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DEVELOPMENT AND PERFORMANCE OF THE JPL GLASS-LINED METAL REFLECTORS FOR THE SOLAR SYSTEM IN THE 25-FOOT SPACE SIMULATOR

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I. INTRODUCTION

The optical system initially delivered to JPL for solar simulation in the 25-foot space chamber (see Figure 1) included stainless steel mirrors in three positions as follows:

Mirrors	Size	No. Req.	See Fig. No.
1. Turning mirror (pseudo-parabola)	33 in dia.	19	2
2. Fly's eye (pseudo-hyperbola)	8.4 in. hex.	19	3
3. Virtual source	3/4 in. hex.	1200	4

These mirrors were unsatisfactory when compared with glass, mainly from a maintenance point of view. The fact that these mirrors required refiguring when they were recoated was both costly and time consuming.

The preference would also be with glass when comparing maximum reflectivity or rate of reflective surface degradation. This assumes, of course, that glass mirrors could be used.

II. REASONS FOR INITIAL SELECTION OF STAINLESS STEEL REFLECTORS

The energy flux designed to impinge the virtual source and fly's eye mirrors is about 11,000 w/ft^2. If the reflectivity is 75% (many were lower than this), the exposed surface will absorb 2750 w/ft^2 or about 9000 BTU/hr.

If a heat sink is provided through one inch of reflector material, and this is the only means by which heat is dissipated, the temperature difference between the exposed and cooled surfaces will be:

[redacted]	6	deg. F.
Silicon	7	"
Brass	12	"
Stainless Steel	76	"
Silica Glass	800	"

It was a calculation similar to this which led Bausch & Lomb to the decision to make these mirrors of metal. Almost any metal would be satisfactory from a surface temperature point of view, but glass is such an inferior thermal conductor that it would probably fail from thermal shock. If this did not happen, the reflective coating would degrade rapidly from the high operating temperatures.

III. PROBLEMS WITH THE STAINLESS STEEL REFLECTORS

Stainless steel mirrors were subsequently fabricated by Bausch & Lomb and installed in the system.

Reflectivity of the virtual source mirrors degraded below a useful value before the lights in the chamber were initially turned on. When the evaporated aluminum coating was stripped from the mirrors, the surface appeared corroded. They were, therefore, polished before being recoated with evaporated aluminum. Later, when it was determined that the figure was not correct, it was generally believed that the polishing operation had destroyed the initial contour to which the mirrors had been polished.

IV. NEW MIRROR MATERIALS CONSIDERED

Before JPL actually took possession of the space chamber, a new set of virtual source mirrors was ordered (see Figures 5 & 6). These mirrors were of different size, different contours, and different materials than the original B & L installation.

The materials to be used in the new mirror fabrication were specified as follows:

1. Stainless steel
2. Brass
3. Brass - nickel plate and refigure before aluminizing.
4. Silicon
5. Glass-lined aluminum - see Figure 6

V. RESULTS OF MIRROR MATERIALS EXPERIMENTS

The glass-bonded-to-aluminum mirror was superior in every respect to the other materials tried except the silicon. Temperature rise in the glass from bond line to the reflective surface is estimated to be 50 deg. F.

The silicon mirrors, from the standpoint of initial reflectivity, durability of coating and ease of maintenance (cleaning and recoating) was as good as, or slightly better than the glass. However, this slim edge in performance was more than offset by high cost. The very high thermal conductivity (nearly that of aluminum) of silicon may bring it back into consideration if flux densities should increase to the point where surface temperatures of the glass would again become a problem.

All of the other metal substrates appear to react with the aluminum reflective coating in such a way that the polish of the substrate is degraded. It is probable that moisture, ozone, or some other contaminant in the atmosphere enters into or catalyzes this reaction.

It might be mentioned that these glass-lined mirrors survived a bond strength test of reduction to liquid nitrogen temperatures and return to ambient.

VI. GLASS-LINED METAL FLY'S EYE (Pseudo-Hyperbolic) MIRRORS (Figure 3 & 7)

After successfully glass bonding the virtual source mirrors, it was decided to take similar action on the fly's eye mirrors. A spare set was ordered which was identical with those which were in place except that the exposed surface was glass and the base metal was copper. When these were installed in the system, a thin layer of glass was bonded to the original stainless steel mirrors. This provides a complete set of spares.

The performance of both these sets of mirrors is satisfactory. No difference can be seen in their operation even though it is obvious that the copper-base mirrors operate at a lower surface temperature than the stainless-base mirrors.

VII. GLASS-LINED METAL HEADLAMP REFLECTORS

The original headlamp collectors furnished by Bausch & Lomb were 16-in. latus rectum reflectors with a 4-in. first (see Figure 3) focus. In our need for more power into the solar system, a 5-KW lamp was installed in place of the 2.5-KW lamp originally furnished. The reflectors could not withstand the additional thermal shock.

Since the glass-lined metal reflector seemed to be resistant to thermal shock, it was decided to move the lamp cluster to the position of the turning mirror (see Figure 8) if a satisfactory reflector could be fabricated for this position. This would decrease the size of the collector to 7 1/2 in. dia. and increase its performance requirements proportionally, but it was believed from our experience with the virutal source and fly's eye reflectors that such a mirror was practical (see Figures 9 and 10).

This modification would increase energy into the solar system in the following ways:

1. It would eliminate the energy absorbing reflection of the turning mirror.

2. It would collect the more readily available part of the energy polar of an Xenon lamp.

3. It would permit the use of more powerful lamps in the system.

VIII. PERFORMANCE OF THE 7 1/2 IN. GLASS-LINED HEADLAMP REFLECTOR.

If its acceptance angle is not changed, the energy which impinges a fly's eye mirror from a cluster of seven headlamps is proportional to the energy in the solar beam. This fact makes the headlamp and reflector combination readily adaptable to bench testing.

