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NASA TECHNICAL MEMORANDUM

NASA TM X-64991



TEST PLANE UNIFORMITY ANALYSIS FOR THE MSFC SOLAR SIMULATOR LAMP ARRAY

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March 1976
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16. ABSTRACT <p>A preliminary analysis was made on the MSFC Solar Simulator Lamp array. The lamp array is a variation on the design used by LeRC. It is an array of 405 tungsten-halogen lamps with fresnel lenses to achieve the required spectral distribution and collimation. A computer program was developed to analyze the lamp array performance at the test plane. A listing and sample run of the computer program is included in the appendices of the report. Measurements were made on individual lamp-lens combinations to obtain data for the computer analysis and that data are included in the report. The analysis indicated that the performance of the lamp array was about as expected, except for a need to position the test plane within 2.7 m (9 ft) of the lamp array to achieve the desired 7 percent uniformity of illumination tolerance.</p>			
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TEST PLANE UNIFORMITY ANALYSIS FOR THE MSFC SOLAR SIMULATOR LAMP ARRAY

SUMMARY

The MSFC Solar Simulator Lamp Array was analyzed to predict its performance. The lamp array consists of 405 Tungsten-halogen lamps with fresnel lenses in a 15×27 array. To calculate the expected performance, measurements were made on a single lamp-fresnel lens combination and a computer program was developed to give the total array performance. The report describes the computer program and Appendices A and B of the report contain a copy and sample run of the program.

The analysis predicted the edge intensity in the 1.2×2.4 m test plane ($4 \text{ ft} \times 8 \text{ ft}$) decreased more than 7 percent at the desired 4.6 m (15 ft) distance to the test plane. It was recommended that the distance be reduced to 2.7 m (9 ft) to maintain uniformity within 7 percent of the nominal value. Experimental measurements of the lamp-fresnel lens combination showed the total collimation angle was 20° , which exceeded the 10° specification. However, no recommendation was made to change the fresnel lens since the larger angle will have very little effect on collector cover transmission or surface absorption when operating near normal incidence.

INTRODUCTION

As part of the Solar Energy Program at Marshall Space Flight Center (MSFC), a solar simulator lamp array is being constructed to obtain controlled experimental data on flat-plate solar collectors. The design of the lamp array is similar to the simulator now in operation at the Lewis Research Center (LeRC), (Ref. NASA TM-X-3059); however, the MSFC array has a higher density of lamps to obtain either higher light intensities or the standard Air Mass 2 at a lower voltage. An increase in size was necessary to test up to 1.2×2.4 -m (4×8 -ft) collectors. The MSFC simulator has 405 Tungsten-halogen lamps in a 15×27 -array. The lamps are General Electric Quartzline model ELH rated at 120 Vac, 300 W. The fresnel lenses used are hexagon shape

12.7 cm (5 in.) across with a 15.24-cm (6-in.) focal length, as shown in Figures 1 and 2.

To calculate the performance, a measurement program was conducted to obtain data on individual lamp-fresnel lens combinations. A computer program was then used to calculate the irradiance uniformity at the test plane from the total lamp array.

This report gives the results of the measurement program, a description of the computer program, and the preliminary results of the computer analysis.

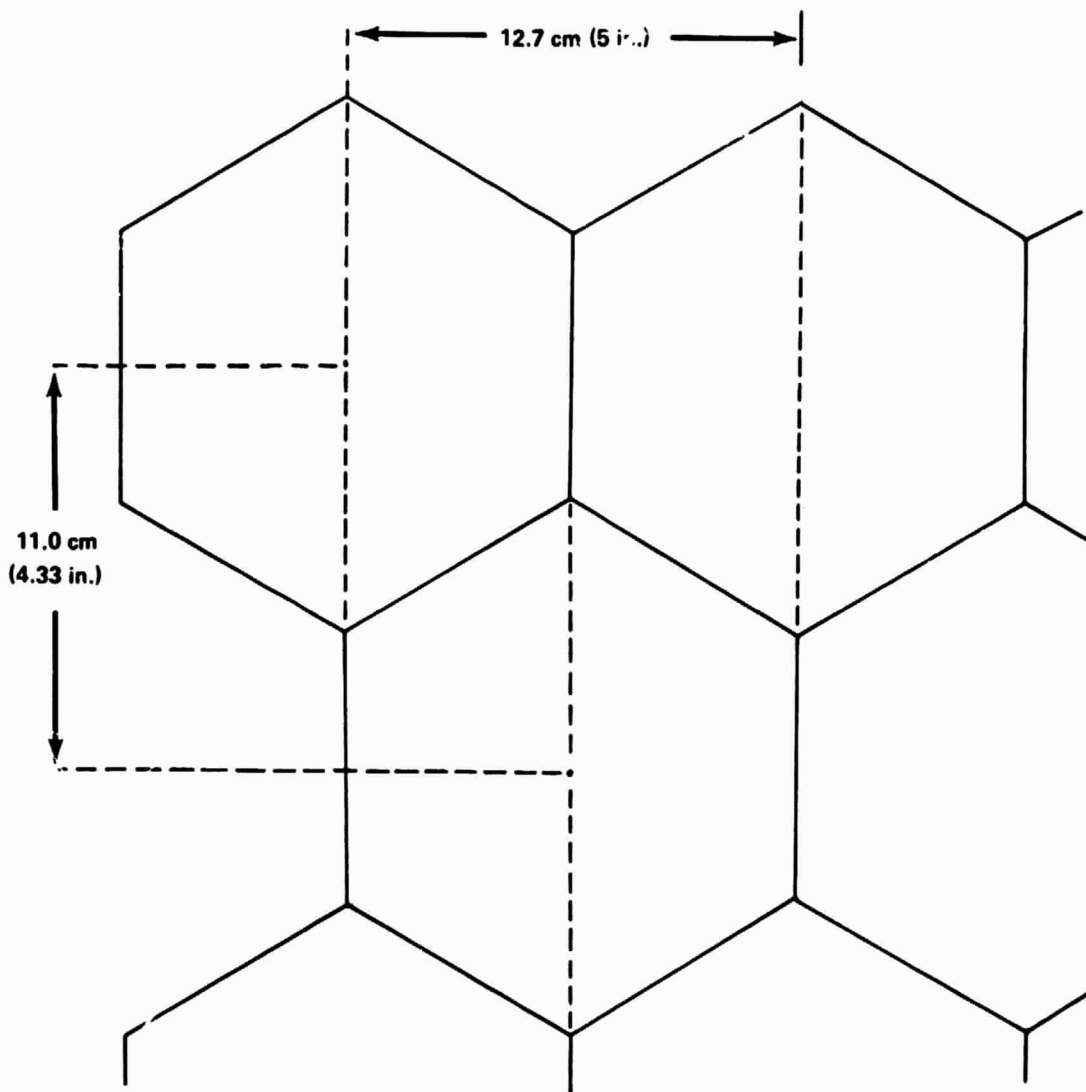


Figure 1. Fresnel lens shape and spacing.

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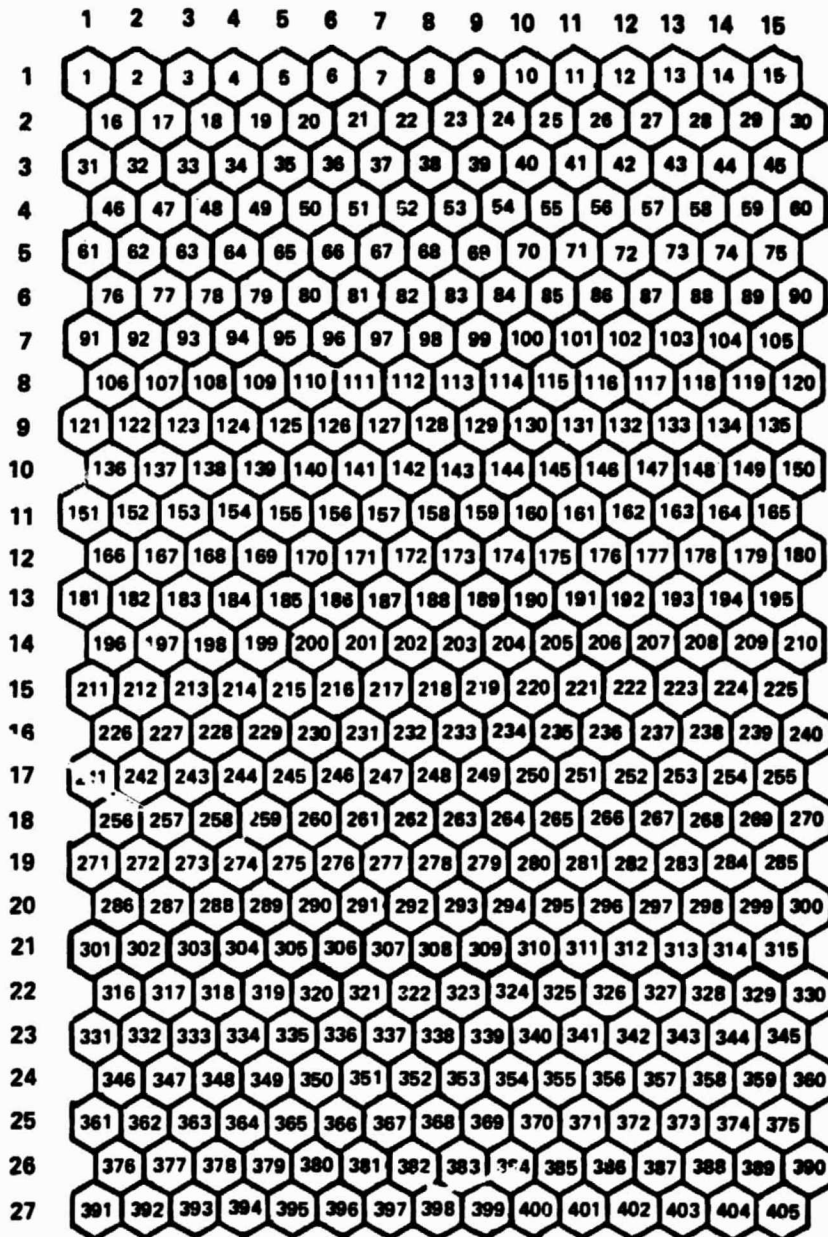


Figure 2. Lamp array configuration.

