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HIGH-TEMPERATURE MIXER DEVELOPMENT

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I. INTRODUCTION

The mixer in the JPL A-6 solar simulator consists of an assembly of hexagonal biconvex quartz lenses; one 19-lens set in front of another 19-lens set. The mixer is the heart of the system. It is here that the beam intensity, intensity uniformity, area, and collimation are determined. Without the mixer, the solar simulator would be just a group of arc lamps directed at the space-craft.

Because of the success of the A-6 system, similar systems of larger capacity will be installed in present and future space environment simulators. The A-6 system has the potential for providing improvement in beam intensity, area, and collimation. Larger, more intense, and more highly collimated systems are those in which the mixer will be subject to energy fluxes far in excess of that seen on the A-6 system. It has been calculated that the mixer may realize intensities in the 100 kw/ft^2 region[1].

Quartz lenses absorb about 3% of the Xenon lamp energy passing through them[2]. Even at the minimal case (50 kw/ft^2 for this Report) the mixer will absorb 750 w/ft^2. It is easy to see that a mixer used in high performance systems, such as those mentioned, will absorb a great deal more energy and will have to withstand very high temperatures. Heat transfer analysis of the system shows that the quartz lenses may reach temperatures as high as 1200° F if not force cooled. The supports for the lenses, presently consisting of a thin honeycomb-shaped web of Invar 0.020 in. wide, may also reach similar temperatures. The question now arises: How can the lenses be supported without subjecting the supporting structure to these elevated temperatures?

II. POSSIBLE SOLUTIONS

Three categories of solutions were arrived at as possible answers to the question. The first solution was a mechanical support as used in previous mixers

[1] See Appendix for calculations.

[2] "Optical Properties", Corning Fused Silica Code 7940, Form FS-2, November, 1960

with the support to be constructed of small-diameter thin-walled hypodermic tubing that would carry enough water flow to sufficiently cool itself (see Fig. 1). However, in the welding of small bore tubing it is extremely difficult, if not impossible, to prevent blockage of the tubing by the molten welding rod. Further, the area of light blocked by these supports would be close to the critical 2% mark (see Fig. 2) so that the design would have to be stressed to the maximum. Other engineering problems such as fabrication tolerances and rigidity make a design of this type impractical.

The second type of solution is the single piece or bonded mixer. Here, either the mixer facets are ground from a single piece of quartz, or the lenses are ground individually and bonded--either by cement or welding. Although opticians have suggested this method, after considering the optical quality required for the lenses, it was decided that one piece grinding would be too difficult and would not produce the desired results. A local vendor has a contract with JPL to study bonding and welding techniques, and the results obtained are as yet unsatisfactory.

The third category of solution consisted of joining the 19 individually ground lenses by some integral support method so that almost no area is blocked. Here, the lenses would be mounted in the hexagonal arrangement in contact with one another, a steel band around the perimeter of the arrangement putting the lenses under slight compression, and some type of locking device located where the facet of one lens contacts that of an adjoining lens. The purpose of the locking device, which may be, for example, a pin, a disc, or a sphere (see Fig. 3, 4, and 5), is to prohibit the lens from "falling out" of the mixer since the bond of frictional forces set up between facets by compression will be slight.

The major objections to the internal locking devices centered around the fact that quartz is very brittle and any cuts made into the lens would necessarily have to be shallow and have rounded edges to keep the quartz from fracturing. Locating a disc or pin between facets may prove difficult because it would be necessary to make sharp corners in the cut-out portions of the quartz. The sphere does not require either a deep cut-out area or sharp corners and is structurally much stronger than the disc or pin.

III. DESIGN DESCRIPTION AND JUSTIFICATION

The experimental design finally decided upon consists of a compression band surrounding aluminum lens holders in which are seated the outer circle of mixer lenses (Fig. 6). At the corners of the lenses (a junction of any 3 lenses) there is an approximately hemispherical cut-out area into which a sapphire sphere of appropriate diameter fits (Fig. 7). The spheres, along with the slight frictional forces produced by the compression band, keep the lenses from slipping out of position or, more exactly, allow the structure to essentially support itself. To further reduce the possibility of lens fracture due to severe torsion and compression loads, the top and bottom edges of each facet are beveled so that the facets contact one another in the center section only.

There are several reasons why this design was chosen. First, the integral support method seemed much more satisfactory than the cooled metal support or the bonded support for reasons already mentioned. Second, the spherical locking device was selected over the pin and the disc because of the problems of working with the very brittle quartz or fused silica glass. Third, the advantages gained by the simplicity of fabrication, lack of light-blocking by internal members, and mechanical and thermal stability far outweighed any disadvantages (such as possibility of mixer collapse due to a single lens failure, etc.).

IV. TEST DESCRIPTION AND RESULTS

Two types of tests were run with a mockup mixer built expressly for this purpose. The tests were designed to exceed actual operating conditions. The philosophy behind this type of testing is that if the novel design can pass such rigorous tests, then it will be a good engineering risk to invest time and money in developing an operational model.