Calorimeter measurements were made on an area representing a fly's eye mirror to determine the energy increase into the system that can be expected using the new reflectors.

Comparison of data taken with various lamp and reflector combinations is as follows:

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Mfg.	Type Lamp	Power Rating	Power into Lamp	Energy into Calorimeter Watts	Comments
Hanovia	HgXe	$2\frac{1}{2}$ KW	$2\frac{1}{2}$ KW	1180	Original Bausch & Lomb configuration, 16-in. dia. reflector cluster of 7 lamps (Figure 1)
Hanovia	HgXe	$2\frac{1}{2}$ KW	$2\frac{1}{2}$ KW	1960	New configuration with $7\frac{1}{2}$ in. dia. glass-lined reflectors. Cluster of 7 lamps (Figure 8)
Osram	Xe	2.5 KW	3 KW	3040	New configuration with $7\frac{1}{2}$ in. dia. glass-lined reflectors. Cluster of 7 lamps (Figure 8)
Osram	Xe	6.5 KW	6.5 KW	6800	New configuration with $7\frac{1}{2}$ in. dia. glass-lined reflectors. Cluster of 7 lamps (Figure 8)
Osram	Xe	6.5 KW	8.0 KW	7160	New configuration with $7\frac{1}{2}$ in. dia. glass-lined reflectors. Cluster of 7 lamps (Figure 8)
Ushio	Xe	5.0 KW	5.0 KW	4360	New configuration with $7\frac{1}{2}$ in. dia. glass-lined reflectors. Cluster of 7 lamps (Figure 8)
Ushio	Xe	5.0 KW	6.2 KW	5340	New configuration with $7\frac{1}{2}$ in. dia. glass-lined reflectors (Figure 8)

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IX. CONCLUSION

Glass-metal reflectors can intercept high energy solar radiation without damage to the reflective coating, the glass, the bond, or to the substrate metal itself.

The combination should not be used in mirrors requiring a highly accurate figure since the glass and metal have different coefficients of expansion and the combination will change figure with temperature. An attempt is made to minimize this deformation by:

1. Making the mass of the metal large compared to that of the glass.

2. Keeping the temperature as constant as possible by making the substrate metal highly conductive and water cooling this metal to minimize temperature rise.

It is probable that silicon substituted for the glass could survive much higher radiation flux since the temperature gradient through the silicon would only be about 1% of that through the glass.

The type of epoxy bonding material is probably not very important providing the bond thickness is kept below .005 in. Hysol 3X was initially specified for the virtual source mirrors after trying many different types.

Hysol 3X was too viscous to accomplish the thin bond line required for the larger fly's eye and headlamp mirrors so General Mills Genepoxy 175 with Furane #9633 hardener was tried and it has proved satisfactory.

It is important that the bond between the glass and the metal be cured at a temperature above which it will be operated. This will always keep the glass in compression...a force which it appears to survive very well.

The glass should be kept thin to minimize warpage and minimize the shear stress which develops at the bond line. The epoxy itself is stronger than the glass in shear so that if the glass thickness is increased, shear failure will occur in the glass near the bond line.

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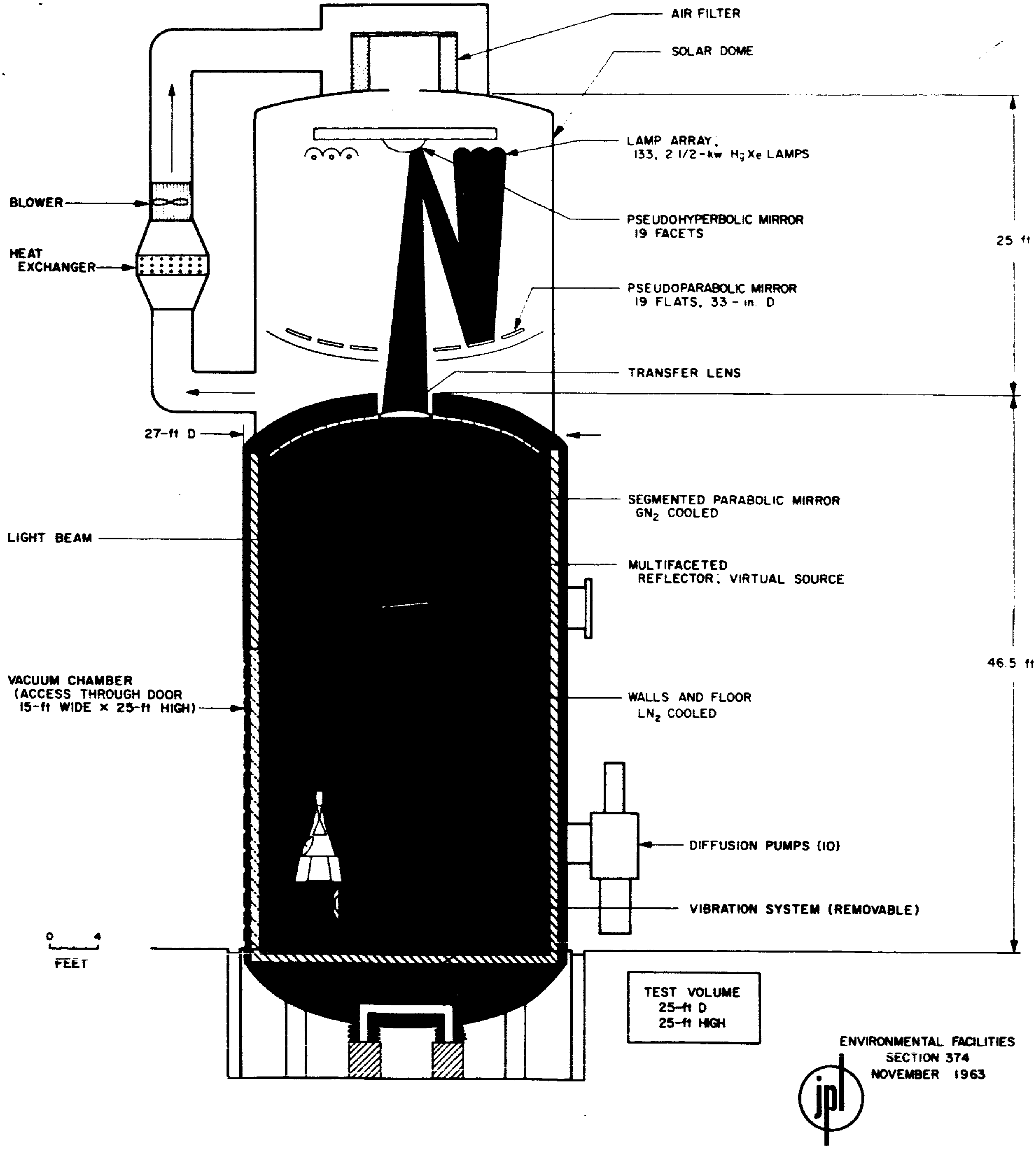

