INSTRUMENT SCIENCE REPORT
CAL/FOS-019

FOS ENTRANCE APERTURE SIZES (CALIBRATION PLAN 10B)

D. J. Linder, R.C. Bohlin & G. F. Hartig

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ABSTRACT

The sizes of 22 FOS entrance apertures are measured directly with a microscope, and the light transmittance is measured with the aperture map technique. The light transmittance is determined by the area of an aperture, so the aperture map results can be compared with areas measured with the microscope. Results show that the areas measured from the aperture maps are consistent with the areas measured by microscope for the larger apertures. As the aperture size decreases the area measured by the aperture map deviates further from the microscope area, reaching 31% for the 0.1 arcsec aperture. This indicates the deviations may be due to diffraction of light through the smaller apertures. Future analysis of aperture sizes versus wavelengths will verify the diffraction effects.

I. Introduction

In order to measure the light transmittance of the FOS entrance apertures, two-dimensional aperture maps were made using a tungsten calibration lamp viewed through the ambient ST optical simulator, which utilized a white diffusing screen to provide a flat field illumination. Two sets of aperture maps were analyzed for each detector. Red tube data were taken in June 84 with lamp #181 at 2.5 amps and in August 84 with lamp #180 at 2.5 amps. Blue tube data were taken in October 83 with lamp #180 at 4.0 amps and in June 84 with lamp #181 at 4.0 amps. An effective area was computed for each aperture using the ratio of its light throughput to that of the square 4.3 arcsec aperture. The effective area of the 4.3 arcsec aperture was set to specifications (18.49 square arcsec), since it would have negligible diffraction
effects and the smallest percentage error in the microscope measurements. Measurements of the dimensions of the 4.3 aperture map data gives an x-width of 4.3 for the red side and 4.2 for the blue side. These values assume a plate scale of 139.7 microns/arcsec at the detectors. Due to the non-uniform signal level over the 4.3 aperture the errors for the widths measured from the aperture maps could not be determined.

II. Aperture Mapping Technique

All apertures were scanned using 26 consecutive channels (NCHAN), while 85 Y-steps were used with a Y-range of 30 giving approximately 11.3 microns ([32 \cdot Y-range]/Y-steps) between Y-steps. This results in a 94% overlap of the 200 micron high diodes in the Y-direction, but does not affect the relative light transmittance of the apertures as measured by the maps. Quarter stepping (X Steps = 4) and overscanning (OVRSCN = 5) were used to give 120 points ([NCHAN + OVRSCN -1] \cdot X STEPS) centered 12.5 microns apart in the X-direction. Because quarter stepping was used, the 10 micron gap between diodes does not affect the relative aperture size determinations, since the gap is covered in the same way for each aperture.

Contour plots of the 4.3 arcsec apertures (Figure 1) show that the signal level is not uniform over the apertures. This is not due to spatial variations in the illumination at the entrance aperture plane, since the ASTOS geometry assures uniformity. Spatial non-uniformity in the photocathode response is a possible contributor. Flat field images made with the internal LED sources show significant variations over large areas of the photocathodes (see Figures 9 and 10). However, the character of the flat field non-uniformity over the area of the photocathode on which the aperture images lie (as indicated in the Figure 9 and 10) does not generally coincide with that of the aperture map variations. This is particularly obvious on the red side, where the "ion bump", which is emphasized with the high level of overall illumination used for the flat field images, occurs in the region on which the aperture image falls. The ion bump contribution to the aperture maps should be small, since the integrated flux is much smaller for those exposures. Determination of the extent to which photocathode non-uniformities are responsible for the variations seen in the aperture maps is precluded by uncertainties in the degree of uniformity of the flat field LED illumination, expected wavelength-dependent differences in the spatial uniformity of the photocathode (especially for the blue tube since the LED flux occurs at the long wavelength tail of its response curve), and the ion bump contribution (red side).