The first test was a simple mechanical load test to determine the self-supporting feature. The mixer was supported from the edges only so that it was positioned parallel to and several inches above a table top. Force, by means of small steel weights, was applied to the center lens only. The weight was increased in 5-lb increments until the center lens was supporting 20 lb. It should be noted that the compression band was fairly loose so that there was some flexing ($\approx$1/8 in. depression at center) of the lens assembly. Other than the expected flexing, there was no sign of damage either to the aluminum ring support or the lenses.

The second test was a little more sophisticated in that it was designed to duplicate the irradiation that the lenses would endure under the most severe operating conditions (good collimation angle, high intensity beam). Since it would be difficult to actually simulate 75 to 100 kw/ft^2 of a Xenon lamp spectrum over an area as large as the model mixer, it was decided to simulate the absorbed energy by using high intensity infrared lamps (Fig. 8 and 9) It can be readily seen that if the lenses have a high coefficient of absorption in the infrared region and a relatively high transmittance in the ultraviolet and visible regions (where most of the energy delivered by the Xenon lamps of a solar simulator is), it will take a much lower infrared energy flux to duplicate the ultraviolet-visible energy absorbed by the lenses.

After making the appropriate calculations[3] based on rather conservative assumptions, it was decided to use a calorimeter to determine exactly how much energy was being delivered by the infrared lamps. The calorimeter data showed that with only half of the lamps in use, the intensity required to simulate 50 kw/ft^2 of the Xenon light was being delivered. This proved that the original assumption about lamp-reflector efficiency was indeed conservative, and a wide latitude of test conditions was apparent. By moving the lamps closer to the target (which was done later), even greater temperatures could be achieved.

The following runs were made: a) one with only half of the lamps on, with a lamp to target distance of 12 in.; b) all lamps on, with a lamp to target distance of 12 in.; c) all lamps on, with a lamp to target distance of 6 in. The first two runs were in accordance with the planned intensity simulation. The third run was a thermal-life test to see how hot and for how long the mixer could operate without being damaged. The lenses reached a stabilized temperature of 633° F during the first run. During the second run, the temperature reached 873° F and remained that high for a period of 3 hr. The third run heated the lenses to 907° F and this temperature was maintained for 5 hr. The only damage sustained was a fracture in one of the lenses (which can be seen in Fig. 6). The cause of this fracture has been attributed to thermal shock

[3] See Appendix for Calculations

induced in the cooling phase of Run No. 2 and not a mechanical deficiency in the design. The lenses used for the mockup are Furex (a form of Pyrex) and are inexpensively pressure-molded with considerable stria in the glass. It is not expected that precision-ground quartz lenses will show any ill effects from either the compression or the thermal loads. The instrumentation for these tests consisted of a chromel-alumel thermocouple with radiation shields bonded to one of the lenses. The output was referenced at 32° F and read out on a digital mv meter.

V. CONCLUSION

From the results of the two types of tests it can be concluded that the design is a very promising solution to the problem. Although the mockup has withstood both high temperatures for extended periods and heavy sheer leads, it has never been subjected to combined heat and loading. This should be the next test undertaken with the model, i. e., a heavy load placed on the center lens only and temperatures close to 200° F for 4 hr or more. If this test is completed successfully, it should provide convincing evidence that the design idea is worthwhile.

However, before expensive quartz lenses are used, a final mockup should be build using 19 Furex lenses. This would simulate exactly the support problem and any unforeseen difficulties could be observed and resolved at this time. A thorough test program, such as the one described, plus a dynamic load test (shake test) would certainly be advisable. If the results of this test are satisfactory, then there should b[illegible] problem in building the final product with high quality quartz lenses.

