FINAL TASK REPORT

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LANL COMPACT LASER PUMPING SIMULATION

By
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INTRODUCTION

Rockwell has been tasked with the objective of both qualitatively and quantitatively defining the performance of LANL Compact Laser coupling systems. The performance criteria of the system will be based upon the magnitude and uniformity of the energy distribution in the laser pumping rod. Once this is understood, it will then be possible to improve the device performance via changes in the system's component parameters.

For this study, we have chosen to use the Los Alamos Radiometry Code (LARC), which was previously developed by Rockwell. LARC, as an analysis tool, is well suited for this problem because the code contains the needed photometric calculation capability and easily handles the three-dimensionality of the problem. Also, LARC's internal graphics can provide very informative visual displays of the optical system.

DEVELOPMENT

Three new program modules have been added to LARC for this project. The first, LASEROD, allows the user to specify the number of shells in the pumping rod and its diameter. The routine calculates the radius of each shell such that all shells contain the same volume of absorbent material. The center of each shell is found and stored in a register for later use in the placement of photometric detectors through the rod. The second module, CLOSEROD, analyzes the results of the photometric calculations to determine the performance of the system. This analysis will produce a merit value for the device, along with diagnostics to further help to interpret the device's performance. The analysis done to produce a merit value is explained in the following section. A third modification to

LARC is a plotting utility. This utility allows the user to plot accumulated luminance as a function of position along or through the pumping rod. Instead of making a new command, this utility is a new modifier of the VIEW command.

Merit Value and Statistical Analysis

To describe the performance of a given optical system, Rockwell uses a two-way analysis of variance (ANOVA) statistical test. The results of this test are a merit value for the system and diagnostics to pinpoint anomalous effects through the pumping rod. The ANOVA test models luminance at a point in the rod in terms of deviations from the average luminance in the rod. If the deviations are systematic along rows or columns or both rows and columns in the grid, the two-way model fits the data better than the model of uniform or constant luminance.

At the first stage of the procedure, a summary statistic is computed to determine which fits better: the model of constant luminance or the two-way model. This summary statistic is the overall model, F statistic. In general, the larger the F statistic, the less uniform the luminance in the grid. Typically an F value greater than three implies significant nonuniformity.

If there is some evidence of nonuniformity in the first stage of the procedure, the second stage attempts to isolate that nonuniformity in terms of systematic deviations due to row location or due to column location in the grid. Two more summary statistics are computed, one for the column effect on luminance and one for the row effect on luminance. The row and column effects are computed as the difference between the row/column average minus the grid average. Each of these summary statistics is also an F statistic, and the flavor of the interpretation is similar to that for the overall model F statistic. The larger the value of the F statistic, the more significant or statistically important the effect. In this situation, we would say that luminance is not uniform throughout the grid, but changes systematically with changes in column location.

The last stage of the procedure quantifies the systematic changes found in the second stage. That is, if row or column effects, or possibly both row and column effects, are found in the second stage, the last stage computes estimates of these effects. These estimates are expressed as deviations from the average luminance in the grid. Again, as an example, suppose that only the column effect is significant in the second stage. The final stage estimates the effect of column location on luminance. Suppose that the i^{th} column effect is +x units. We interpret this estimate as saying that the i^{th} column is +x units above the overall average luminance on the average. Similarly, if the estimate for the j^{th} column effect is -y units, then we say that on the average, the j^{th} column is y units below the overall average luminance in the grid.

Because no statistical model is a panacea, some caution is in order about interpreting results. We should keep in mind that the two-way model may not adequately describe the structure in the data. Because of real limitations on the acquisition of data, each site in the grid can only be measured once. We, therefore, cannot statistically model sites individually using a combined row and column effect. This means that the procedure will not, in general, detect an isolated flaw in the rod.

Nevertheless, the two-way model procedure should perform well as far as detecting systematic departures from constant luminance. The F value computed in the first stage of the procedure gives a fair and sensible way to compare and order different rods, providing the size of the grid is the same for all systems. The second and third stages of the procedure provide a detailed look at where the deviations occur and how large these deviations are.