TEST APPARATUS

Several parameters of the lamp, fresnel lens, and lamp-fresnel lens combination were measured using the experimental arrangement shown in Figure 3. A precision rotation table held the fresnel lens and lamp so that the intensity versus angle data of the resulting light cone could be measured. For the experimental measurements involving relative intensity readings, a Spectra Physics Model 401 power meter was used. To measure absolute power output of the lamp, a Quantronix Model 504 power meter was used with the watt energy detector head. A Dana Model 3800A Digital Multimeter measured the voltage applied to the lamp.

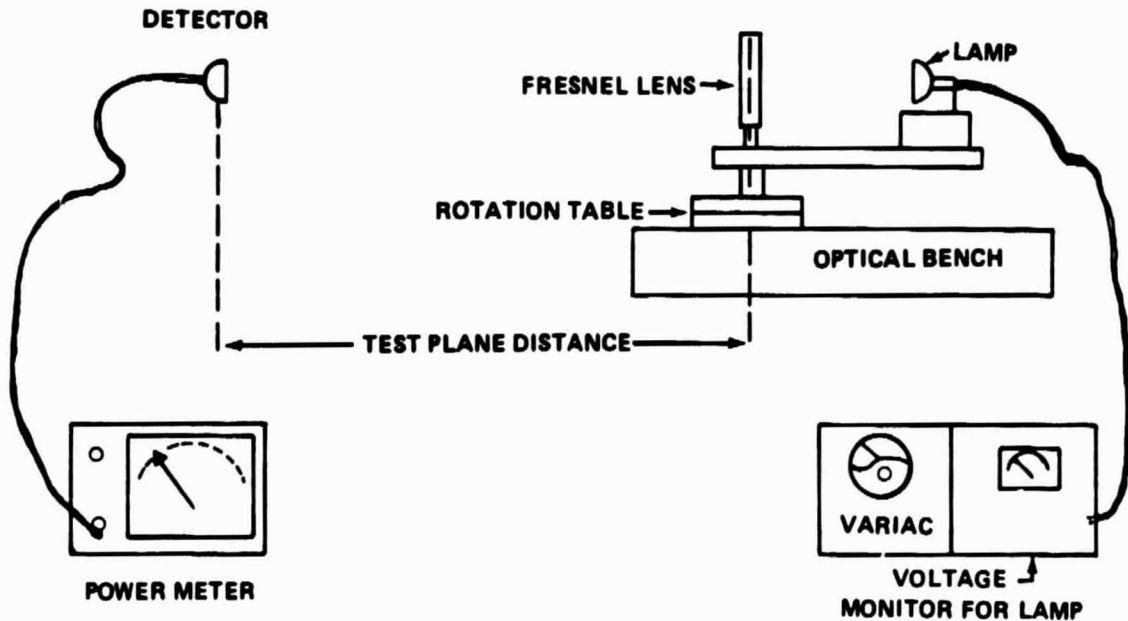


Figure 3. Experimental arrangement to measure parameters of lamp-fresnel lens combination.

DISCUSSION OF TEST

Tests were first made to measure the intensity profile of the cone of light produced by the lamp-fresnel lens combination. During this measurement the detector was fixed at 4.6 m (15 ft) from the fresnel lens. The lamp-fresnel lens combination was rotated on an axis through the fresnel lens to obtain the

intensity readings at various angles. Table 1 presents the result of the measurements averaged on a random sample of 10 fresnel lenses. Figure 4 presents a plot of the same data compared to a Gaussian curve. There was little variation between individual fresnel lenses. Some nonsymmetrical points were observed but the average deviation was less than 5 percent. Measurements were also made on a single 25.4-cm (10 in.) focal length lens of the type used by LeRC. Figure 5 presents a comparison of the two lenses with both normalized to the centerline intensity. Figure 6 presents a comparison of the two lenses with the LeRC 25.4-cm (10-in.) lens normalized in relative power to the MSFC 15.2-cm (6-in.) focal length lens. The intensity of the LeRC lens is approximately 2.4 times that of the MSFC lens in the central region. The larger angle provided by the MSFC lens gives better uniformity in the test plane by merging more lamps.

TABLE 1. RELATIVE INTENSITY VERSUS ANGLE AVERAGED FOR 10 FRESNEL LENSES (15.2 cm FOCAL LENGTH)

Angle (deg)	Relative Intensity (%)	Angle (deg)	Relative Intensity (%)
0	100.0	6	24.3
1	98.0	7	12.5
2	93.5	8	4.2
3	80.0	9	2.5
4	63.5	10	1.8
5	42.0		

A random sample of 10 lamps were measured to determine the variation in intensity between lamps. The values of intensity measured for the 10 lamps are shown in Table 2. The largest variation is 28 percent but since the variation is so large, 10 is probably too small a sample size to obtain an accurate average intensity value for the total lamp array. A larger sample will be obtained during buildup of the lamp array when all 405 lamps will be measured.

The lamp-fresnel lens combination intensity profile was measured at various distances from the fresnel lens. The relative intensity curve shape changed very little beyond 2 m (6.5 ft). At distances less than 2 m, hot spots were observed which were attributed to the geometry of the lamp. In all measurements at the 4.6-m (15-ft) distance, the lamp was defocused approximately 3 mm (0.1 in.) to prevent imaging of the lamp and thereby produce a smoother intensity profile curve.

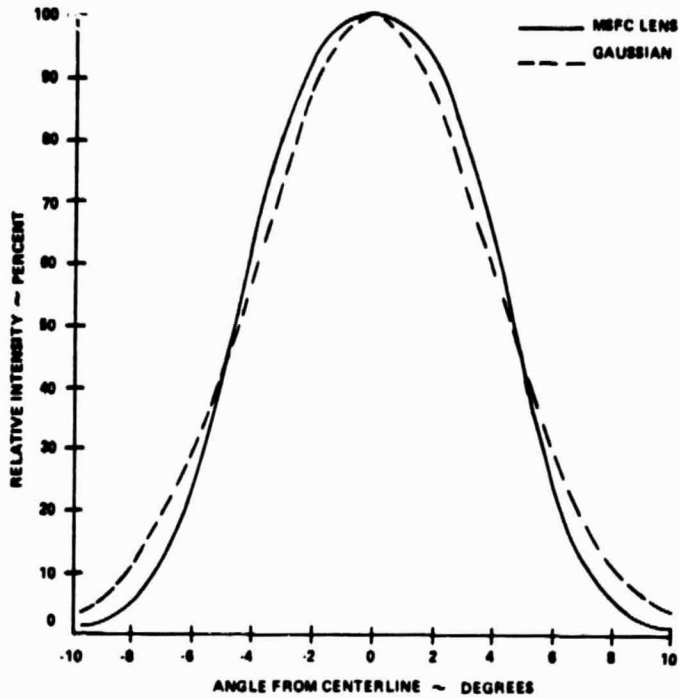


Figure 4. Plot of relative intensity versus angle for MSFC lamp-fresnel lens combination.

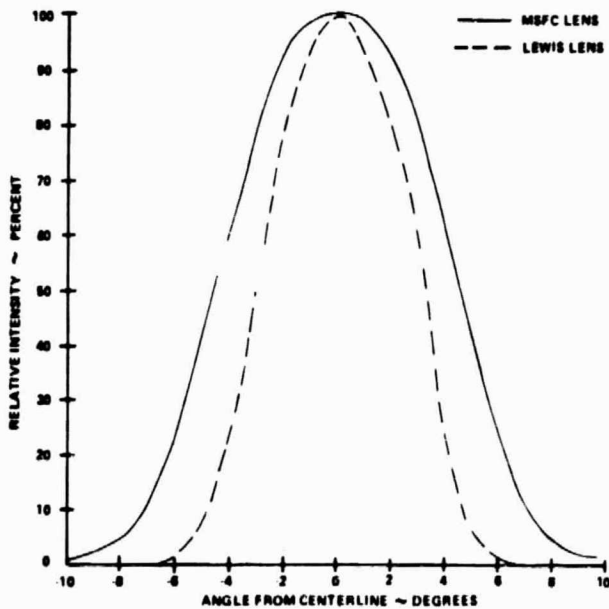


Figure 5. Comparison of MSFC and LeRC fresnel lenses with both lenses normalized to 100 percent.