JPL 25-ft SPACE SIMULATOR

Figure 1.

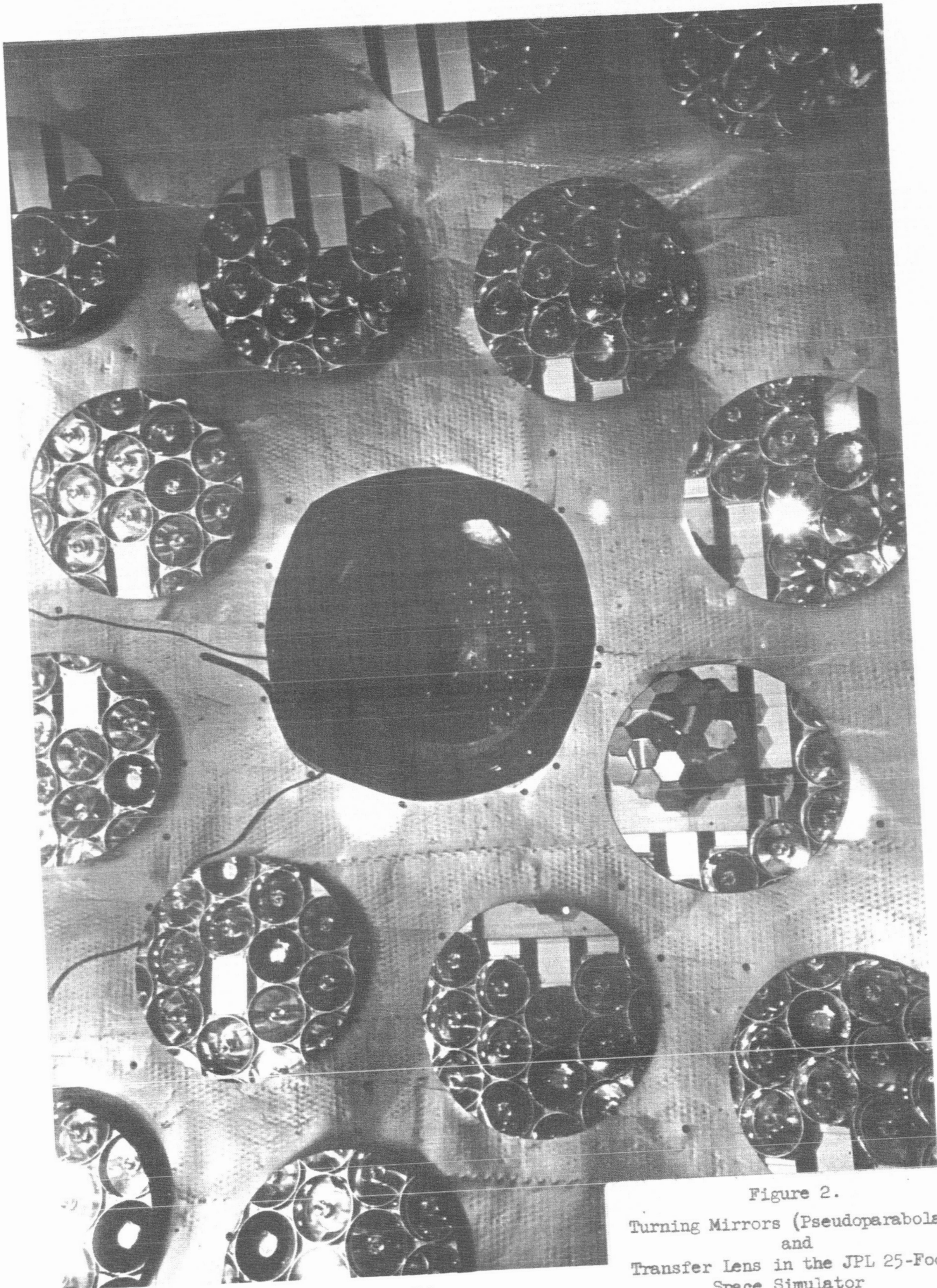

Figure 2.
Turning Mirrors (Pseudoparabola)
and
Transfer Lens in the JPL 25-Foot
Space Simulator