<u>Optical Systems</u>

Specific macro command files have been created to analyze five candidate optical systems. Each macro builds an individual system and performs the photometric ray-trace calculations automatically.

The candidate systems are parabolic reflector, elliptical reflector, conical reflector, spherical reflector, and a combination of two conical reflectors.

The specific component parameters, i.e., sizes, focal lengths, etc., will be omitted in this report.

ANALYSIS

Analysis of the individual systems is currently being done on MicroVAX and CRAY computers. Photometric calculations were done using a 25 x 25 ray bundle for each detector. The greater the size of the bundle, the better, because the larger ray sample more accurately models the physical reality. Due to symmetry considerations, detectors were placed along a slice on the diameter of the rod and only along the top half of the rod.

The results of the LARC test runs are shown in Appendix A. Each array shows the accumulated luminance for a rectangular grid in a rod five shells deep. The top left corner is the center of the outermost shell. Its location is five units from the beginning of the rod. Each detector is then placed 15 units from the previous one along the rod. The average luminance for each column is shown below the array. The average luminance for each row is shown to the right of the array.

Next, the F statistic or value is shown for the column and row results. The overall system F model value is shown. Finally, the total accumulated luminance of the grid is given along with the grid average. The luminance of the source for all systems is 1,000.

CONCLUSIONS

Due to the very large F model values that resulted from the photometric calculations, we can say that, statistically speaking, all the optical systems are significantly nonuniform, the main problem being the inability of the reflectors to evenly focus the rays along the rod. Continued design evolution will probably make significant improvements to distribution uniformity.

Of the five systems, two clearly stand out as the optimal designs. They are parabolic and elliptical reflectors with F model values of 16.81 and 18.33, respectively. Between the two, the parabolic reflector appears to win over the elliptical, not only for its lower F model value, but it shows a larger average luminance and total luminance.

Because good radial uniformity has been observed in all configurations modelled, it will be desirable to increase axial sampling density and reduce radial sampling density. That is, we may constrain analysis to points along the rod's axis performing photometric calculations with fans of rays. The reduction from a two to a one dimensional problem allows us to examine effects along the rod in greater detail without much more computational time.

Rockwell has performed preliminary tests upon five candidate optical systems. The results of these tests indicate the parabolic reflector is the optimal configuration (given the present physical constraints) compared to the conical reflector configuration now in use. Further testing with larger ray bundles and more point detectors may now be done on the LANL CRAY system. Greater sampling sizes will probably reveal more subtle features in the optical systems. Continued testing for design optimization will most likely necessitate changing design physical parameters.

APPENDIX A

RESULTS OF LARC TEST RUNS

Parabolic Reflector 25x25 Ray Bundle

					Avg Row	Row Effects
3431.14	3210.30	2972.00	3173.07	3536.38	3264.58	106.47
3209.84	2979.19	2966.03	3109.54	3552.73	3163.47	5.36
3100.92	2954.96	3074.53	3017.44	3540.74	3137.72	-20.39
3032.67	2926.67	3077.20	2992.15	3498.24	3105.38	-52.72
3074.71	2938.32	3080.40	2972.12	3531.39	3119.39	-38.72

Avg Column

3169.85	3001.89	3034.03	3052.86	3531.90

Column Effects

11.75	-156.22	-124.08	-105.24	373.79

F STATISTIC ROW = 2.612132
F STATISTIC COLUMN = 31.02289
F MODEL STATISTIC = 16.81751

The total luminance is 78952.66

The average luminance of the rod is 3158.106

Two Conical Reflectors 25x25 Ray Bundle

					Avg Row	Row Effects
2794.10	2977.25	3037.93	3472.36	4215.84	3299.50	135.49
2578.61	2801.15	2865.51	3428.74	4249.33	3184.67	20.66
2480.39	2700.01	2797.39	3410.46	4281.70	3133.99	-30.02
2480.30	2736.08	2793.73	3363.88	4224.17	3119.63	-44.38
2459.09	2774.75	2758.04	3293.08	4126.28	3082.25	-81.76