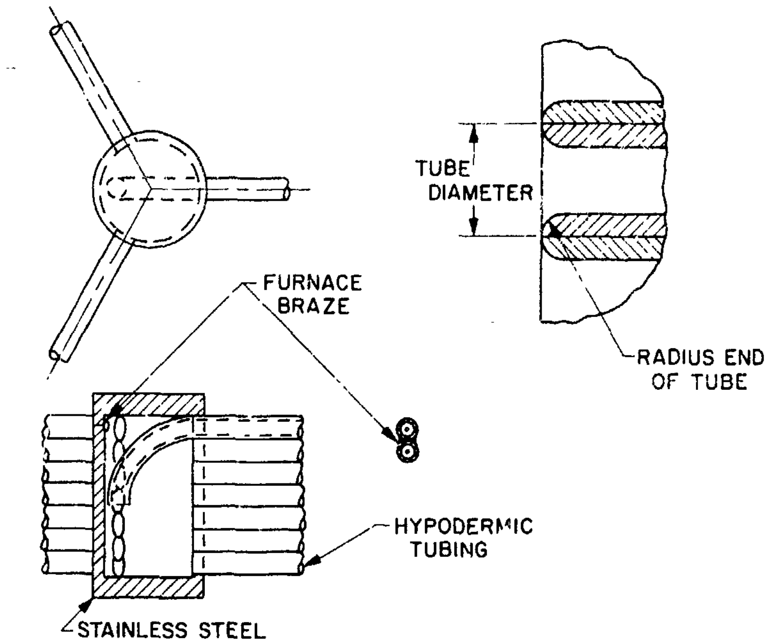


Fig. 1. Proposed hypodermic mixer support

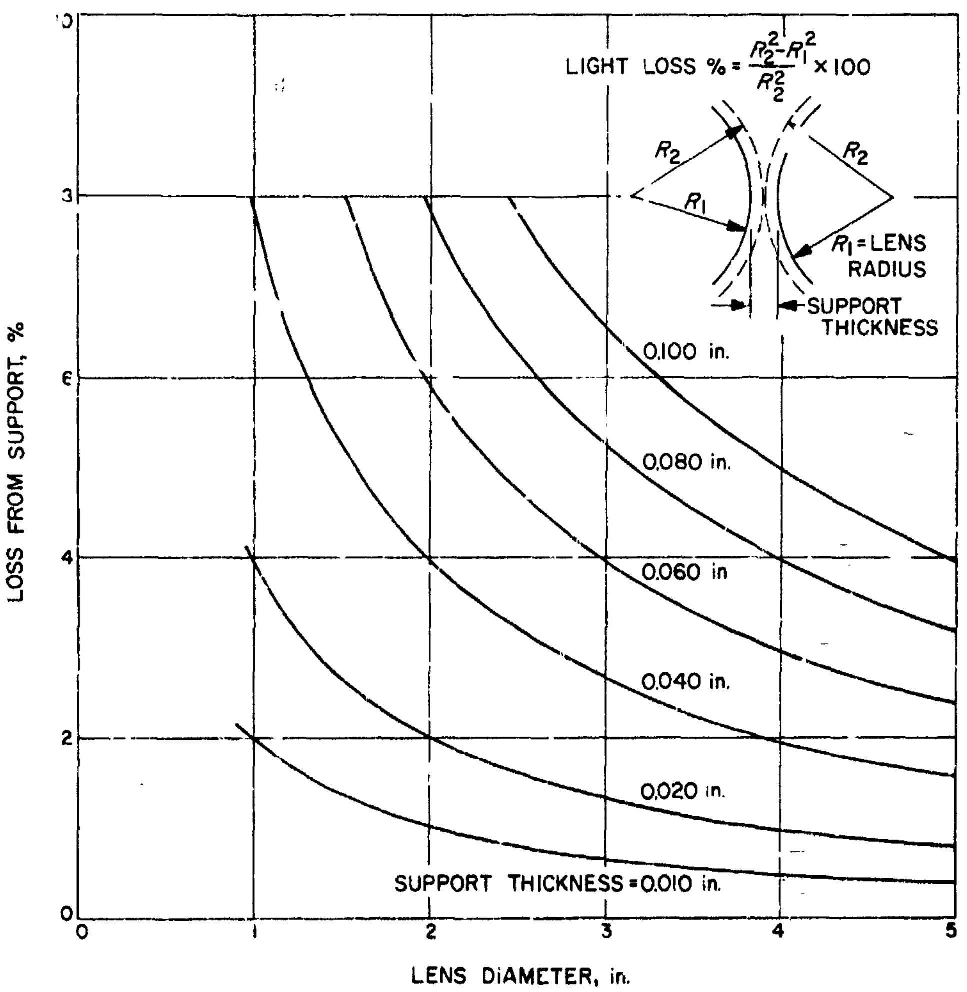


Fig. 2. Percent light blockage

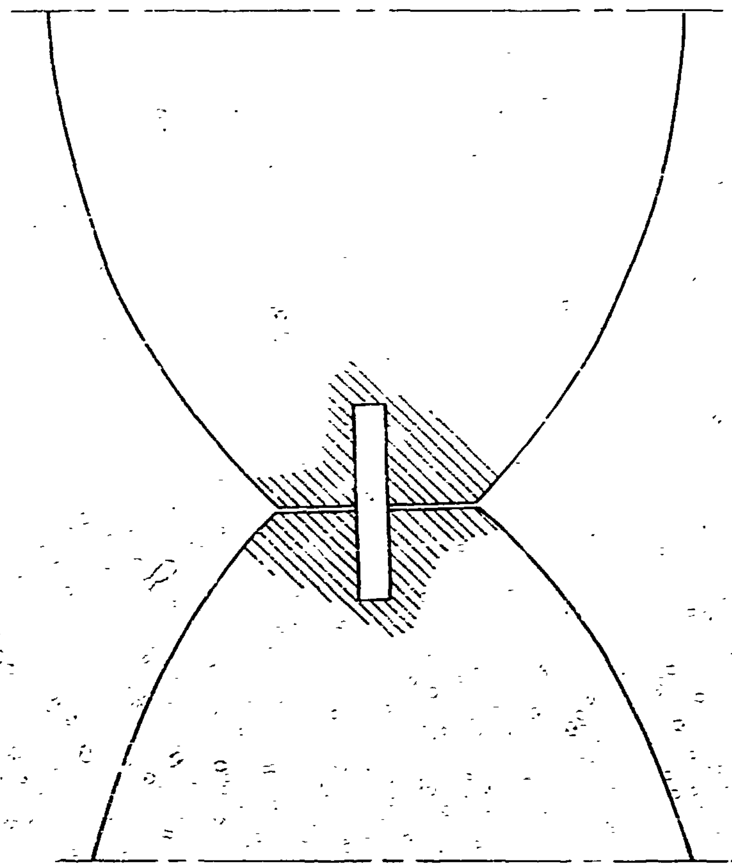


Fig. 3. Proposed disc or pin interlocking method

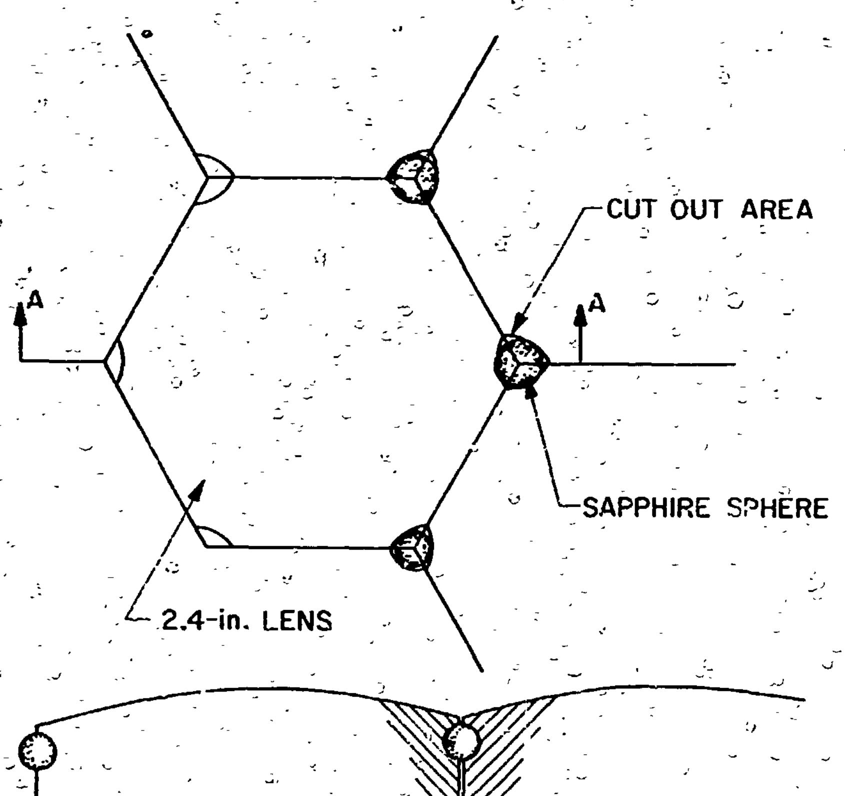


Fig. 4. Sphere interlocking method

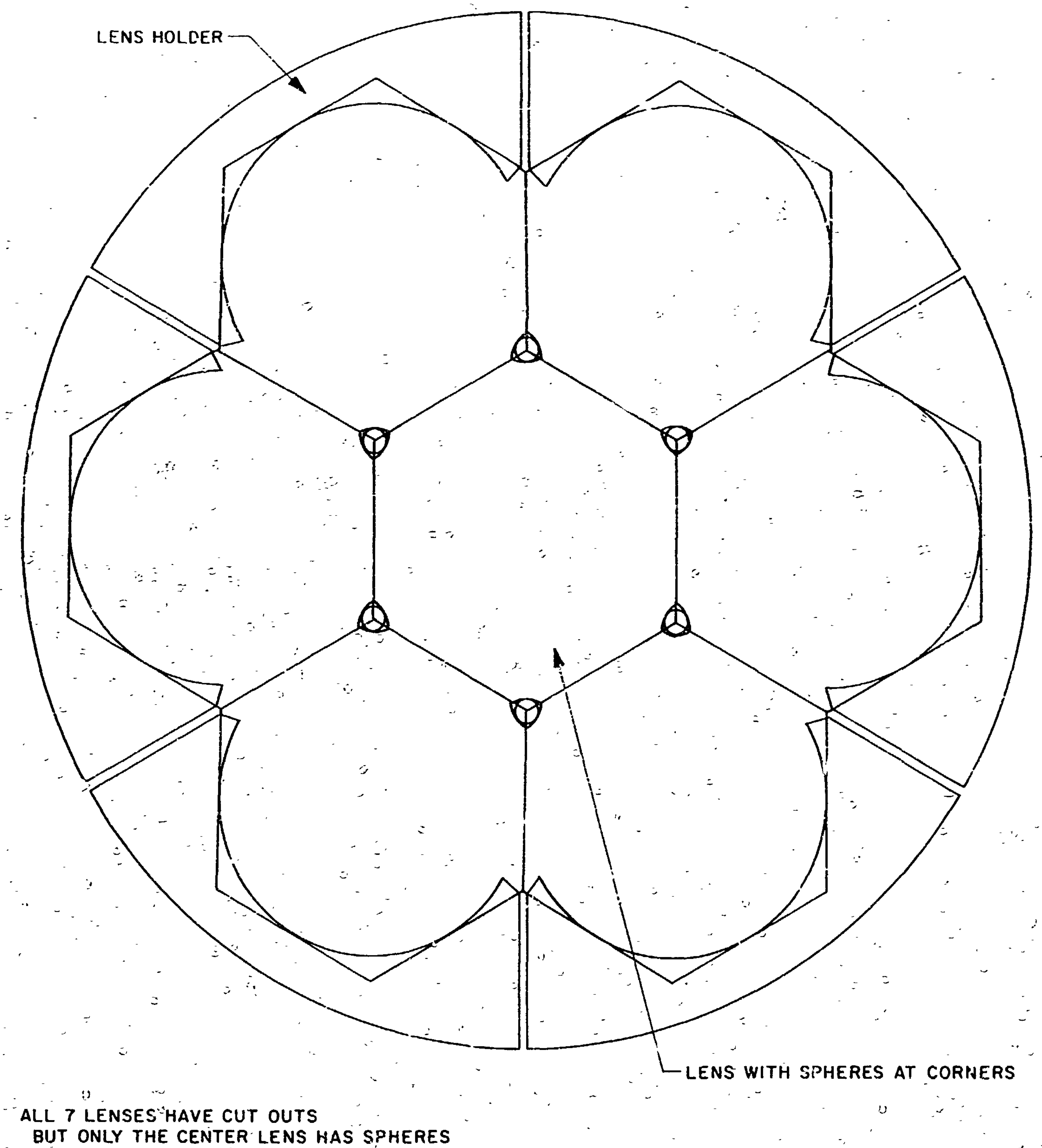


Fig. 5. Mixer mockup

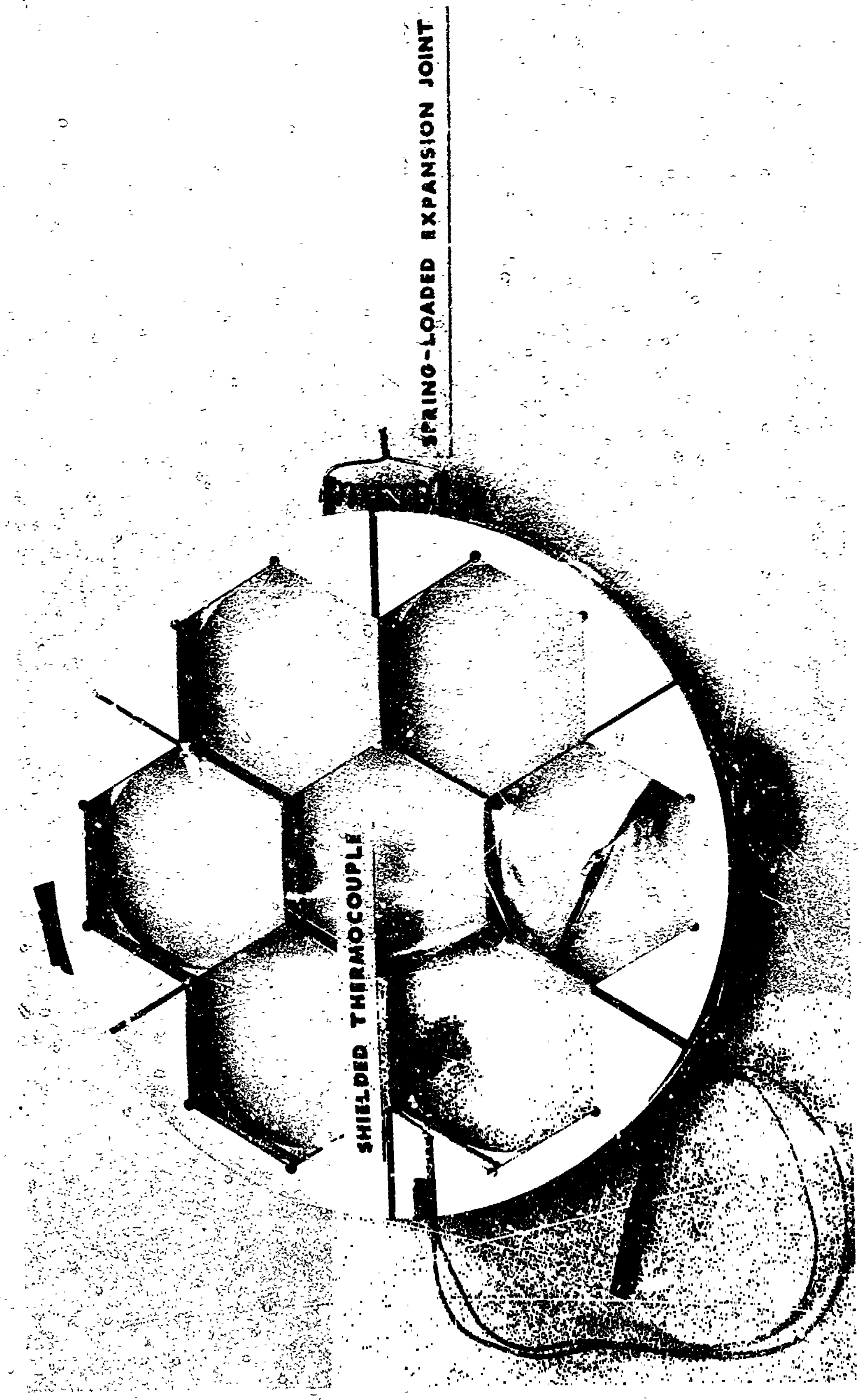


Fig. 6. Experimental design

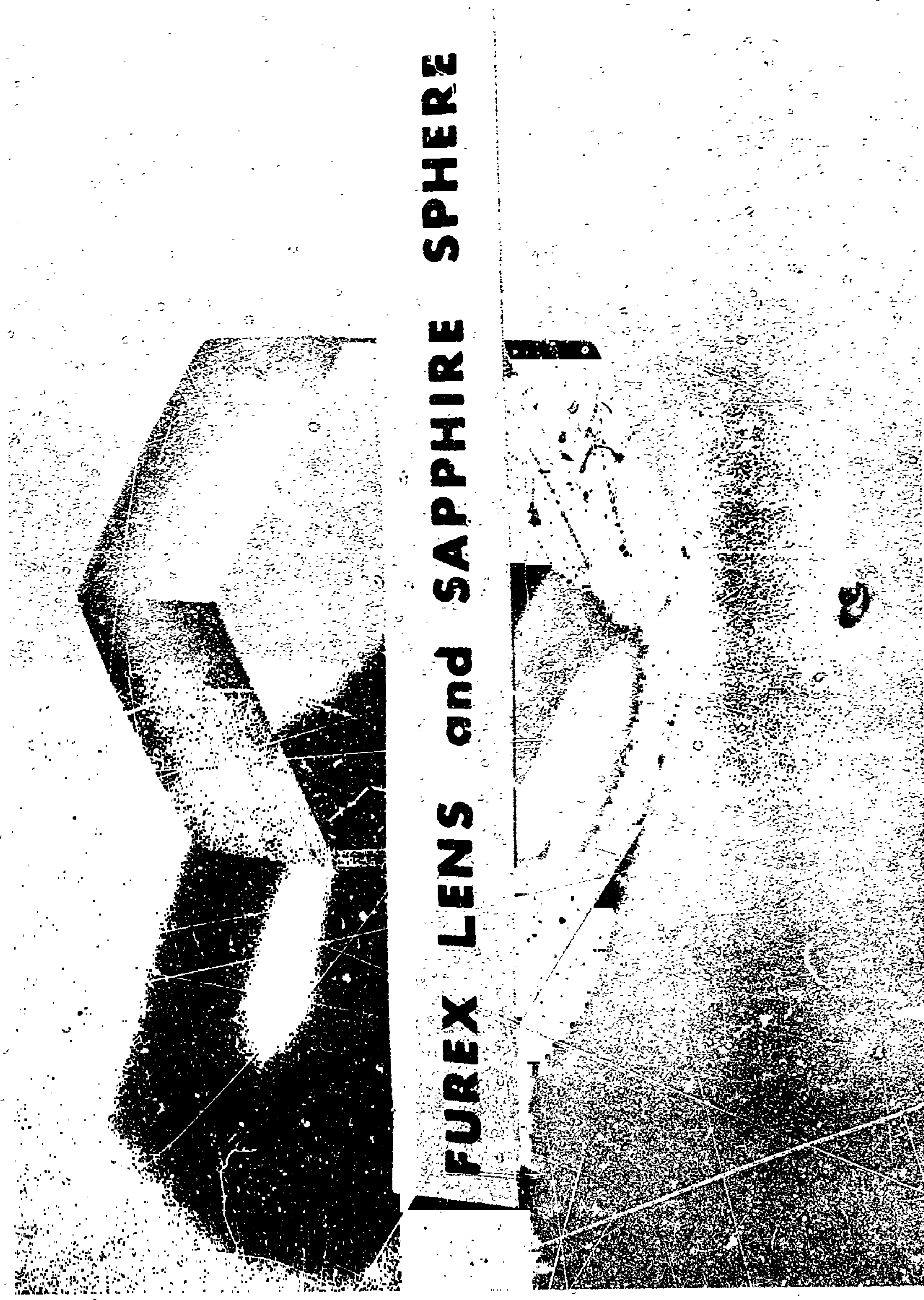


Fig. 7. Furex lens and sapphire sphere

Fig. 8. Infrared lamps

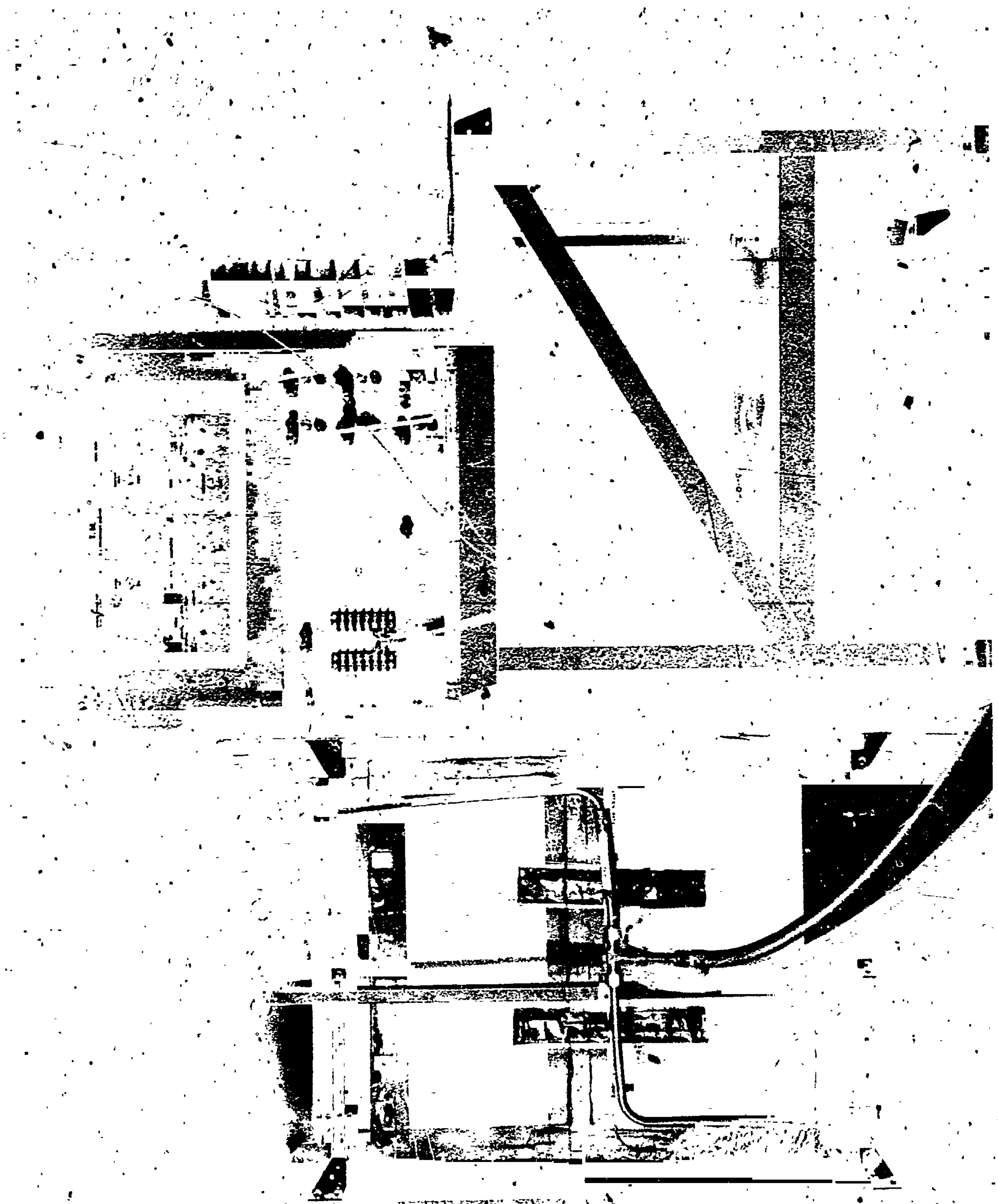


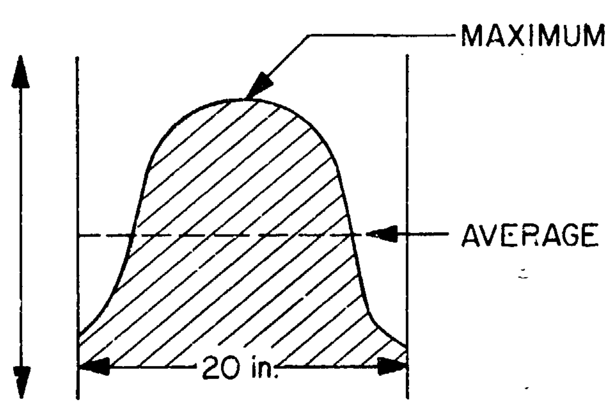