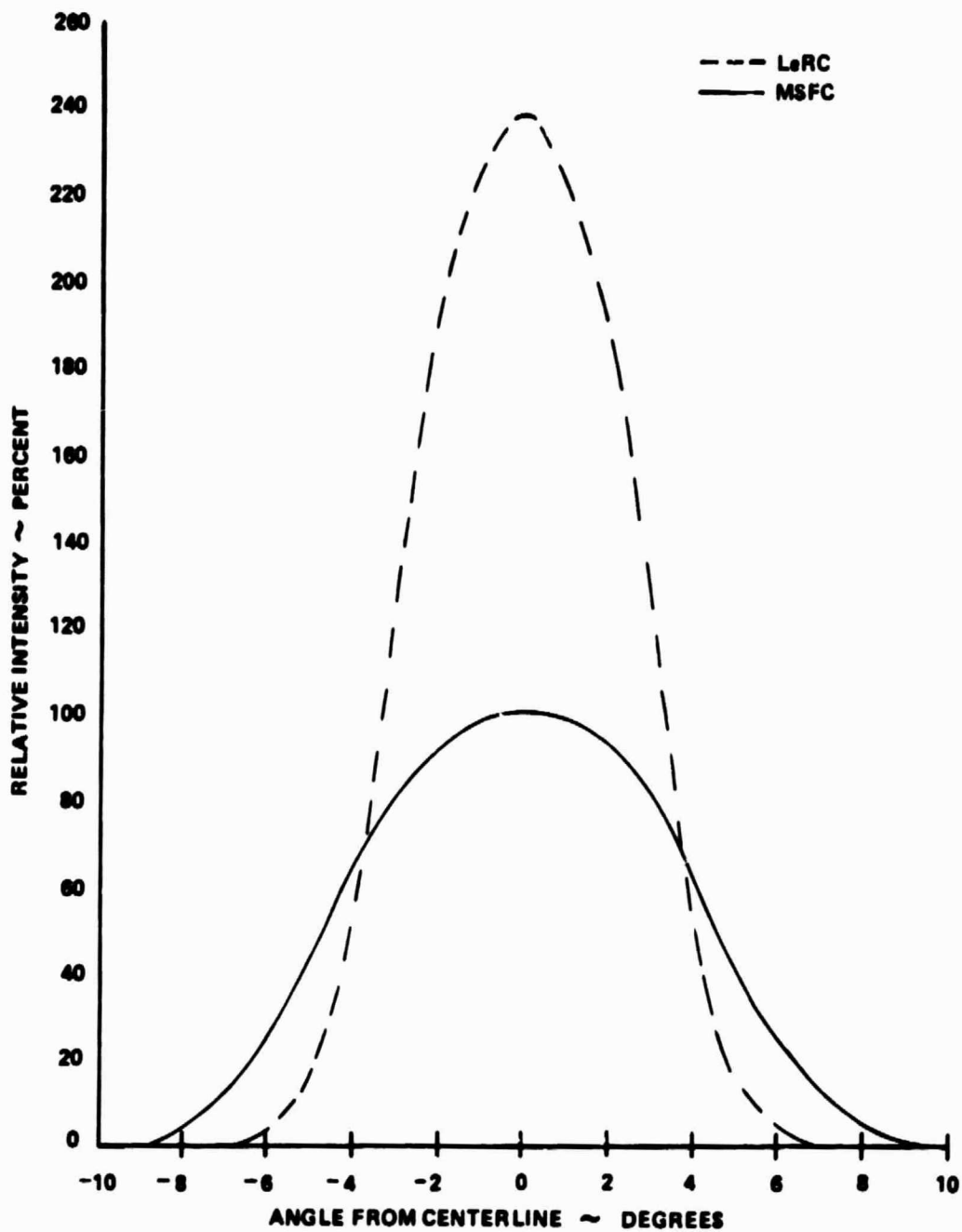


Figure 6. Comparison of MSFC and LeRC fresnel lenses with LeRC lens normalized to MSFC lens.

TABLE 2. RELATIVE INTENSITY MEASURED FROM 10 DIFFERENT LAMPS

Lamp Number	Relative Intensity (%)	Lamp Number	Relative Intensity (%)
1	83.1	6	86.3
2	81.1	7	97.6
3	84.2	8	77.9
4	94.7	9	100.0
5	73.7	10	71.6

Figure 7 shows the measured peak intensities of the relative intensity (I_1) profile curve at various distances ratioed to the peak intensity at 4.6 m (15 ft) (I_0). Also shown is the calculated value to be expected due to the ratio of the inverse square of the area covered at each position. The measurements agreed very well with the calculated values.

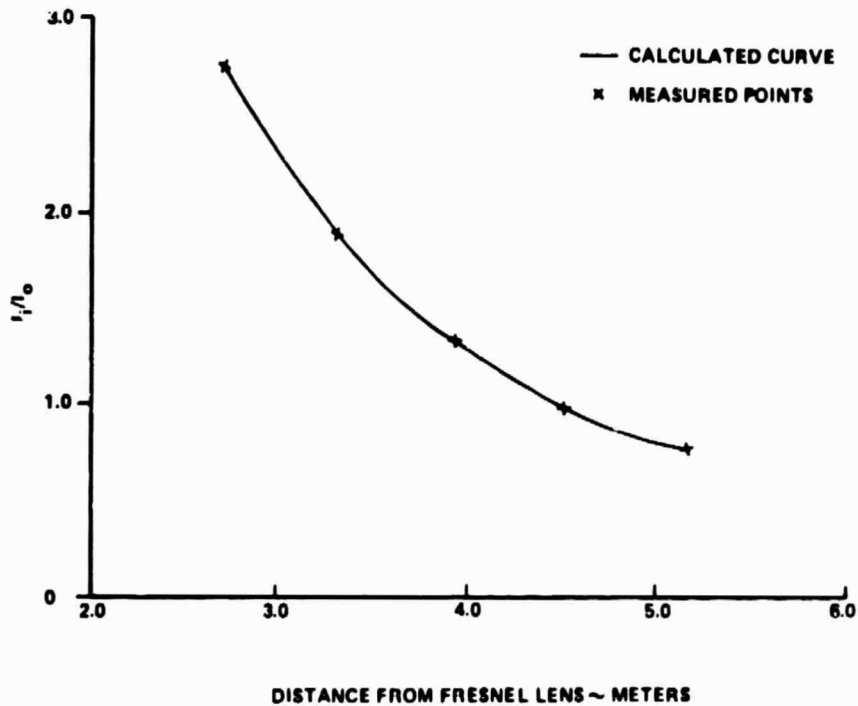


FIGURE 7 PEAK INTENSITY (I_1) VARIATION WITH DISTANCE FROM THE FRESNEL LENS RATIONED TO THE INTENSITY AT 4.6 METERS (15 FEET) (I_0)

Figure 7. Peak intensity (I_1) variation with distance from the fresnel lens ratioed to the intensity at 4.6 m (15 ft) (I_0).

A single lamp was measured to determine the relative intensity as a function of voltage. Table 3 gives the results from 60 to 128 V and Figure 8 shows this voltage versus intensity. In Figure 8 there are two breaks in the curve, one at approximately 75 Vac and a second at 100 Vac. The breaks are probably related to the Tungsten-halogen cycle. If the Tungsten-halogen cycle is no longer operating below 100 Vac, the lamp life may be reduced.

TABLE 3. RELATIVE INTENSITY AS A FUNCTION OF LAMP VOLTAGE

Vac	Relative Intensity (%)	Vac	Relative Intensity (%)
128	123	95	62
125	117	90	54
120	107	85	47
117	100	80	40
115	97	75	32
110	87	70	27
105	79	65	22
100	69	60	17

The irradiance of both the MSFC and the LeRC lamp-fresnel lens combinations at 117 Vac was measured with the Quantronix power meter. The peak irradiance measured for the MSFC combination was 4 mW/cm² (12.7 BTU/h ft²) and 9.7 mW/cm² (30.8 BTU/h ft²) for the LeRC. The irradiance is only an indication of the absolute power due to the large variation in lamps; however, if it is representative, then the lamp array should provide 107 mW/cm² or 340 BTU/h ft² at slightly over 100 Vac. 90 Vac would give 80 mW/cm² (254 BTU/h ft²). The irradiance of the lamp array is approximately 37 times the irradiance of one lamp.

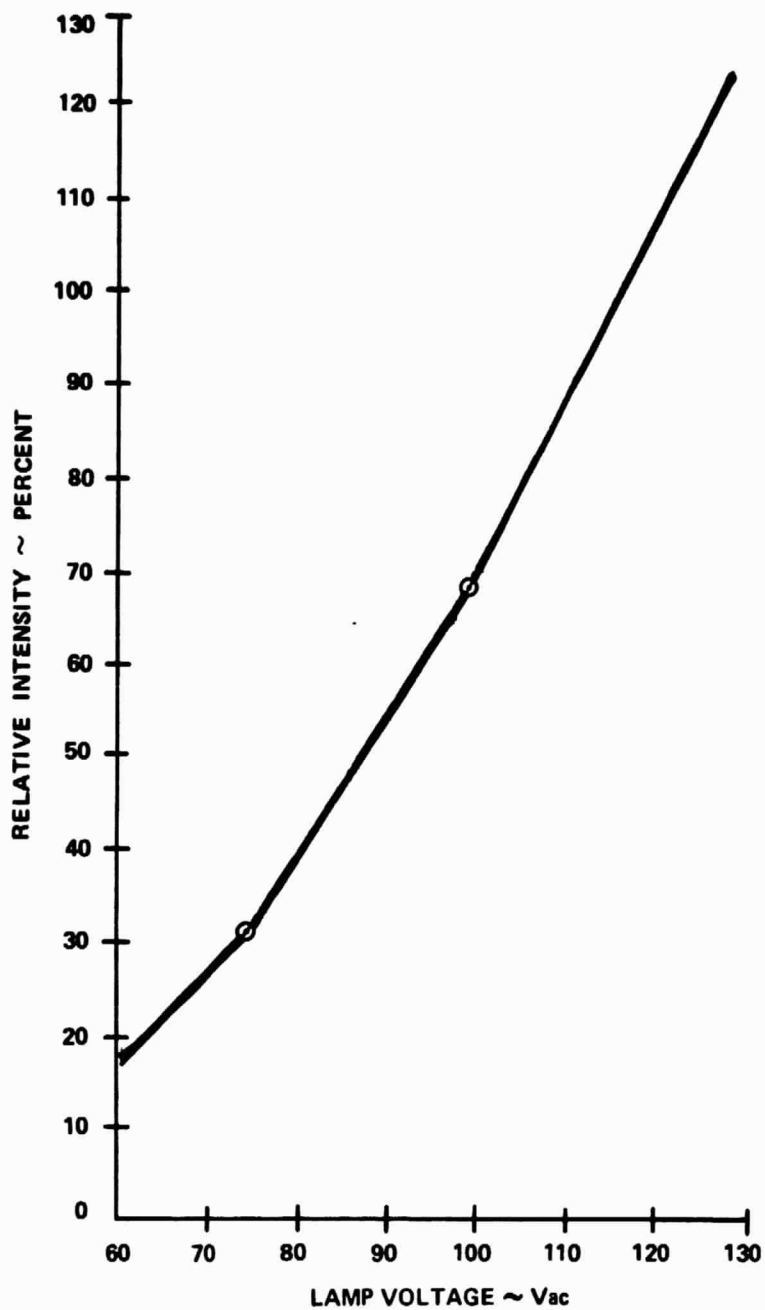


Figure 8. Plot of relative intensity as a function of lamp voltage.