Avg Column

2558.50	2797.85	2850.52	3393.70	4219.46

Column Effects

-605.51	-366.16	-313.49	229.70	1055.46

F STATISTIC ROW = 8.776968
F STATISTIC COLUMN = 546.8663
F MODEL STATISTIC = 277.8216

The total luminance is 79100.16

The average luminance of the rod is 3164.007

Conical Reflector 25x25 Ray Bundle

					Avg Row	Row Effects
2797.84	3019.13	3039.84	3468.79	4232.31	3311.58	129.41
2586.60	2848.87	2864.64	3429.90	4258.03	3197.61	15.44
2495.58	2720.11	2816.94	3420.17	4283.17	3147.19	-34.97
2460.64	2733.09	2819.63	3360.99	4271.98	3129.27	-52.90
2416.14	2760.28	2856.35	3288.82	4304.37	3125.19	-56.98

Avg Column

2551.36	2816.30	2879.48	3393.73	4269.97

Column Effects

-630.81	-365.87	-302.69	211.57	1087.80

F STATISTIC ROW = 5.483202
F STATISTIC COLUMN = 418.5614
F MODEL STATISTIC = 212.0223

The total luminance is 79554.23

The average luminance of the rod is 3182.169

Elliptical Reflector 25x25 Ray Bundle

					Avg Row	Row Effects
3973.12	3077.36	2766.42	2941.77	3026.38	3157.01	135.61
3750.55	2758.27	2801.41	2963.22	2947.04	3044.10	22.70
3563.55	2718.25	2842.01	2939.23	2798.31	2972.27	-49.13
3472.30	2735.13	2894.35	2944.24	2795.41	2968.28	-53.12
3370.35	2658.74	2949.33	3032.48	2815.80	2965.34	-56.06

Avg Column

3625.97	2789.55	2850.70	2964.19	2876.59

Column Effects

604.57	-231.85	-170.70	-57.21	-144.81

F STATISTIC ROW = 2.001064
F STATISTIC COLUMN = 34.66590
F MODEL STATISTIC = 18.33348

The total luminance is 75535.02

The average luminance of the rod is 3021.401

Spherical Reflector 25x25 Ray Bundle

					Avg Row	Row Effects
4312.65	1551.15	2395.53	2306.58	2689.08	2651.00	49.52
4296.65	1597.32	2321.22	2269.72	2683.74	2633.73	32.25
4164.93	1629.27	2226.96	2232.80	2609.78	2572.75	-28.72
4240.33	1717.85	2183.15	2172.30	2575.87	2577.90	-23.57
4307.21	1741.61	2153.51	2117.81	2539.84	2572.00	-29.48

Avg Column

4264.35	1647.44	2256.07	2219.84	2619.66

Column Effects

1662.88	-954.03	-345.40	-381.63	18.19

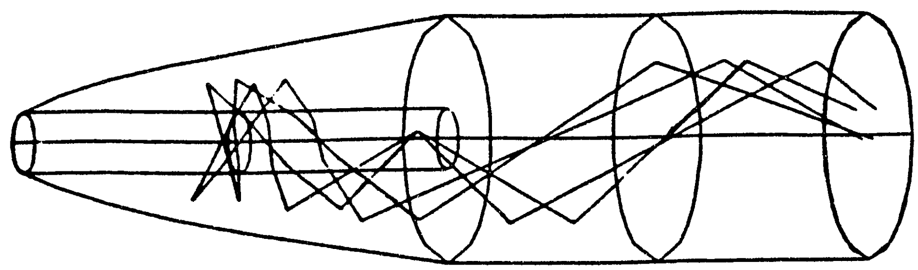
F STATISTIC ROW = 1.229204
F STATISTIC COLUMN = 843.4809
F MODEL STATISTIC = 422.3551