Fig. 9. Test apparatus

APPENDIX. Calculations

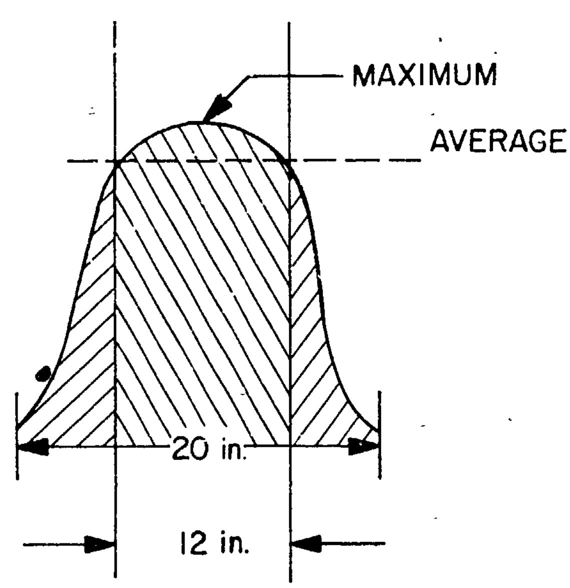
I. ENERGY IN SS-A8 TEST VOLUME AT VENUS INTENSITY

1. Venus intensity = 0.255 kw/ft^2
2. 8-ft hexagon = 55.5 ft^2
3. 0.255 x 55.5 = 14.1 kw
4. Skirt losses = 2 kw
5. Total 16-kw incident on 12-in. D mixer, 0.785 ft^2 area = 16/0.785≈ 20 kw/ft^2 average
6. Maximum intensity may be 30 kw/ft^2

Explanation of item 6:



ORIGINAL INTENSITY SURVEY AT MIXER, SS-A6



SS-A8

In the SS-A8 system the same headlamps are used and therefore, the same intensity contour. However, only the center 12-in. wide section is used so that the average and maximum are closer together.

II. MIXER HEAT TEST CALCULATIONS