It should be noted that all the aforementioned experimental data were taken with the lamp in open air and no forced air cooling. They were operated only for short periods of time to prevent damage to the lamp. Since the lamp characteristics vary with operating temperature, these data should be considered preliminary and only designed to catch "show stoppers" in construction of the solar simulator.

DISCUSSION OF COMPUTER PROGRAM

The Lamp Uniformity Analysis Computer Program (LUMP) used to analyze the total lamp array is listed in Appendix B. Appendix A is a sample run of the program which includes the instructions for the computer monitor. The program is written in Fortran IV and is intended to be executed from a time share terminal connected to the XDS Sigma V computer located in Building 4487 at MSFC.

The technique used to compute the test plane intensity is depicted in Figure 9. A point of interest in the test plane (A) is mapped to lamp positions in the lamp array, (B is an example of one lamp position). The intensity at A from the lamp at B is calculated by first finding the angle ABE, then calculating the relative intensity given off by the lamp at that angle. The total power at A is found by going through this sequence for all 405 lamps and adding up the results. To develop an intensity scan through the test plane, the computer program increments A through different values of X while holding Y constant. By sequencing X at the same increments as the Y spacing between scans, a regular array of data points in the test plane can be generated. The regular array is useful for calculating total power at the test plane and obtaining statistics on the total surface uniformity. A program is now being written to plot the intensity profile and provide statistics on the intensity surface. It will be described in a subsequent TMX.

To compute the intensity component from each lamp, the assumption is made that the cone of light from the lamp is rotationally symmetrical. Some non-symmetry was noted during the experimental measurements of the 10 fresnel lenses but the average deviations were less than 5 percent. When averaged over many lamps the assumption should lead to negligible errors.

IVSA is the subroutine of the computer program which provides the intensity value at different angles. The array AI in the data statement stores the relative intensity values in percent at 1° increments for the light cone intensity

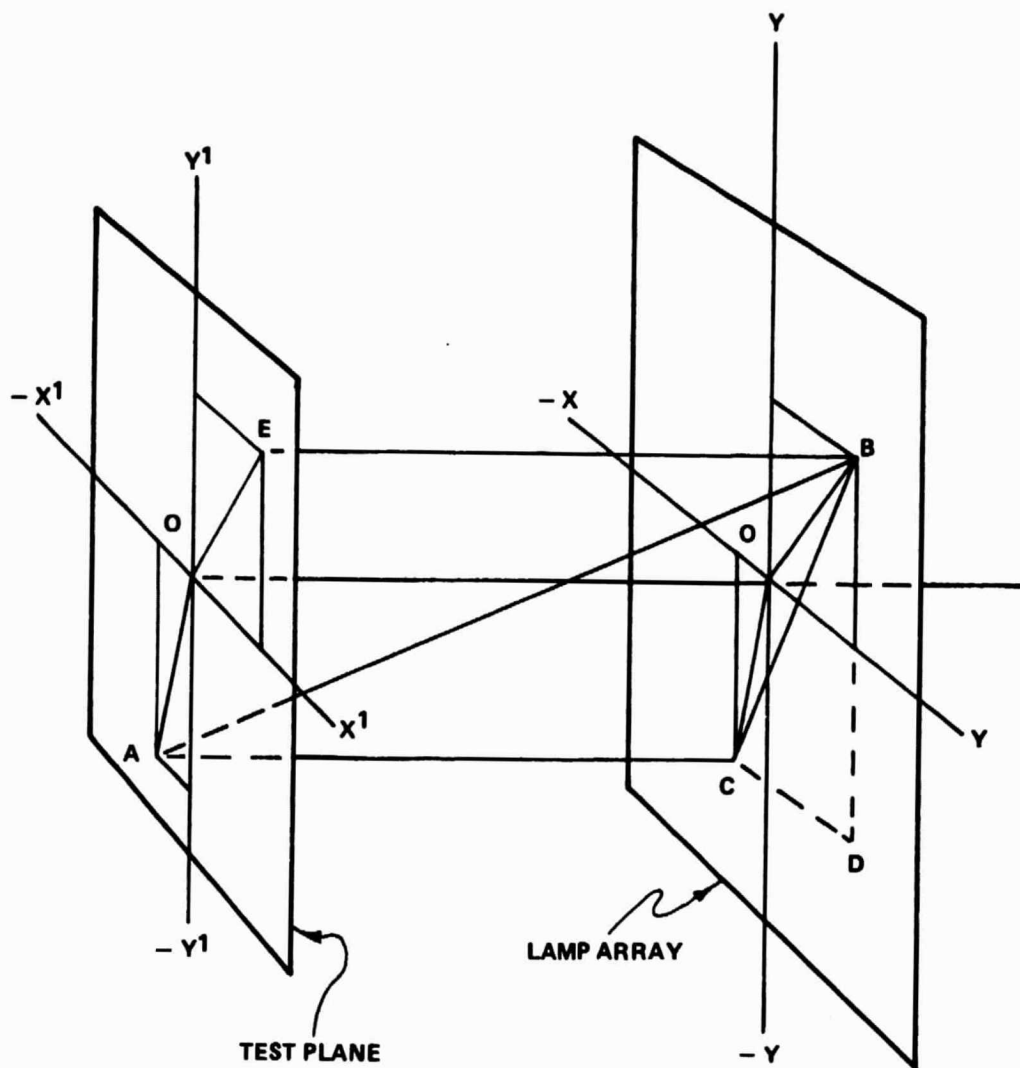


Figure 9. Arrangement of test plane to lamp array.

profile. The range is from 0 to 10° . To obtain values at any angle, the subroutine linearly interpolates between the stored values. Angles greater than 10° are assigned a zero contribution to the point A.

To calculate absolute power at the point A for different spacings (0'-0) between the test plane and lamp array, power readings at a reference distance from the lamp are ratioed by the inverse square rule to obtain power per unit area at a different distance. This is the reason for the multiplication factor TMFAC, line 87 of the program, in obtaining the intensity contribution from each lamp.

Data are input to the program through a file assigned to Unit 201. The distance between the test plane and the lamp array (SPACE) is input first and then an array (TLI), which has an intensity value for each lamp, is input. This was necessary because of the large variation in intensity from individual lamps. All other variables that might require frequent changing are stored in the program. The edit capability of the time share monitor makes it practical to change only the variable in the program when needed.

The program has the option to print out the lamp intensity array and the X, Y locations assigned to the lamps. The lamp intensity array will be printed if NCO is set to some value other than one. The X, Y spacing position of the lamps will be printed out if NCODE is set not equal to one.

The variables NLINES, DELX, TPY, DELY, and SX control the scan lines to be calculated. NLINES is the number of scan lines to be calculated, TPY is the Y position of the scan line, and DELY is the spacing between scan lines. SX is the first part of the scan line and it will be incremented by units of DELX. Format statement 650 is intended as a comment line to label the output data page.

An attempt was made to keep the program as flexible as possible. For instance, all Do loops were set with variable limits. The lamp array size can be changed from the present 15×27 to any size which will fit in the arrays as dimensioned. The array size is set by assigning the desired values to NLX and NLY.

DISCUSSION OF COMPUTER ANALYSIS

An array of lamps with equal intensities was used as an input to the computer program to determine the best uniformity that could be expected at the test plane. The uniformity as calculated was very good in the central region of the test plane but dropped off at the edge. Figure 10 presents a plot of the percent intensity for two scan lines across the narrow direction (X axis), one line in the center and one at the edge. Figure 11 shows the edge and corner variations as a function of distance from the lamp array. Figure 12 presents a comparison of a similar run on the LeRC array.