The total luminance is 65036.86

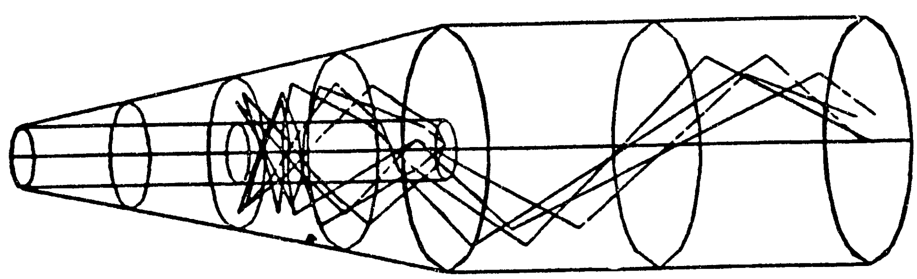
The average luminance of the rod is 2601.474

APPENDIX B

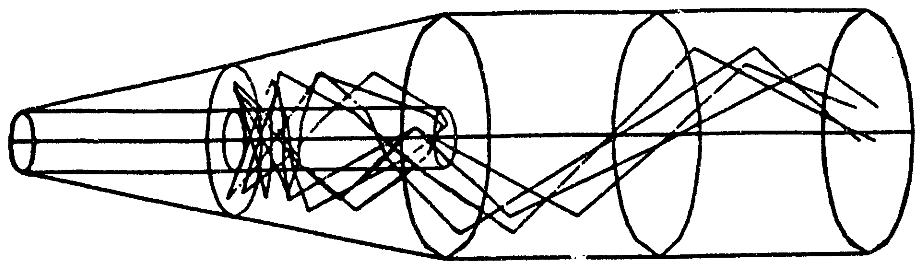
MERIT FUNCTIONS OF CANDIDATE OPTICAL SYSTEMS



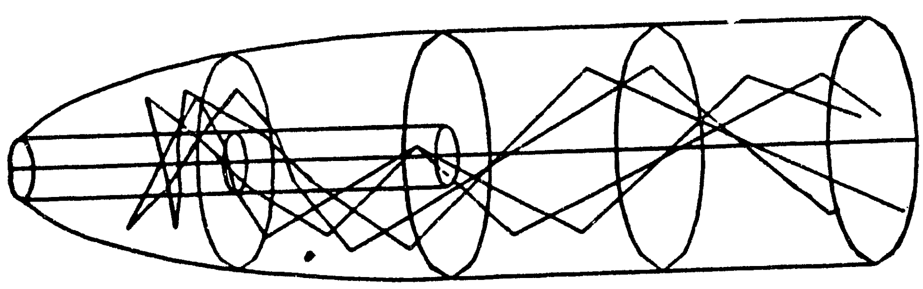
Parabolic Reflector
F Model Statistic = 16.81



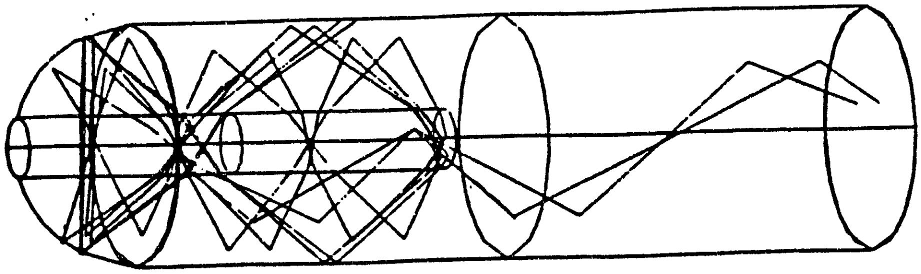
Two Conical Reflectors
F Model Statistic = 277.82



Conical Reflector
F Model Statistic = 212.02



Elliptical Reflector
F Model Statistic = 18.33



Spherical Reflector
F Model Statistic = 422.35

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