Alternatively, the image non-uniformity may be ascribed to
misalignment of the ASTOS or, less likely, to internal misalignment or vignetting of the beam edge by a misplaced baffle. Each of these possibilities can remove more light from the beam from one side of the aperture than from the other side, resulting in the non-uniform images. Since analysis of the absolute photometric calibration data obtained with the same ASTOS configuration has shown that some ASTOS misalignment was present (Hartig and Bohlin, 1985), this is the most likely explanation.

III. Data Reduction

A paired pulse correction was applied to all data using the equation:

\[ N_0 = \frac{N e^{-t_1 N}}{1 + N t_2 e^{-t_1 N}} \]

where \( N_0 \) is the observed count rate and \( N \) is the true count rate. The time constants \( t_1 = -0.17 \times 10^{-6} \) and \( t_2 = 10.5 \times 10^{-6} \) (E. Beaver, private communication, April 1985) were used.

The light transmittance was computed for each aperture by summing the corrected counts in the aperture maps. Because of the non-uniform signal level over the entrance apertures, the lower aperture counts were corrected by dividing by the following factors:

<table>
<thead>
<tr>
<th>Data</th>
<th>Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blue Tube Oct. 83</td>
<td>0.956</td>
</tr>
<tr>
<td>Blue Tube June 84</td>
<td>0.969</td>
</tr>
<tr>
<td>Red Tube June 84</td>
<td>0.956</td>
</tr>
<tr>
<td>Red Tube Aug 84</td>
<td>0.964</td>
</tr>
</tbody>
</table>

These factors were computed by taking a vertical cross section through the center of the 4.3 aperture. A linear fit was done to the lower portion of the aperture profile normalized to 1.0 at the aperture center (Figure 2). The fit was extrapolated to the center of the lower aperture of the pair to give the illumination correction factor.

The aperture area that is more relevant to observations of extended sources is defined by the limiting height of the diode array. Computation of the relative effective aperture sizes as viewed by the 200 micron high diode array were computed by summing the counts in the diode array when centered on the aperture. These values were corrected for non-uniform signal level in the same manner as the total aperture areas. The absolute effective aperture sizes were computed by normalizing to the 4.3 arcsec aperture. The
effective size of the 4.3 arcsec aperture was computed to be 1.432 arcsec x 4.3 arcsec = 6.158 square arcsec where 1.432 arcsec is the height of the diode array assuming a scale of 3.58020 arcsec/mm at the aperture and a demagnification of 2.0 at the detector.

IV. Results

Tables 1 and 2 give the aperture sizes measured with the microscope and the sizes computed from the light transmittance using the aperture maps. Tables 3 and 4 give the relative effective aperture sizes as viewed by the 200 micron high diode array. The results for the two sets of aperture maps were averaged and an error computed. The error represents the uncertainties in the paired pulse correction. All other measurable errors were negligible. In cases where the difference in the aperture sizes between the two sets of aperture maps was greater than the paired pulse error, the error for the aperture was set to the difference.

The total accumulated counts in each aperture ranged from 8000 counts for the 0.1 arcsec square aperture to 25 million counts for the 4.3 arcsec square aperture. These counts gave approximately 1% (one sigma) counting statistic error for the 0.1 arcsec aperture and less than 0.5% for all other apertures. The results are repeatable to within the expected errors on the blue side. Discrepancies on the red side greater than the counting error between the two sets of aperture maps can not be explained by the paired pulse correction error. Both sets of data had approximately the same counting rates. The paired pulse error was, therefore, the same for both sets of data. One possible cause for the variations is changes in the lamp intensity. A radiometer, used during the August 84 calibration, showed that the lamp was stable to better than 1%. No data on lamp stability was available for the other data. A more likely cause of the discrepancies is the photocathode granularity or dust particles. The two sets of aperture data illuminated slightly different positions on the photocathode due to filter grating wheel non-repeatability, etc. LED flat field maps show small blemishes with 1 to 4% variation in photocathode sensitivity (Figure 9). For the LED flat fields the granularity and blemishes are averages over the area of a diode. Depending on the size of the granules, an aperture illuminating a smaller area of the photocathode could show even larger variations.