The desired tolerance was 7 percent from the nominal value. Since most of the test plane area intensity varies less than 1 percent, the nominal value of intensity is almost 100 percent. Therefore, 93 percent would be the minimum

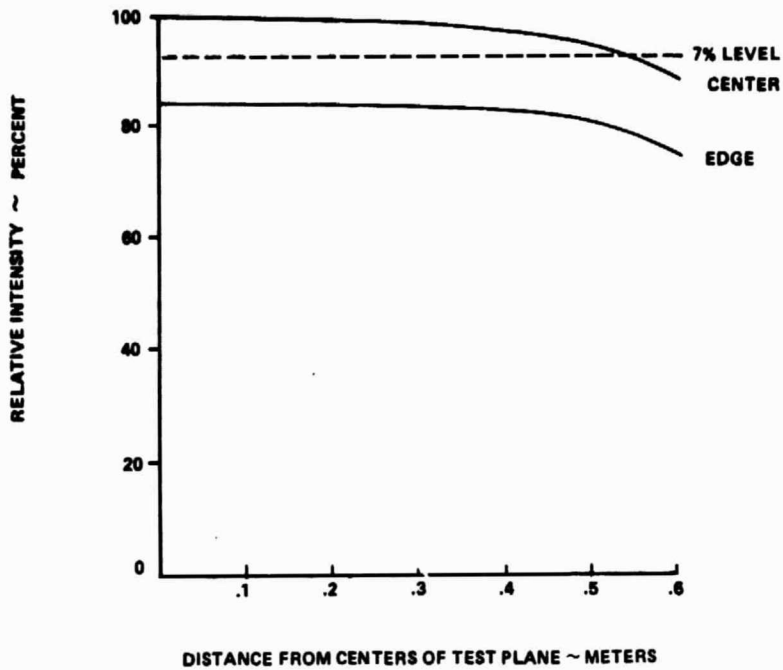


Figure 10. Two scans of relative intensity in the test plane, one at the center and one at the edge.

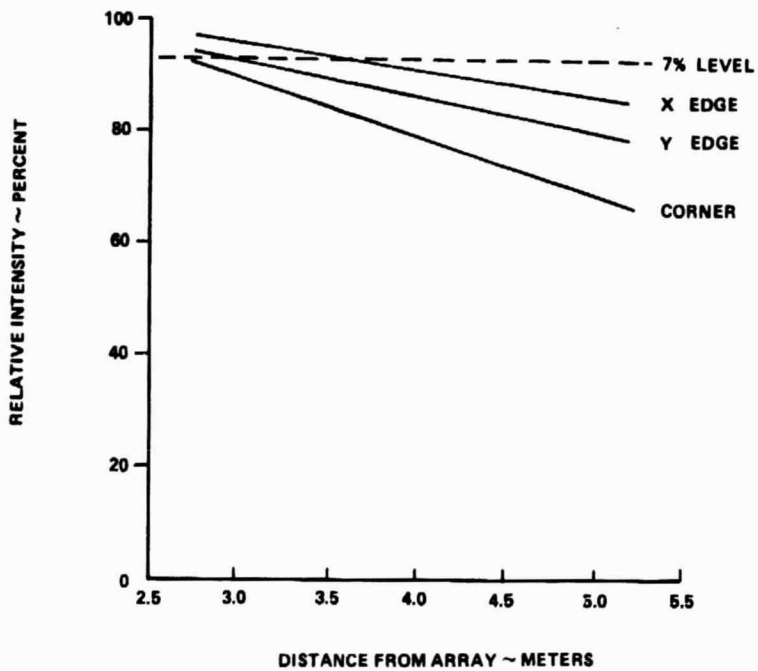


Figure 11. Test plane edge variation in intensity as a function of distance from the lamp array.

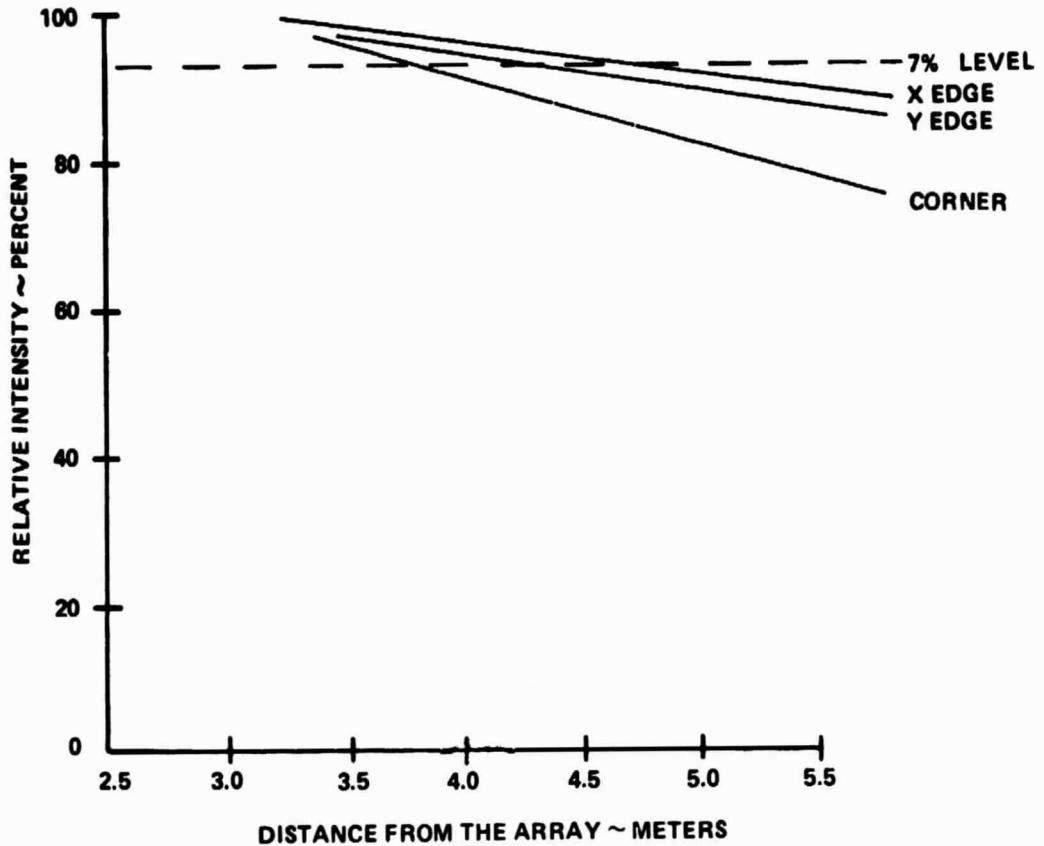


Figure 12. LeRC array test plane uniformity as a function of distance from the array.

acceptable. To analyze the decrease in nominal value due to varying intensity from each lamp, a run was made with lamps varying at random up to 30 percent. The absolute power dropped in percentage but the nominal value was still almost 100 percent (99.9 percent). The variation in lamps is not as evident in the MSFC array as much as in the LeRC array because the MSFC lamp-fresnel lens combination has a wider cone angle and a higher density of lamps per unit area.

As the distance to the lamp array is decreased, the number of lamps averaged at a point in the test plane decreases. This does not result in a decrease in irradiance at the point in the test plane because the individual lamp irradiance increases. The increase in irradiance is inversely related to the square of the distance (Fig. 7) but the decrease in number of lamps averaged is directly related to the square of the distance due to the decreasing area covered by the cone of light. The result is that the irradiance from the lamp

array is uniform within the central region as the distance is increased from the lamp array. This is true only within a limited range near the lamp array. As the distance increases, the edge intensity will drop off until there is no flat central region as shown in Figure 13.

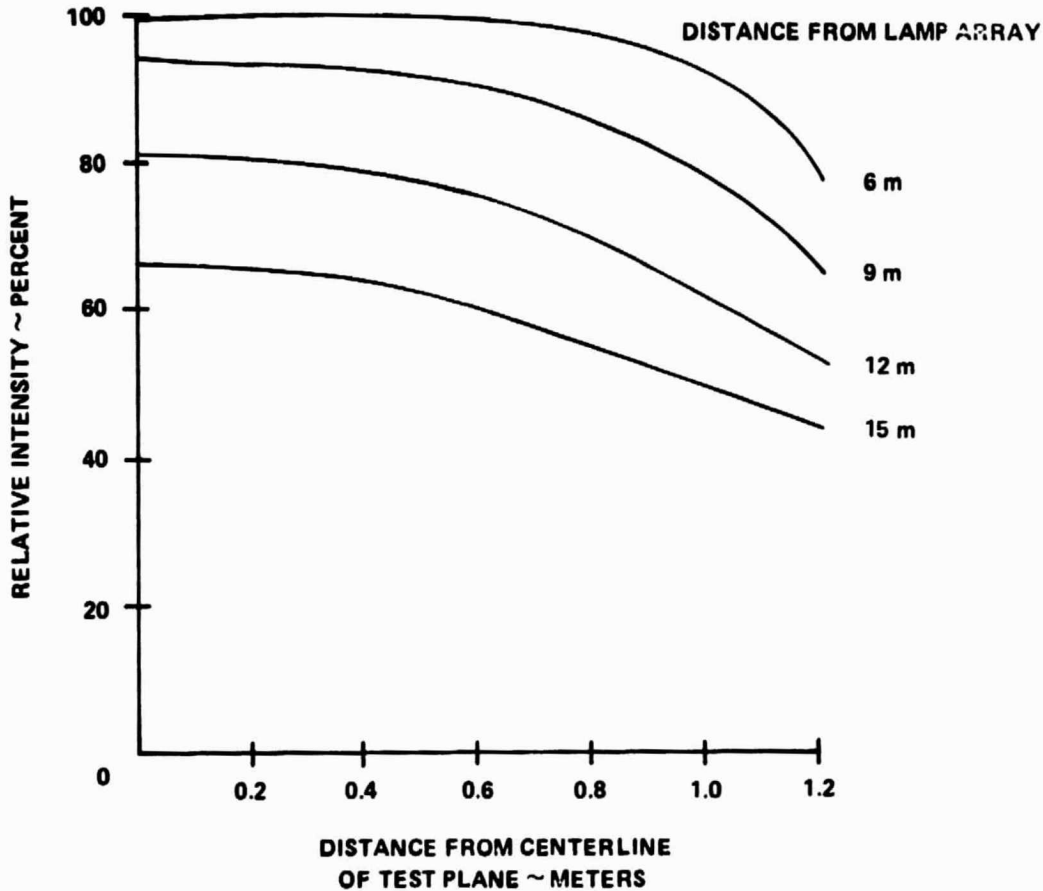


Figure 13. Test plane uniformity as a function of distance from the lamp array — y axis scans.