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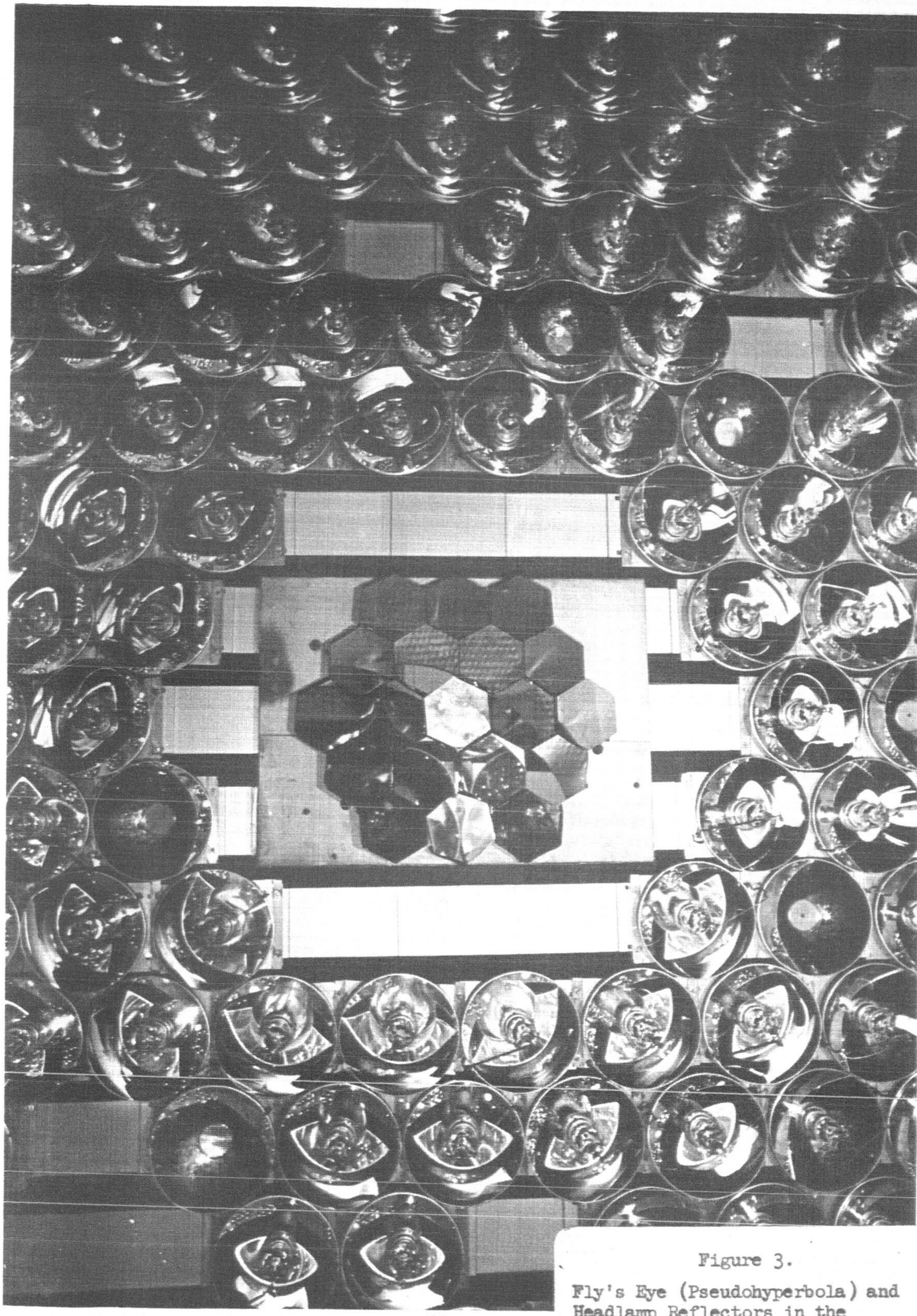


Figure 3.

Fly's Eye (Pseudohyperbola) and Headlamp Reflectors in the JPL 25-Foot Space Simulator

Figure 4.