The aperture sizes computed from the aperture maps are in close agreement with the microscope sizes for the larger apertures. As the dimensions of the apertures decrease, the deviations from the (larger) microscope sizes increases. This indicates that the deviations are due to diffraction
of the light through the smaller apertures, such that an increasing fraction of the flux through the aperture is diffracted to points off the collimator mirror (and thereby lost) as the aperture size decreases. The light lost in this manner will increase with wavelength, rendering the effective aperture size wavelength-dependent. This behavior will be investigated as the subject of a separate report.

An abnormality seen in the red side aperture maps is the discrepancy between the sizes of the upper and lower 0.1 arcsec apertures. For both sets of data the upper aperture is approximately 60% larger than the smaller aperture. The smaller size of the 0.1 arcsec lower aperture is in agreement with the blue side sizes and with preliminary calculations of diffraction loss in a 0.1 arcsec hole.
# TABLE 1

Red Tube Aperture Sizes

<table>
<thead>
<tr>
<th>Aperture</th>
<th>Dimensions (arcsec)</th>
<th>Specifications (1)</th>
<th>Microscope (1)</th>
<th>June 84 (1)</th>
<th>Aug 84 (1)</th>
<th>Average (2)</th>
<th>Error (3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>B1</td>
<td>0.5 circle</td>
<td>.196</td>
<td>.182</td>
<td>.168</td>
<td>.172</td>
<td>.170</td>
<td>.005</td>
</tr>
<tr>
<td>B2</td>
<td>0.3 circle</td>
<td>.071</td>
<td>.067</td>
<td>.055</td>
<td>.057</td>
<td>.056</td>
<td>.002</td>
</tr>
<tr>
<td>B3</td>
<td>1.0 circle</td>
<td>.785</td>
<td>.746</td>
<td>.75</td>
<td>.75</td>
<td>.75</td>
<td>.02</td>
</tr>
<tr>
<td>A1</td>
<td>4.3 x 4.3</td>
<td>18.49</td>
<td>18.5</td>
<td>18.49(4)</td>
<td>18.49(4)</td>
<td>18.49(4)</td>
<td>--</td>
</tr>
<tr>
<td>A2L</td>
<td>0.5 x 0.5</td>
<td>.25</td>
<td>.238</td>
<td>.228</td>
<td>.226</td>
<td>.227</td>
<td>.006</td>
</tr>
<tr>
<td>A2U</td>
<td>0.5 x 0.5</td>
<td>.25</td>
<td>.239</td>
<td>.224</td>
<td>.227</td>
<td>.226</td>
<td>.006</td>
</tr>
<tr>
<td>A3U</td>
<td>0.25 x 0.25</td>
<td>.063</td>
<td>.058</td>
<td>.049</td>
<td>.050</td>
<td>.050</td>
<td>.002</td>
</tr>
<tr>
<td>A3L</td>
<td>0.25 x 0.25</td>
<td>.063</td>
<td>.057</td>
<td>.048</td>
<td>.048</td>
<td>.048</td>
<td>.002</td>
</tr>
<tr>
<td>A4L</td>
<td>0.1 x 0.1</td>
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<td>.0103</td>
<td>.0098</td>
<td>.0107</td>
<td>.0103</td>
<td>.0009</td>
</tr>
<tr>
<td>A4U</td>
<td>0.1 x 0.1</td>
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<td>.0092</td>
<td>.0059</td>
<td>.0069</td>
<td>.0064</td>
<td>.0010</td>
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<td>C1L</td>
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<td>.99</td>
<td>.98</td>
<td>.99</td>
<td>.02</td>
</tr>
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<td>1.0 x 1.0</td>
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<td>.985</td>
<td>.97</td>
<td>.98</td>
<td>.98</td>
<td>.02</td>
</tr>
<tr>
<td>C2</td>
<td>0.25 x 2.0</td>
<td>.50</td>
<td>.482</td>
<td>.44</td>
<td>.44</td>
<td>.44</td>
<td>.01</td>
</tr>
<tr>
<td>C3</td>
<td>2.0 x 2.0 (5)</td>
<td>3.46</td>
<td>3.34</td>
<td>3.31</td>
<td>3.57</td>
<td>3.44</td>
<td>.26</td>
</tr>
<tr>
<td>C4</td>
<td>0.7 x 2.0 (5)</td>
<td>1.19</td>
<td>1.18</td>
<td>1.13</td>
<td>1.22</td>
<td>1.18</td>
<td>.09</td>
</tr>
</tbody>
</table>