An effective number of lamps averaged at any distance from the lamp array by a point in the test plane can be computed by defining N , where the test plane irradiance equals N times the irradiance from one lamp.

Figure 14 presents a plot of the effective number of lamps averaged at various distances using the intensity profile of Table 1. This curve is important because it is representative of the number of lamps averaged at any one point.

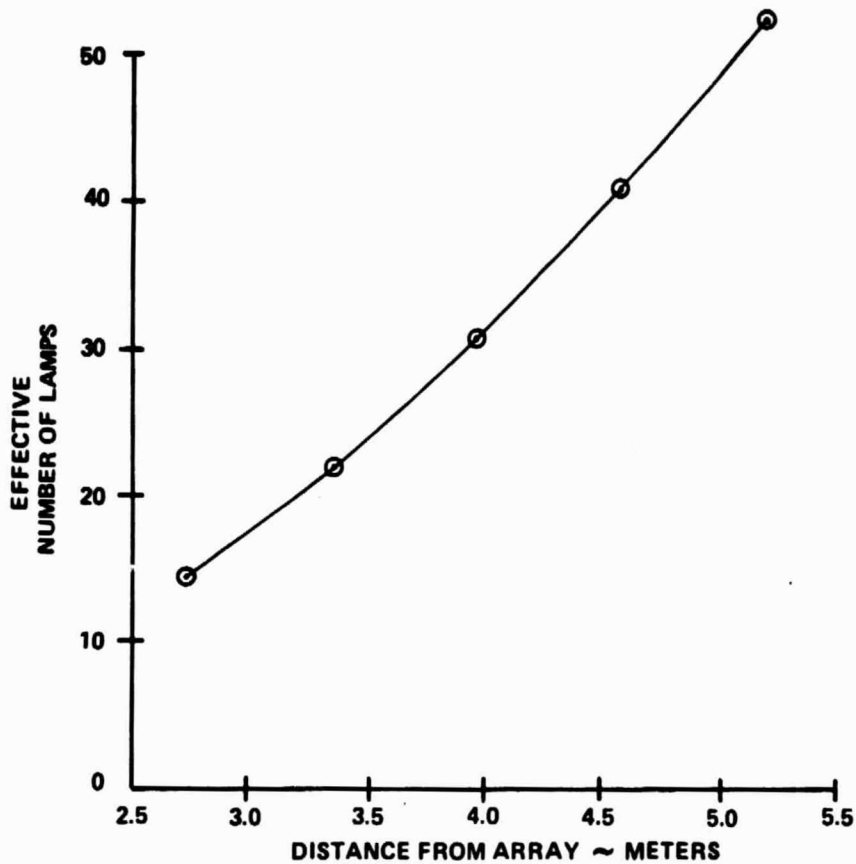


Figure 14. Effective number of lamps viewed as a function of distance from the lamp array.

The LeRC array averaged approximately 7 lamps at 4.6 m (15 ft) and therefore was sensitive to individual lamp variation. At 4.6 m (15 ft) the MSFC array averages 37 lamps. Even at 2.7 m (9 ft) the MSFC array averages 14 lamps and is correspondingly less sensitive to lamp intensity variation.

As can be seen in Figure 10, the desired tolerance can be achieved by operating at a distance of 2.7 m (9 ft). As the number of lamps average is still high, the recommendation was made to adopt 2.7 m (9 ft) as the standard operating distance. For test articles smaller than 1.2×2.4 m (4×8 ft) the distance can be increased.

Other options to increase the uniformity at distances of 4.7 m (15 ft) or greater were analyzed. One option is to increase the array size. The lamp array is now unsymmetrical with respect to the 1.2×2.4 m test plane. Across the narrow distance, the lamps extend 0.33 m (13 in.) past the test bed edge. Across the long axis the lamps only extend 0.2 m (8 in.). Expanding the array to 15×29 would make the system more symmetrical and bring both edges up to within 10 percent (the corners would still be down 20 percent).

The placement of brighter lamps around the edges of the array to improve the uniformity was analyzed and proved to be feasible provided 34 percent brighter lamps could be used. Since the maximum variation measured was 28 percent, this could probably not be obtained by measuring all the purchased lamps and picking the brighter ones for the edge. The placement of brighter bulbs near the edge, however, would be a method of arranging lamps to achieve the maximum uniformity for a particular set of lamps at a standard operation spacing. The uniformity is good for only one spacing (Appendix A).

Of all the options considered, the reduction of the standard operating distance involved the least cost and time impact to the present system which is well on the way to completion.

CONCLUSIONS

The experimental measurements and the computer analysis revealed no real problems with the design of the solar simulator lamp array. A recommendation was made to change the standard operating distance for the test specimen to 2.7 m (9 ft). This recommendation was made because the edge intensity drop-off would be less than 7 percent and enough lamps would still be averaged to keep the central region uniformity better than 2 percent.

The irradiance measurement of the 10 lamps indicated more data are needed on individual lamp variation to make realistic predictions of total irradiance of the lamp array. Additional data are also required on lamp life and variations in irradiance with age. These data will be obtained during lamp array checkout.

Measurements of the lamp fresnel lens combination indicated the lamp should be positioned 3 mm (0.1 in.) from the focal point of the fresnel lens to keep from imaging the lamp at the test plane.

The intensity profile of the light cone from the lamp fresnel lens combination is not a true Gaussian curve but is very close. The point-by-point storage of a measured curve used by the computer program is probably not necessary for realistic analysis; a Gaussian equation could be used.

Measurements of the lamp intensity versus voltage show the lamp intensity varies linearly with voltage but has slope changes above 75 and 100 V.

APPENDIX A

EXAMPLE RUNS OF COMPUTER PROGRAM LUMP
(LAMP UNIFORMITY MAPPING PROGRAM)

PRECEDING PAGE ~~IS~~ NOT FILMED

*****EXAMPLE OF EXECUTION OF LUMP PROGRAM*****_

ISET F:201/DASTT

ISET F:108 = LP

IFORT4 LUMP OVER LUMPC
EXT. FORTRAN IV, VERSION F00
OPTIONS >BC,NS

IRUN LUMPC
LINKING LUMPC
'P1' ASSOCIATED.
STOP 0

!*****PROGRAM HAS BEEN RUN AND RESULTS PRINTED ON THE LINE PRINTER*****_

*****DATA CAN BE CHANGED AND PROGRAM RERUN AS FOLLOWED *****_

IEDIT DASTT
EDIT HERE
*TY1
1.000 108.0
*SE1;/108/S/180/;TY
1.000 180.0
*END

I@UN LUMPC
LINKING LUMPC
'P1' ASSOCIATED.
STOP 0

!

!

OUTPUT DATA PAGE 3

MSFC ARRAY AND 6 IN FL LENS

INTENSITY AT 9.0 FEET UNITS ARE BTU/HR-FT²

X POS IN INCHES	Y SCAN POS IN INCHES				
	-48.0	-36.0	-24.0	-12.0	0
-30.0	403.4	416.7	415.9	418.8	415.7
-28.0	426.6	443.8	442.7	442.7	439.9
-26.0	439.4	456.6	457.1	457.0	455.5
-24.0	447.6	466.1	465.8	465.5	460.2
-22.0	450.7	468.0	467.7	467.7	467.3
-20.0	452.8	468.0	466.1	469.6	467.7
-18.0	451.6	468.8	467.2	468.7	465.3
-16.0	448.9	467.7	468.3	467.3	466.2
-14.0	450.4	469.2	468.9	468.4	464.0
-12.0	450.7	468.9	468.6	468.5	468.2
-10.0	452.8	468.0	466.1	469.6	467.7
-8.0	451.6	468.8	467.2	468.7	465.3
-6.0	448.9	467.7	468.3	467.3	466.2
-4.0	450.4	469.2	468.9	468.4	464.0
-2.0	450.7	468.9	468.6	468.5	468.2
0	452.8	468.0	466.1	469.6	467.7
2.0	451.6	468.8	467.2	468.7	465.3
4.0	448.9	467.7	468.3	467.3	466.2
6.0	450.4	469.2	468.9	468.4	464.0
8.0	450.7	468.9	468.6	468.5	468.2
10.0	452.8	468.0	466.1	469.6	467.7
12.0	451.6	468.8	467.2	468.7	465.3
14.0	448.9	467.7	468.3	467.3	466.2
16.0	450.4	469.2	468.9	468.4	464.0
18.0	450.7	468.9	468.6	468.5	468.2
20.0	452.8	468.0	466.1	469.6	467.7
22.0	450.6	467.9	466.3	467.7	465.3
24.0	445.8	464.8	465.3	464.3	463.4
26.0	439.8	458.8	457.7	457.4	454.5
28.0	425.4	442.9	442.4	443.4	441.4
30.0	401.0	417.2	416.1	417.2	416.7