The Furex lamp delivers 45% of the input energy to the target (about 70% of delivered radiation is absorbed).

λ range μ	Absorption* %	Total energy in band** %	Absorbed by Furex lenses %
1 - 2	2	15	0.3
2 - 3	50	25	12.5
3 - 10	95	60	57.0

* Taken from a Furex absorption curve.

**Taken from Fostoria Co. curve for 550/QT/120 lamps.

When simulating 50 kw/ft^2 at a 3% average absorption in the 1-2 μ band of the Xenon lamp spectrum note that 1.5 kw/ft^2 is actually absorbed. Consequently, at 70% absorption in the 1-10 μ range of the Fostoria lamp spectrum, it will be necessary to irradiate the target with 2.14 kw/ft^2 to match the 1.5 kw/ft^2 absorption. However, since the lamps are only capable of delivering 45% of the input energy to the target, the input rated power of the system must be 4.75 kw/ft^2. By irradiating the target on both sides, it is possible to achieve this input power.

Four 712-0220 reflectors, holding 12 No. 550/WT/120 lamps, give a total of 5.24 kw/ft^2 maximum on the target (2.62 kw/ft^2 on each side). 850 cc/2 min gives a flow rate of 0.425 liter/min. To obtain the required 2.14 kw/ft^2, the 7.2-in. D calorimeter will have to see a rise in temperature calculated as follows: $3.6^2\pi = 40.7$ in.^{2} or 0.283 ft^2, so input is $0.283 \times 2.14 \times 10^3 = 605$ w. However, power watts = 69.9 x ΔT, °C x litter/min and