(1) All areas in square arcsec.

(2) Average of June 84 and August 84 Maps.

(3) Error in arcsec for average (see text for description of computation).

(4) Aperture maps normalized to the specification for this aperture.

(5) With occulting bar.
<table>
<thead>
<tr>
<th>Aperture</th>
<th>Dimensions (arc sec)</th>
<th>Specifications</th>
<th>Microscope(1)</th>
<th>Oct 83(1)</th>
<th>June 84(1)</th>
<th>Average(2)</th>
<th>Error(3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>B1</td>
<td>0.5 circle</td>
<td>.196</td>
<td>.184</td>
<td>.174</td>
<td>.174</td>
<td>.174</td>
<td>.005</td>
</tr>
<tr>
<td>B2</td>
<td>0.3 circle</td>
<td>.071</td>
<td>.063</td>
<td>.054</td>
<td>.055</td>
<td>.055</td>
<td>.002</td>
</tr>
<tr>
<td>B3</td>
<td>1.0 circle</td>
<td>.785</td>
<td>.738</td>
<td>.74</td>
<td>.74</td>
<td>.74</td>
<td>-.02</td>
</tr>
<tr>
<td>A1</td>
<td>4.3 x 4.3</td>
<td>18.49</td>
<td>18.6</td>
<td>18.49(4)</td>
<td>18.49(4)</td>
<td>18.49(4)</td>
<td>--</td>
</tr>
<tr>
<td>A2L</td>
<td>0.5 x 0.5</td>
<td>.25</td>
<td>.243</td>
<td>.231</td>
<td>.230</td>
<td>.231</td>
<td>.006</td>
</tr>
<tr>
<td>A2U</td>
<td>0.5 x 0.5</td>
<td>.25</td>
<td>.246</td>
<td>.229</td>
<td>.228</td>
<td>.229</td>
<td>.006</td>
</tr>
<tr>
<td>A3U</td>
<td>0.25 x 0.25</td>
<td>.063</td>
<td>.0575</td>
<td>.050</td>
<td>.050</td>
<td>.050</td>
<td>.002</td>
</tr>
<tr>
<td>A3L</td>
<td>0.25 x 0.25</td>
<td>.063</td>
<td>.0575</td>
<td>.049</td>
<td>.050</td>
<td>.050</td>
<td>.002</td>
</tr>
<tr>
<td>A4L</td>
<td>0.1 x 0.1</td>
<td>.01</td>
<td>.00905</td>
<td>.0060</td>
<td>.0058</td>
<td>.0059</td>
<td>.0003</td>
</tr>
<tr>
<td>A4U</td>
<td>0.1 x 0.1</td>
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<td>.00855</td>
<td>.0059</td>
<td>.0059</td>
<td>.0059</td>
<td>.0003</td>
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<tr>
<td>C1L</td>
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<td>.981</td>
<td>.98</td>
<td>.96</td>
<td>.97</td>
<td>.02</td>
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<td>C1U</td>
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<td>.989</td>
<td>.97</td>
<td>.97</td>
<td>.97</td>
<td>.02</td>
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<td>C2</td>
<td>0.25 x 2.0(5)</td>
<td>.50</td>
<td>.475</td>
<td>.43</td>
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<tr>
<td>C3</td>
<td>2.0 x 2.0(5)</td>
<td>3.46</td>
<td>3.36</td>
<td>3.30</td>
<td>3.31</td>
<td>3.31</td>
<td>.05</td>
</tr>
<tr>
<td>C4</td>
<td>0.7 x 2.0(5)</td>
<td>1.19</td>
<td>1.18</td>
<td>1.11</td>
<td>1.11</td>
<td>1.11</td>
<td>.02</td>
</tr>
</tbody>
</table>