PROGRAM COMPLETE

EXAMPLE 2 OF OUTPUT DATA PAGE 3

MSFC ARRAY AND 6 IN FL LENS

INTENSITY AT 15.0 FEET

UNITS ARE BTU/HR-FT²

X POS IN	Y SCAN POS IN INCHES				
INCHES	-48.0	-36.0	-24.0	-12.0	0
-30.0	300.8	354.2	356.2	355.9	356.6
-28.0	323.8	380.3	382.8	384.1	383.3
-26.0	343.2	403.5	406.0	406.2	406.2
-24.0	358.0	422.4	426.0	425.2	426.2
-22.0	371.1	436.6	439.8	439.7	438.8
-20.0	379.7	447.8	450.0	449.7	451.1
-18.0	386.8	454.3	457.1	458.8	458.1
-16.0	391.4	459.4	462.6	462.4	462.1
-14.0	392.6	462.5	466.4	465.0	466.7
-12.0	394.8	463.8	467.0	466.7	466.1
-10.0	395.0	464.4	467.4	467.6	467.5
-8.0	395.3	464.7	467.5	468.8	468.3
-6.0	394.4	464.4	467.6	467.8	467.1
-4.0	394.8	464.8	468.7	467.6	469.1
-2.0	395.3	464.6	467.8	467.5	467.2
0	395.0	464.4	467.4	467.6	467.5
2.0	395.3	464.7	467.5	468.8	468.3
4.0	395.8	464.4	467.6	467.8	467.1
6.0	394.8	464.8	468.7	467.6	469.1
8.0	395.3	464.6	467.8	467.5	467.2
10.0	395.0	464.4	467.4	467.6	467.5
12.0	394.2	463.9	466.7	467.7	467.5
14.0	394.0	462.2	465.3	465.5	464.9
16.0	390.5	459.4	463.4	462.5	463.6
18.0	386.1	454.7	457.8	457.1	457.8
20.0	379.8	446.6	450.0	451.0	450.0
22.0	369.9	436.9	439.9	440.1	440.5
24.0	358.2	421.9	425.0	425.1	424.6
26.0	341.4	403.1	406.8	406.3	407.2
28.0	321.5	380.3	383.1	382.7	383.5
30.0	298.5	353.2	356.2	356.6	356.0

PROGRAM COMPLETE

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR

DATA INPUT FOR RUN WITH BRIGHT LAMPS AT EDGE

LAMP INTENSITY ARRAY

1	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0
2	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0
3	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0
4	17.0	17.0	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	17.0	17.0
5	17.0	17.0	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	17.0	17.0
6	17.0	17.0	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	17.0	17.0
7	17.0	17.0	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	17.0	17.0
8	17.0	17.0	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	17.0	17.0
9	17.0	17.0	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	17.0	17.0
10	17.0	17.0	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	17.0	17.0
11	17.0	17.0	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	17.0	17.0
12	17.0	17.0	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	17.0	17.0
13	17.0	17.0	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	17.0	17.0
14	17.0	17.0	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	17.0	17.0
15	17.0	17.0	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	17.0	17.0
16	17.0	17.0	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	17.0	17.0
17	17.0	17.0	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	17.0	17.0
18	17.0	17.0	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	17.0	17.0
19	17.0	17.0	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	17.0	17.0
20	17.0	17.0	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	17.0	17.0
21	17.0	17.0	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	17.0	17.0
22	17.0	17.0	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	17.0	17.0
23	17.0	17.0	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	17.0	17.0
24	17.0	17.0	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	12.7	17.0	17.0
25	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0
26	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0
27	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0

SAMPLE RUN WIH LAMP DATA AS ON PAGE A6

MSFC ARRAY AND 6 IN FL LFNS

INTENSITY AT 9.0 FEET UNITS ARE BTU/HR-FT2

X POS IN	Y SCAN POS IN INCHES				
INCHES	-48.0	-36.0	-24.0	-12.0	0
-30.0	522.5	506.1	501.8	504.8	501.5
-28.0	547.3	524.0	518.3	518.4	514.6
-26.0	557.6	523.1	518.1	517.9	516.3
-24.0	561.7	518.1	511.1	510.6	504.7
-22.0	560.2	505.1	497.3	497.6	496.7
-20.0	558.1	493.3	483.1	486.8	485.3
-18.0	553.5	485.9	475.5	477.5	473.9
-16.0	548.2	479.6	472.1	470.8	469.8
-14.0	549.0	478.9	469.9	469.3	465.3
-12.0	549.1	477.6	468.9	468.8	468.6
-10.0	551.6	476.3	466.1	469.6	467.7
-8.0	550.1	477.5	467.2	468.7	465.3
-6.0	546.9	475.9	468.3	467.3	466.2
-4.0	548.5	477.8	468.9	468.4	464.0
-2.0	549.1	477.2	468.6	468.5	468.2
0	551.6	476.3	466.1	469.6	467.7
2.0	550.1	477.5	467.2	468.7	465.3
4.0	546.9	475.9	468.3	467.3	466.2
6.0	548.5	477.8	468.9	468.4	464.0
8.0	549.1	477.2	468.6	468.5	468.2
10.0	551.6	476.3	466.1	469.6	467.7
12.0	550.1	477.8	467.5	469.0	465.3
14.0	546.9	476.9	469.3	468.4	467.1
16.0	549.7	481.3	472.7	472.1	467.2
18.0	551.2	485.6	477.5	477.0	477.3
20.0	556.5	492.7	483.0	487.4	484.9
22.0	557.4	504.8	496.0	497.1	495.3
24.0	556.6	515.3	510.6	509.2	508.3
26.0	554.8	524.8	518.9	518.3	515.2
28.0	542.4	521.8	517.9	518.6	517.0
30.0	516.6	505.3	501.9	503.6	502.4

PROGRAM COMPLETE

SAMPLE RUN WITH LAMP DATA AS ON PAGE A6

MSFC ARRAY AND 6 IN FL LENS

INTENSITY AT 15.0 FEET UNITS ARE BTU/HR.FT2

X POS IN INCHES	Y SCAN POS IN INCHES				
	-48.0	-36.0	-24.0	-12.0	0
-30.0	376.6	421.3	413.0	412.1	412.5
-28.0	402.5	447.0	437.0	437.7	436.7
-26.0	423.9	468.7	456.6	455.8	455.8
-24.0	439.4	484.5	471.8	469.8	470.8
-22.0	452.1	494.8	479.7	478.0	477.1
-20.0	459.4	501.3	483.3	481.5	483.1
-18.0	465.0	502.6	483.9	484.1	483.5
-16.0	467.9	503.0	483.4	481.5	481.1
-14.0	467.3	501.5	481.9	478.5	480.4
-12.0	467.6	499.4	477.9	475.9	475.3
-10.0	466.9	496.9	475.0	473.6	473.1
-8.0	466.0	495.3	472.7	472.1	471.7
-6.0	466.7	493.5	471.1	469.7	468.8
-4.0	464.6	493.0	471.3	468.5	469.9
-2.0	464.8	492.5	469.8	467.8	467.6
0	464.4	491.9	469.1	467.6	467.5
2.0	464.8	492.4	469.4	469.1	468.6
4.0	466.1	492.7	470.2	468.6	467.9
6.0	464.8	493.8	472.3	469.3	470.9
8.0	465.9	495.0	472.9	471.1	470.4
10.0	466.4	496.9	475.0	473.2	473.5
12.0	466.8	499.1	477.4	477.0	476.6
14.0	468.1	501.0	480.7	479.2	478.5
16.0	466.1	502.4	484.2	481.6	482.8
18.0	463.3	502.6	484.6	482.3	483.0
20.0	458.7	499.2	483.1	483.0	481.8
22.0	449.6	494.2	479.6	478.5	479.0
24.0	438.2	483.3	470.6	469.5	469.1
26.0	420.6	467.2	457.4	455.9	456.9
28.0	398.8	446.1	437.4	436.2	437.1
30.0	372.9	419.3	412.8	412.6	412.1

PROGRAM COMPLETE

APPENDIX B

LISTING OF LUMP WITH EXAMPLE OF INPUT FILE DASTT

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PROGRAM LUMP \\\\\\\\\\\\\\\\\\\\\\\TY 1-50
  1.000 C   LAMPS UNIFORMITY MAPPING PROGRAM
  2.000 C   PROGRAM SET FOR MSFC ARRAY
  3.000     DIMENSION TLX(35,35), TLY(35,35), TLI(35,35), TPI(10,100)
  4.000     DIMENSION TTPX(100), TTPY(30)
  5.000     REWIND 201
  6.000     READ(201,10) SPACE
  7.000 10   FORMAT(F10.1)
  8.000 C   SPREF IS SPACE REF FOR INTENSITY
  9.000 C   SPREF = DISTANCE AT WHICH POWER READING IS TAKEN
10.000     SPREF = 180.0
11.000     NLX = 15; NLY = 27
12.000     DO 50 I = 1, NLY
13.000     READ(201,100) NLX, (TLI(I,J), J = 1, NLX)
14.000 50   CONTINUE
15.000 100  FORMAT(NF4.1)
16.000     NCO = 0
17.000     IF(NCO.EQ.1) GO TO 115
18.000     WRITE(108,105)
19.000 105  FORMAT(1H1, 'LAMP INTENSITY ARRAY',/)
20.000     DO 110 I = 1, NLY
21.000     WRITE(108,120) I, NLX, (TLI(I,J), J = 1, NLX)
22.000 110  CONTINUE
23.000 115  CONTINUE
24.000 120  FORMAT(1H ,I3,2X,N(F4.1,2X))
25.000 C   BUILD UP X,Y SPACING
26.000     TSPX = 5.0
27.000     TSPY = 4.33
28.000     X1 = -36.25
29.000     DO 160 J = 1, NLX
30.000     Y1 = +56.29
31.000     DO 150 I = 1, NLY,2
32.000     TLX(I,J) = X1
33.000     TLY(I,J) = Y1
34.000     Y1 = Y1 - (TSPY*2.0)
35.000 150  CONTINUE
36.000     X1 = X1 + TSPX
37.000 160  CONTINUE
38.000     X1 = -33.75
39.000     DO 210 J = 1, NLX
40.000     Y1 = +51.96
41.000     DO 200 I = 2, (NLY-1),2
42.000     TLX(I,J) = X1; TLY(I,J) = Y1
43.000     Y1 = Y1 - (TSPY*2.0)
44.000 200  CONTINUE
45.000     X1 = X1 + TSPX
46.000 210  CONTINUE
47.000 C   OPTION TO PRINT OUT X,Y LOCATIONS
48.000     NCODE = 0
49.000     IF (NCODE.EQ.1) GO TO 340
50.000     WRITE(108,305)

