final 100% reading." Replace the test aperture plate and obtain reading with plate in position. Divide this reading by the "no aperture plate, final 100%" reading. The result is the "percent performance" for the aperture used.

4.15 If the "percent performance" figure is equal to or greater than the specification, the mirror is acceptable. (88% or better is required for the 2.2 KW, M-60 reflectors, other specifications may apply for different programs.)

4.16 Record all data as required on test log and individual data sheets.

APPENDIX B

INTERRELATIONSHIPS AND EFFECTS OF DIFFERENCES IN THERMAL EXPANSION RATES OF REFLECTOR ASSEMBLY COMPONENTS

Upon examination of expansion characteristics of the various materials associated with the SC-D-647010 reflector assembly, it appears that there are (3) distinct coefficients to be considered. The following coefficients are representative and may vary from one data source to another, however statistics show that the amount of difference between one "T" condition (temper) and another does not vary enough to warrant an in depth discussion insofar as total linear movement is concerned. All numerical designators are to be considered as $X10^{-6}$.

2024 Alum. Alloy	= 12.9
Carbon Steel	= 6.33
Nickel	= 7.00

It can be seen by the above listed coefficients, that there is a noticeable ratio between the three; steel and nickel having an expansion factor of about 45 to 50 percent less than the aluminum. When considering total movement it must be remembered that the coefficients apply to per degree Fahrenheit per unit of measure.

As an example of this movement, consider the 3.760 diameter bolt circle of the SC-D-647010-6 reflector adapter and SC-D-647010-7 retainer, both made of aluminum. A temperature variance of 122°F was considered as obtained by theoretical reflector assembly temperature (in searchlight) operating at a soak temperature of 200° and an ambient temperature of 78° (before searchlight operation).

$$200° - 78° = 122°$$

This leads to:

$$3.760\left[12.9 \times 10^{-6}\,(122)\right] = 3.760\,(.15738 \times 10^{-3})$$
$$= 5.917488 \times 10^{-3}$$
$$\Rightarrow .006 \text{ inches}$$

By adding total theoretical movement to 3.760, it is determined:

$$3.7600 + .006 = 3.766$$

The above data is figured on a diametrically opposed configuration. It can be seen that an initial characteristic (3.760) which has been classified as a basic dimension has now become theoretically enlarged to an oversize condition in excess of .006 inches.

The above is to be carried further by locating a hole on this bolt circle which possesses those thread parameters for a 4-40 UNC 2B as described by MIL-S-7742.

Limits are:

Minor Diameter	
Min	Max
.0849	.0939

Computing Expansion

$$.0849\left[12.9 \times 10^{-6}\,(122)\right] = .0849(1.5738 \times 10^{-3})$$
$$= 1.3361562 \times 10^{-4}$$
$$\Rightarrow .0001 \text{ Minor Dia. (min) increase}$$

Major Diameter
Min
.1120

Computing Expansion

$$.0939\left[12.9 \times 10^{-6}\,(122)\right] = .0939\,(1.5738 \times 10^{-3})$$
$$= 1.477982 \times 10^{-4}$$
$$\Rightarrow .0001 \text{ minor dia. (max) increase}$$

$$.1120\left[12.9 \times 10^{-6}\,(122)\right] = .1120\,(1.5738 \times 10^{-3})$$
$$= 1.762656 \times 10^{-4}$$
$$\Rightarrow .0002 \text{ major dia. (min) increase}$$

Screw thread characteristics for an MS16995-10 are:

Major Diameter	
Max	Min
.1112	.1061

$.1112\left[6.33 \times 10^{-6}\ (122)\right] = .1112\ (7.7226 \times 10^{-4})$
$= 8.58753 \times 10^{-5}$
$\Rightarrow .00008$ maj. dia. (max) increase

Minor Diameter
.0805

$.1061\left[6.33 \times 10^{-6}\ (122)\right] = .1061\ (7.7226 \times 10^{-4})$
$= 8.1936786 \times 10^{-5}$
$\Rightarrow .00008$ maj. dia. (min) increase

$.0805\left[6.33 \times 10^{-6}(122)\right] = .0805\ (7.7226 \times 10^{-4})$
$= 6.216693 \times 10^{-7}$
$= .0000006$ min. dia. increase

Although screw security or loosening does not appear to be an immediate problem, based on the amount of theoretical movement which can take place, possible torque degradation is possible which could possibly contribute to relaxing of the clamping force resulting in reflector movement within the adaptor/retainer.

Since the coefficient of nickel is stated to be 7.00×10^{-6} and the theoretical profile of the SC-D-647010-5 (on the reflective surface) is 7.10 inches, profile movement shall be:

$7.10\left[7.00 \times 10^{-6}\ (122)\right] = 7.00\ (8.54 \times 10^{-4})$
$= 5.978 \times 10^{-3}$
$\Rightarrow .006$ inches

However profile movement at the area of interface shall be:

$3.760\left[7.00 \times 10^{-6}\ (122)\right] = 3.760\ (8.54 \times 10^{-4})$
$= 3.21104 \times 10^{-3}$
$\Rightarrow .003$ inches

The foregoing data clearly shows that for a moment of movement along a given profile, the reflector will expand only about 50% of that of its aluminum retainers.