Contractor Furnished Virtual Source Mirrors for the JPL 25-Foot Space Simulator

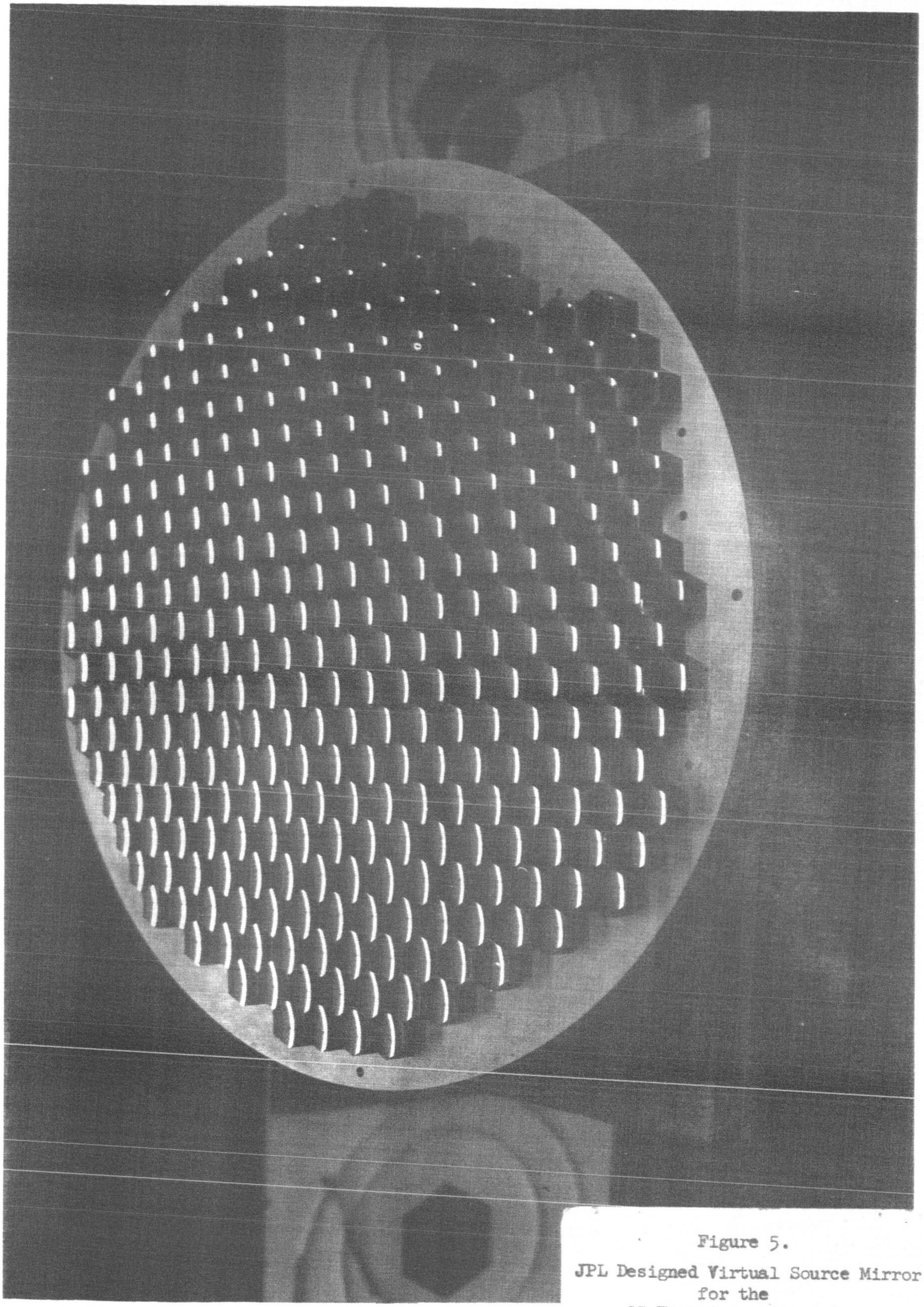
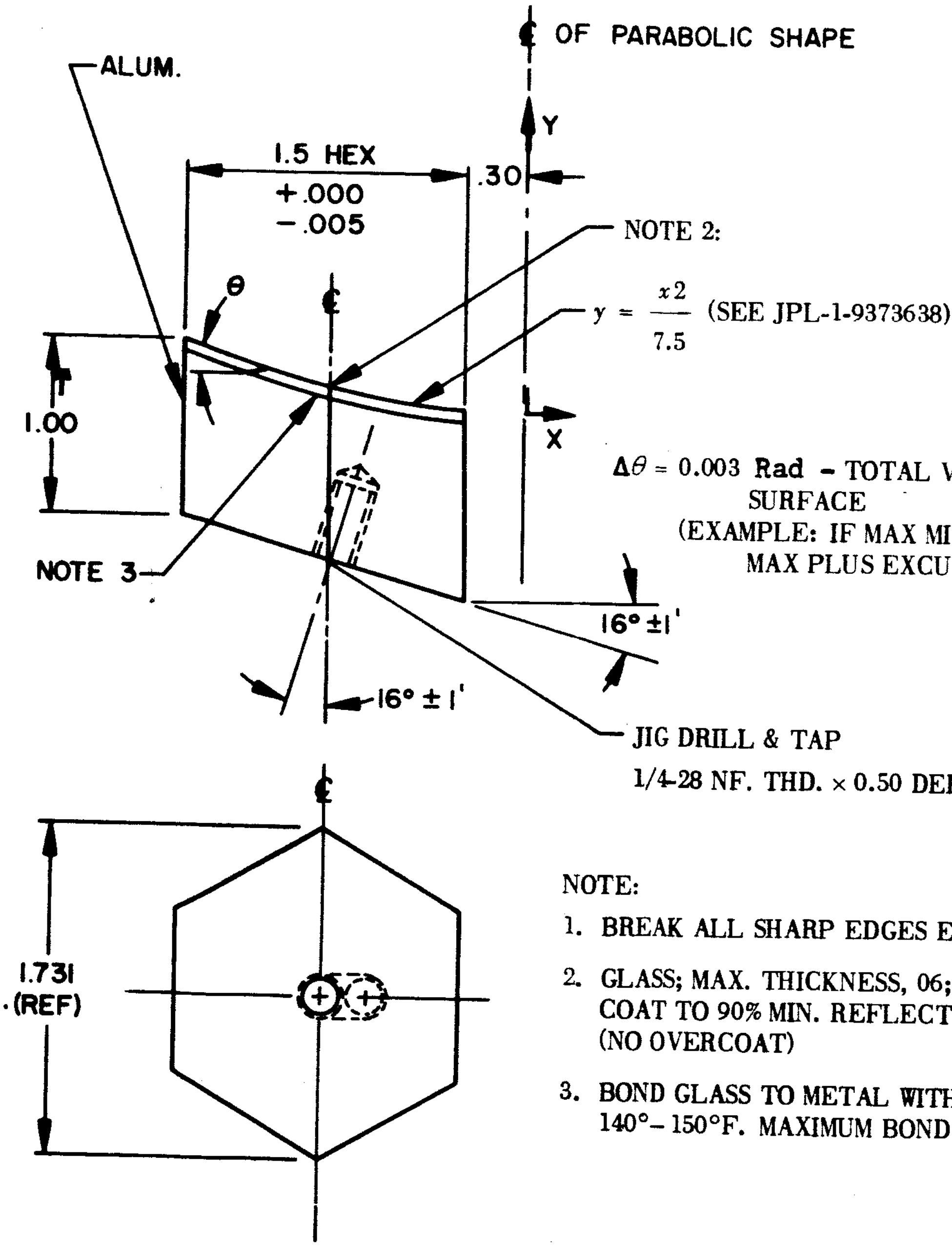


Figure 5.
JPL Designed Virtual Source Mirror
for the
25-Foot Space Simulator



$\Delta\theta$ = 0.003 Rad - TOTAL VARIATION FROM PARABOLIC SURFACE
(EXAMPLE: IF MAX MINUS EXCURSION IS −0.001 Rad; MAX PLUS EXCURSION IS +0.002 Rad)