$$\frac{605}{0.425 \times 69.9} = 20.2°\,C$$

Therefore, each set of lamps should give a 10.1° C rise. There are 40 μ v/° C for the thermocouples, so the potentiometer should read 4.04×10^2 μ v.

By first determining the lamp surface-to-target surface distance at which this power output is achieved, it will be possible to adjust the lamp separation so that the mixer will see this equal power input on both sides. Note that this test will serve as an adequate check for the "45% efficiency" figure used in the theoretical calculations.

III. MIXER HEAT TEST DATA SUMMARY

A 7.2-in calorimeter which is 12 in. face-to-face from a lamp reflector shows power input from one set of lamps to be

$$= \frac{69.9 \times \Delta T \times \text{flow rate}}{\text{area of calorimeter}} = \text{power/ft}^2$$

$$\Delta T = 22.8° \text{ C}$$

$$\text{flow rate} = 0.450 \text{ liter/min}$$

$$P = \frac{69.9 \times 22.8 \times 0.450}{0.286} = 2.50 \text{ kw/ft}^2$$

Note that this is with only one set of lamps in use. With 6 lamps, 12 in. face-to face, the mixer reached 633° F. With 12 lamps, 12 in. face-to-face, the mixer reached 822° F. After sealing all thermal leaks in the oven, the mixer reached 873° F (3 hr at 873° F). By moving the lamps 6 in. closer, the mixer reached 907° F (5 hr at 907° F).