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PROGRAM LUMP \\\\\\\\\\\\\\\\\\\\\\\TY 51-100
51.000 305  FORMAT(1H1,'X,Y POSITION OF LAMP ARRAY-IN INCHES')
52.000      DO 310 I = 1,NLY
53.000      WRITE(108,320) I,NLX,(TLX(I,J),J = 1,NLX)
54.000      WRITE(108,322) NLX,(TLY(I,J),J = 1,NLX)
55.000 310  CONTINUE
56.000 320  FORMAT(1H ,13,2X,N(F5.1,2X))
57.000 322  FORMAT(1H ,5X,N(F5.1,2X))
58.000 C    START INTENSITY SCAN CALCULATIONS
59.000 340  CONTINUE
60.000      NLINES = 5
61.000      DELX = 2.0
62.000      TPY = -48.0
63.000      DELY = 12.0
64.000      SX = -30.0; ALX = 30.0
65.000      LIM = 1 + IFIX((ALX-SX)/DELX)
66.000      TSX = SX-DELX
67.000      DO 350 I = 1,LIM
68.000      TTPX(I) = TSX+DELX
69.000 350  TSX = TTPX(I)
70.000      DUMY = TPY-DELY
71.000      DO 360 I = 1,NLINES
72.000      TTPY(I) = DUMY+DELY
73.000 360  DUMY = TTPY(I)
74.000      DO 600 L = 1,NLINES
75.000      LP = 1
76.000      TSX = SX
77.000 400  TPI(L,LP) = 0.0
78.000      DO 500 J = 1,NLX
79.000      DO 500 I = 1,NLY
80.000      DX = TLX(I,J)-TSX; DY = TLY(I,J)-TPY
81.000      DIST = SQRT(DX*DX+DY*DY)
82.000      ANGLE = ATAN(DIST/SPACE)
83.000      ANGLE = ANGLE*180.0/3.14159
84.000      IF(ANGLE.GT.10.0) TI = 0.0; GO TO 450
85.000      CALL IVSA(ANGLE,TI)
86.000      TLENGT = SQRT(DIST*DIST + SPACE *SPACE)
87.000      TMFAC = (SPREF*SPREF)/(TLENGT*TLENGT)
88.000 450  CONTINUE
89.000      TI = TI*TMFAC*TLI(I,J)
90.000      TPI(L,LP) = TPI(L,LP)+TI
91.000 500  CONTINUE
92.000      LP = LP+1
93.000      TSX = TSX+DELX
94.000      IF(TSX.LE.ALX) GO TO 400
95.000      TPY = TPY +DELY
96.000 600  CONTINUE
97.000 C    PRINT OUT DATA ON SCAN
98.000      WRITE(108,650)
99.000 650  FORMAT(1H1,'MSFC ARRAY AND 6 IN FL LENS')
100.000     WRITE(108,700) SPACE/12.0

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PROGRAM LUMP \\\\\\\\\\\\\\\\\\\\\\\TY101-130
101.000 700  FORMAT(1H0,'INTENSITY AT',F8.1,2X,'FEET',10X,'UNITS ARE',
102.000      X' BTU/HR-FT2',///'X POS IN',15X,'Y SCAN POS IN INCHES')
103.000      WRITE(108,POO) N LINES,(TTPY(I),I = 1,N LINES)
104.000 800  FORMAT('INCHES',1X,N(F8.1,5X))
105.000      DO 1000 I = 1,LIM
106.000      WRITE(108,1100) TTPX(I),N LINES,(TPI(J,I),J = 1,N LINES)
107.000 1000 CONTINUE
108.000 1100 FORMAT(F6.1,2X,N(F8.1,5X))
109.000      OUTPUT 'PROGRAM COMPLETE'
110.000      END
111.000 C    SUBROUTINE TO OBTAIN INTENSITY VS ANGLE
112.000      SUBROUTINE IVSA(ANGLE,TI)
113.000      DIMENSION ANG(11),AI(11)
114.000      DATA (AI(I),I = 1,11)/100.0,98.0,93.5,80.0,63.5,42.0,
115.000      X24.3,12.5,4.2,2.5,1.8/
116.000      DO 100 I = 1,11
117.000      ANG(I) = FLOAT(I-1)
118.000 100  CONTINUE
119.000      IF(ANGLE.GT.10.0) TI = 0.0; GO TO 1000
120.000 C    INTERPOLATE INTENSITY
121.000      I = 0
122.000 200  I = I+1
123.000      IF(I.GE.11) TI = 0.0; GO TO 1000
124.000      IF(ANGLE.GT.ANG(I)) GO TO 200
125.000      IF(ANGLE.EQ.ANG(I)) TI = AI(I); GO TO 1000
126.000      SLOPE = (AI(I)-AI(I-1))/(ANG(I)-ANG(I-1))
127.000      TI = SLOPE*(ANGLE-ANG(I-1))+AI(I-1)
128.000 1000 TI = TI*0.01
129.000      RETURN
130.000      END

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EXAMPLE OF INPUT FILE DASTT

TY 1-2R

1.000 10R.0
2.000 12.712.712.712.712.712.712.712.712.712.712.712.712.7
3.000 12.712.712.712.712.712.712.712.712.712.712.712.7
4.000 12.712.712.712.712.712.712.712.712.712.712.712.7
5.000 12.712.712.712.712.712.712.712.712.712.712.712.7
6.000 12.712.712.712.712.712.712.712.712.712.712.712.7
7.000 12.712.712.712.712.712.712.712.712.712.712.712.7
8.000 12.712.712.712.712.712.712.712.712.712.712.712.7
9.000 12.712.712.712.712.712.712.712.712.712.712.712.7
10.000 12.712.712.712.712.712.712.712.712.712.712.712.7
11.000 12.712.712.712.712.712.712.712.712.712.712.712.7
12.000 12.712.712.712.712.712.712.712.712.712.712.712.7
13.000 12.712.712.712.712.712.712.712.712.712.712.712.7
14.000 12.712.712.712.712.712.712.712.712.712.712.712.7
15.000 12.712.712.712.712.712.712.712.712.712.712.712.7
16.000 12.712.712.712.712.712.712.712.712.712.712.712.7
17.000 12.712.712.712.712.712.712.712.712.712.712.712.7
18.000 12.712.712.712.712.712.712.712.712.712.712.712.7
19.000 12.712.712.712.712.712.712.712.712.712.712.712.7
20.000 12.712.712.712.712.712.712.712.712.712.712.712.7
21.000 12.712.712.712.712.712.712.712.712.712.712.712.7
22.000 12.712.712.712.712.712.712.712.712.712.712.712.7
23.000 12.712.712.712.712.712.712.712.712.712.712.712.7
24.000 12.712.712.712.712.712.712.712.712.712.712.712.7
25.000 12.712.712.712.712.712.712.712.712.712.712.712.7
26.000 12.712.712.712.712.712.712.712.712.712.712.712.7
27.000 12.712.712.712.712.712.712.712.712.712.712.712.7
28.000 12.712.712.712.712.712.712.712.712.712.712.712.7

REPRODUCIBILITY OF THE
ORIGINAL PAGE IS POOR

LIST OF VARIABLES USED IN LUMP
(in the order they appear in the program)

TLX	Array for storage of x location of lamps
TLY	Array for storage of y location of lamps
TLI	Array for storage of lamp intensities
TPI	Array for storage of test plane point intensities
TTPX	Array to store x location of points in test plane
TTPY	Array to store y location of points in test plane
201	Input unit number
SPACE	Distance from lamp array to test plane
SPREF	Distance at which lamp intensity measured
NLX	Number of lamps in x direction
NLY	Number of lamps in y direction
NCO	Code to obtain printout of lamp intensity array. If valve is set to 1 there will be no printout of lamp intensity array.
TSPX	Spacing of lamps in x direction
TSPY	Spacing of lamps in y direction
X1	First lamp position in x direction
Y1	First lamp position in y direction
NCODE	Code to obtain printout array of lamp positions if set equal to 1 printout will not be obtained
NUNES	Number of scan lines to be calculated
DELX	Distance between points to be calculated in the x direction

TTY	y position of first scan line to be calculated
DELY	Distance between scan lines
SX	First point in test plane scan line to be calculated
ALX	Last point in scan line to be calculated
LIM	Number of points to be calculated in each scan line
TSX	Dummy variable to hold x scan position during calculation of intensity
DUMY	Dummy variable to hold y scan position during calculation of intensity
DY	Calculated x separation between lamp and test plane point
DY	Calculated y separation between lamp and test plane point
DIST	Diagonal distance from lamp to test plane point
ANGLE	Calculated angle from lamp center line to test plane point
IVSA	Subroutine to calculate lamp intensity at the calculated angle
TLENET	Distance from lamp to test plane point
TMFAC	The multiplication factor to adjust lamp intensity for different spacings to test plane
TI	Dummy variable to hold intensity calculated at test plane point


APPROVAL

TEST PLANE UNIFORMITY ANALYSIS FOR THE MSFC SOLAR SIMULATOR LAMP ARRAY

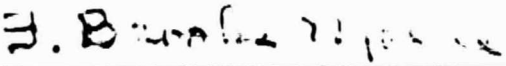
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The information in this report has been reviewed for security classification. The report, in its entirety, has been determined to be unclassified and contains no information concerning Department of Defense - Atomic Energy Commission programs.

This document has also been reviewed and approved for technical accuracy.



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