NOTE:

1. BREAK ALL SHARP EDGES EXCEPT OPTICAL SURFACES.
2. GLASS; MAX. THICKNESS, 06; POLISH SURFACE & ALUM. COAT TO 90% MIN. REFLECTIVITY TO SOLAR SPECTRUM; (NO OVERCOAT)
3. BOND GLASS TO METAL WITH EPOXY; SET EPOXY AT 140°– 150°F. MAXIMUM BOND THICKNESS – 0.005

Figure 6. Virtual Source Mirror - 7-ft Solar Beam

JPL 25-ft SPACE SIMULATOR

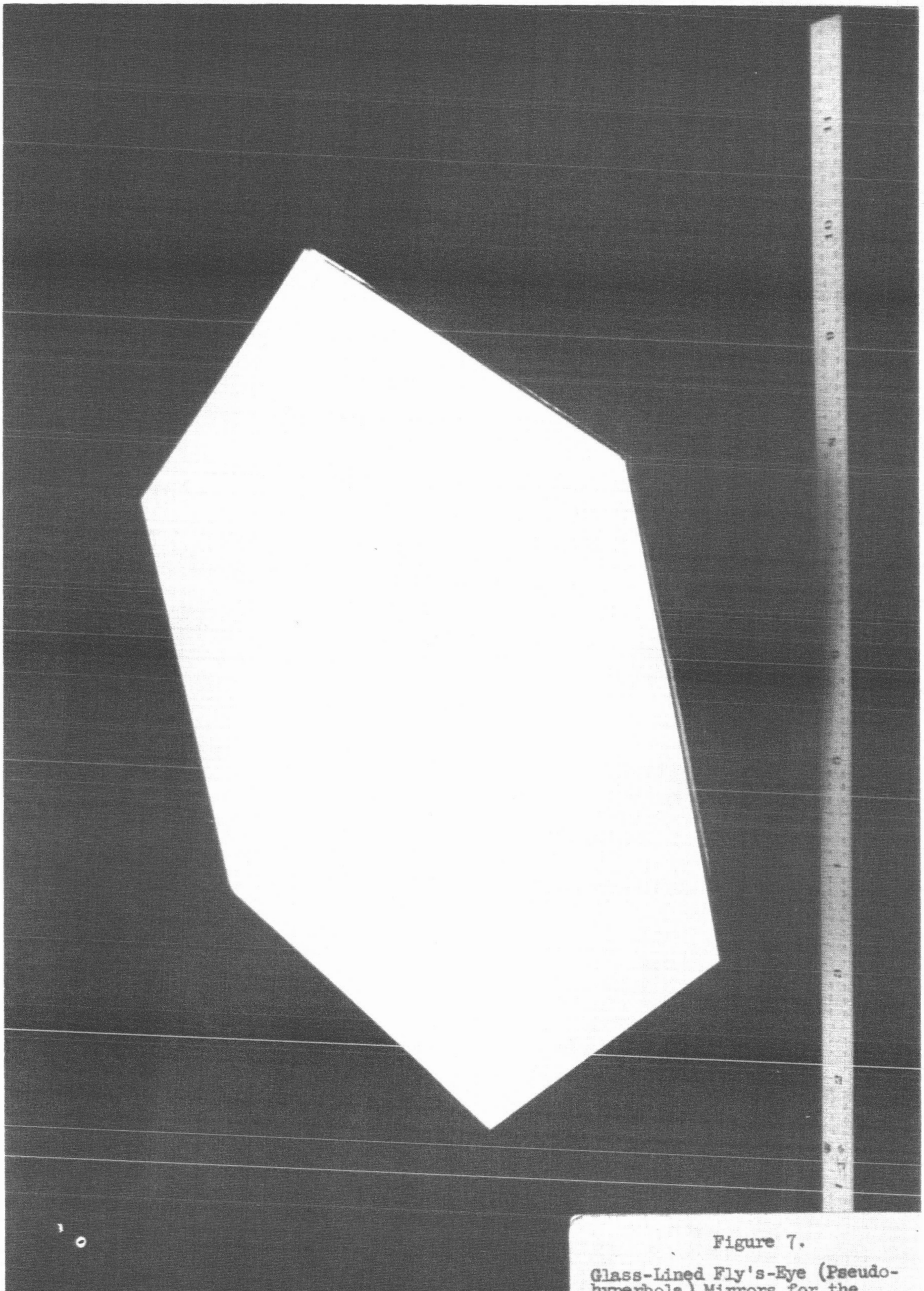
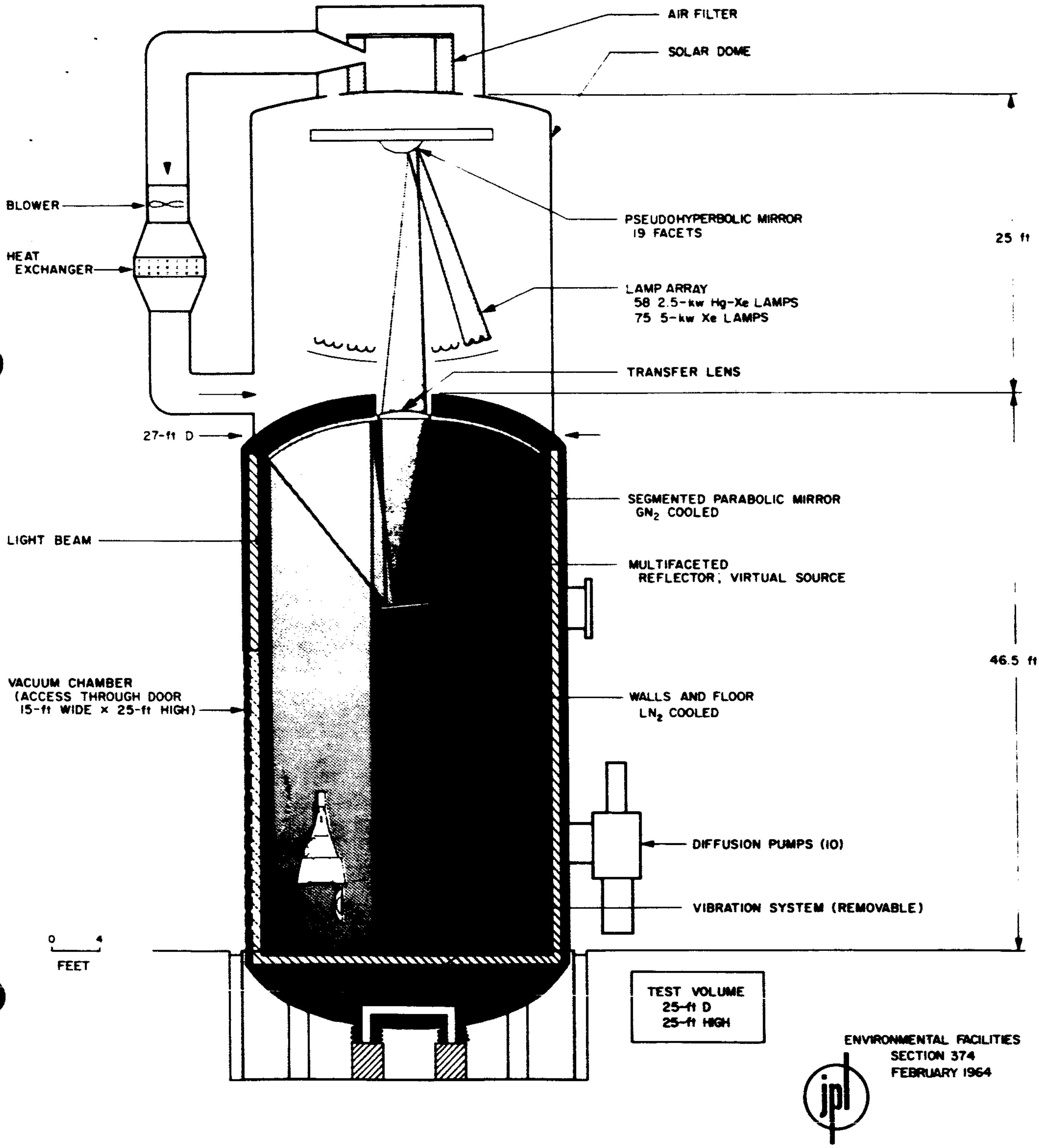