It is quite evident by the above that, to state it simply, the X-Y coordinates of the reflector are unable to properly interface with the coordinates of the adapter and retainer under existing thermal conditions.

APPENDIX C

COMPILATION OF OPTICAL TEST PROCEDURES AND SPECIFICATION FOR SC-D-647010, REV. B REFLECTOR ASSEMBLY.

1. DRAWINGS: SC-D-647010, Rev. B, sheet 1 of 2

Dimensions:

a) $2.350 \pm .010$ Focal Length

Remarks: Reflector to be measured for compliance to above tolerance with no requirement or tolerance with regard to dimension from "best" focus to point of attachment to searchlight.

Notes:

#7 - Sphere of confusion not to exceed .040 in. as measured by MIL-R-52351, Para. 4.6.1.

Remarks: - see below

2. MIL-R-52351A (15 Feb. 1968)

Para. 4.6.1 Sphere of Confusion - The zero-length searchlight photometry system illustrated in "Illuminating Engineering", VOL LVII, No. 3, March 1962 or equivalent system approved by the contracting officer, shall be used throughout this test. The test facility consists of a goniometer to position and rotate the test reflector and a collimator mirror to accept and focus the reflector beam. For a sphere-of-confusion measurement, a point source of light is placed at the focal point of the reflector. This light beam, after

being reflected and collimated, is accepted by an integrating sphere positioned at the focal point of the collimator mirror. The aperture of the integrating sphere is adjusted to an opening which by previous calibration corresponds to intercepting 100 percent light output of the reflector. The light output from the integrating sphere is measured by a light cell and recorded as the 100 percent light output of the reflector. At this point, the integrating sphere aperture is adjusted to an opening which also by previous calibration corresponds to the aperture necessary to fulfill a sphere of confusion of .040 inches at the reflector. The light output (energy) collected by the sphere is again measured, and the percent of energy transmission derived from the ratio of the two measurements constitutes the sphere of confusion in terms of percent of energy transmission. A sphere of confusion less than 90 percent shall constitute failure of this test.

Remarks: Although the general test facility is adequately described by the above specification, and by the "zero-length searchlight photometry system" illustrated in Illuminating Engineering", VOL LVII, No. 3, March 1962, certain important details affecting accuracy of test procedures and resultant reflector assembly performance data have been omitted from the combined specification.

Areas requiring further clarification or more detailed specification are as follows.

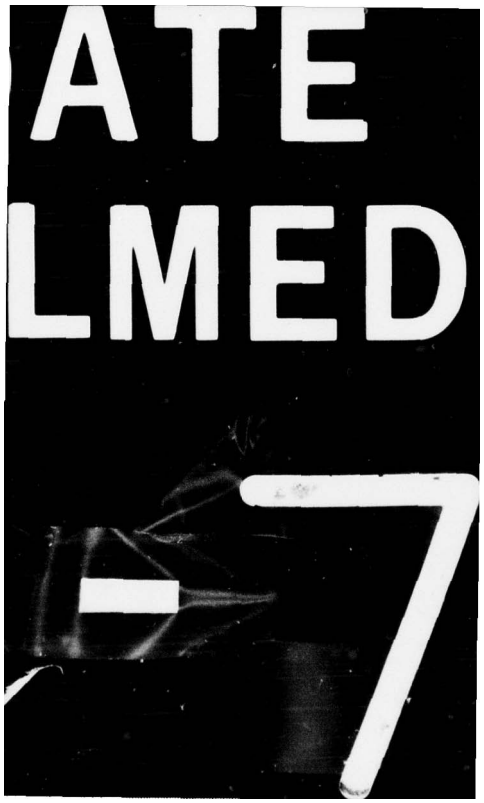
1. Integrating sphere. - The integrating sphere design and construction

details, light intensity detecting device and readout equipment are not specified or defined. Although a variety of approaches would provide satisfactory results, it would appear desirable to standardize this equipment and to define the calibration technique to insure the accuracy of test results.

2. Aperture plate sizing and relationship to specification. - The mathematical and/or geometric relationship between "sphere of confusion" specification requirements and actual test aperture plates to be used at the entrance to the integrating sphere should be clearly defined and examples presented to insure that aperture plate sizing and resultant data are correct.

3. Point Light Source. - The point light source is not defined in any manner within the specification or procedures. The filament size and shape, because of magnification factors which result from the ratio of the focal lengths of the two reflectors, have a distinct affect on, and relationship to, the test results.

The test source envelope size, shape and quality also directly influence observed performance due to a number of factors including "apparent source position shift" caused by refraction of the envelope, and "secondary source effects" caused by low level luminance from the glass envelope itself, which is displaced from the true position of the filament.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