Figure 7.

Glass-Lined Fly's-Eye (Pseudo-hyperbola) Mirrors for the JPL 25-Foot Space Simulator



JPL 25-ft SPACE SIMULATOR

Figure 8.

Modified Solar System Proposed for the 25-Foot Space Simulator

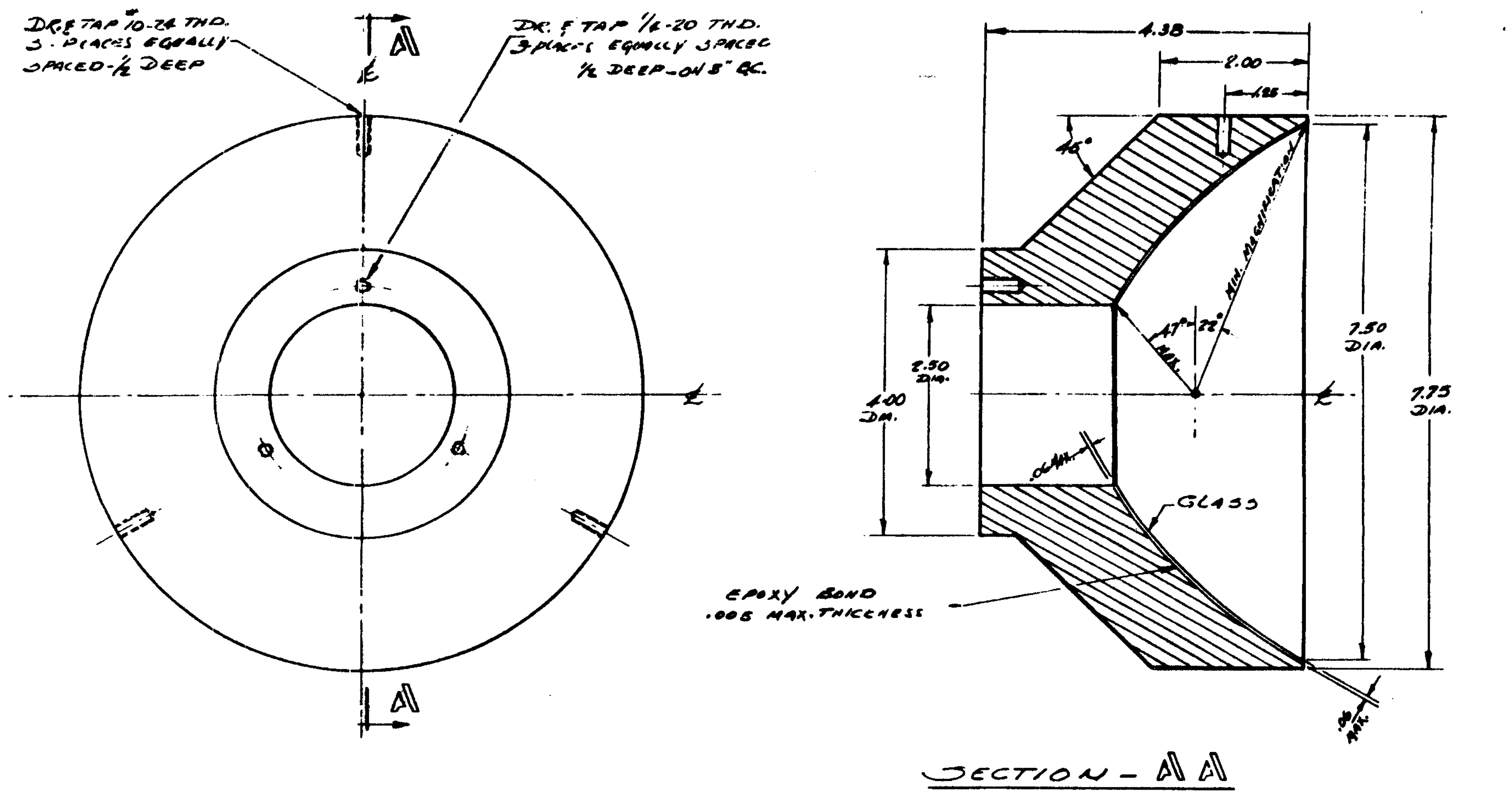


Figure 9.

Detail of 7½-in. Headlamp Reflector

NOTES: MATERIAL: #6061-T6 ALUM.
FIGURE ELLIPSE - F_1 = 1.3"; $F_2 - F_1$ = 130"
O.D. = 7.5 DIA.; TOLERANCE ± 2 MIN.
MAGNIFICATION = MAX = 107; MIN. = 40

TOLERANCE EXCEPT AS SPECIFIED: DECIMAL XX ± .030; DECIMAL XXX ± .010; DECIMAL XXXX ± .001; ANGULAR ± ½°

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7½" DIA. COLLECTOR
SOLAR LAMPS
25' SIMULATOR

UNCLASS — FULL

4-9373667

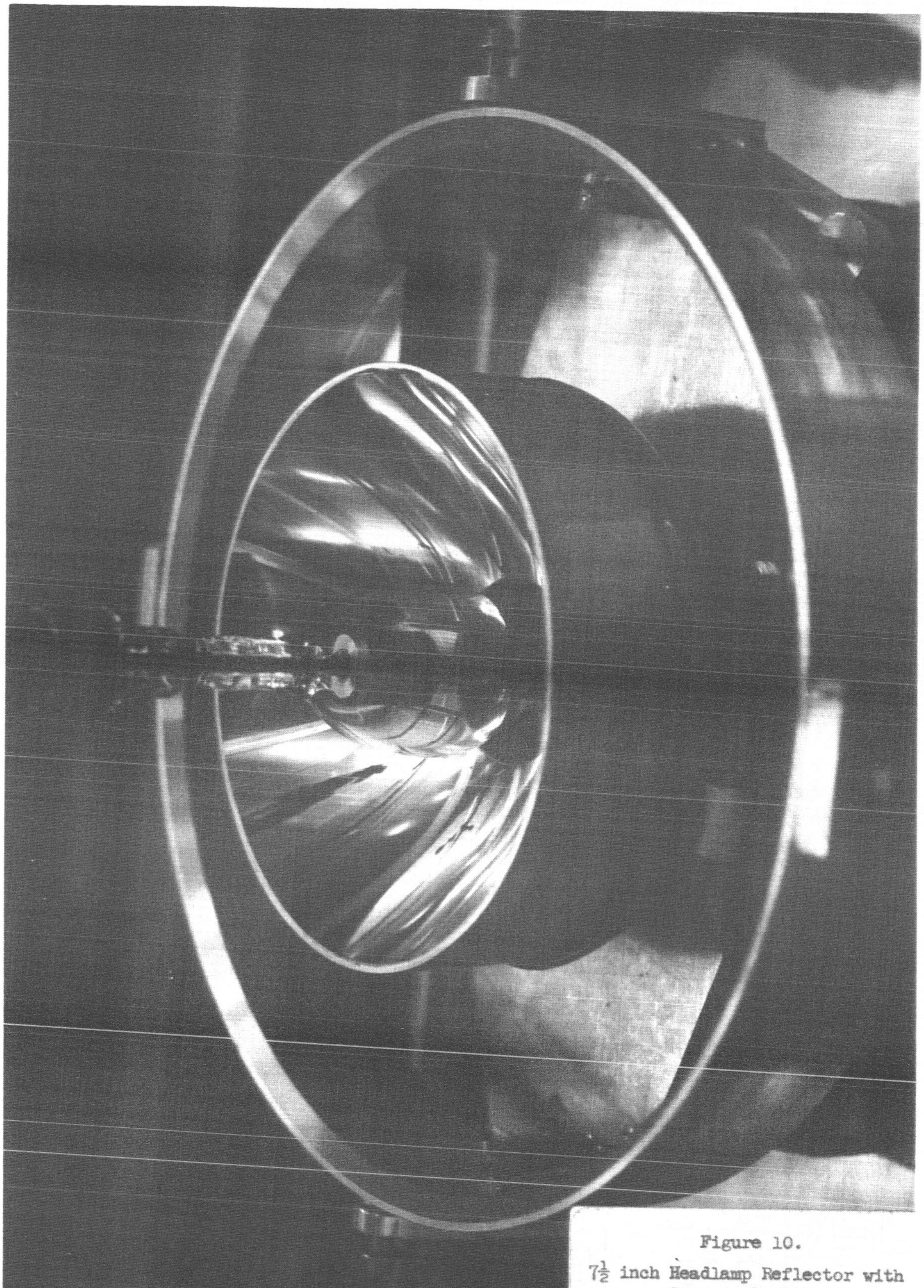

Figure 10.

$7\frac{1}{2}$ inch Headlamp Reflector with Lamp in Position JPL 25-Foot Space Simulator