(1) Areas in square arcsec.
(2) Average of Oct. 83 and June 84
(3) Error in arcsec for average (see text for description of computation).
(4) Aperture maps normalized to the specification for this aperture.
(5) With occulting bar.
### TABLE 3

Red Tube effective aperture sizes viewed by the 1.432 arcsec high diode array

<table>
<thead>
<tr>
<th>Aperture</th>
<th>June 84(^{(1)})</th>
<th>Aug 84(^{(1)})</th>
<th>Average</th>
<th>Error(^{(2)})</th>
</tr>
</thead>
<tbody>
<tr>
<td>B1</td>
<td>.162</td>
<td>.161</td>
<td>.162</td>
<td>.005</td>
</tr>
<tr>
<td>B2</td>
<td>.052</td>
<td>.054</td>
<td>.053</td>
<td>.002</td>
</tr>
<tr>
<td>B3</td>
<td>.70</td>
<td>.70</td>
<td>.70</td>
<td>.02</td>
</tr>
<tr>
<td>A1</td>
<td>6.158(^{(3)})</td>
<td>6.158(^{(3)})</td>
<td>6.158(^{(3)})</td>
<td>--</td>
</tr>
<tr>
<td>A2L</td>
<td>0.222</td>
<td>.219</td>
<td>.221</td>
<td>.006</td>
</tr>
<tr>
<td>A2U</td>
<td>.215</td>
<td>.215</td>
<td>.215</td>
<td>.006</td>
</tr>
<tr>
<td>A3L</td>
<td>.047</td>
<td>.050</td>
<td>.049</td>
<td>.002</td>
</tr>
<tr>
<td>A3U</td>
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<td>.046</td>
<td>.047</td>
<td>.002</td>
</tr>
<tr>
<td>A4L</td>
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<td>.0003</td>
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<td>.0003</td>
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<td>C1L</td>
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<td>.02</td>
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<td>.73</td>
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</table>

1. Areas in square arcsec.
2. Error in arcsec for average (see text for description of computation).
3. Sizes normalized to this aperture, set to 1\(^{\prime}\)432 \times 4\(^{\prime}\)3.
## TABLE 4

Blue Table effective aperture sizes viewed by the 1.432 arcsec high diode array

<table>
<thead>
<tr>
<th>Aperture</th>
<th>Oct 83(^{(1)})</th>
<th>June 84(^{(1)})</th>
<th>Average</th>
<th>Error(^{(2)})</th>
</tr>
</thead>
<tbody>
<tr>
<td>B1</td>
<td>.164</td>
<td>.161</td>
<td>.163</td>
<td>.005</td>
</tr>
<tr>
<td>B2</td>
<td>.054</td>
<td>.051</td>
<td>.053</td>
<td>.002</td>
</tr>
<tr>
<td>B3</td>
<td>.70</td>
<td>.69</td>
<td>.70</td>
<td>.02</td>
</tr>
<tr>
<td>A1</td>
<td>6.158(^{(3)})</td>
<td>6.158(^{(3)})</td>
<td>6.158(^{(3)})</td>
<td>--</td>
</tr>
<tr>
<td>A2L</td>
<td>.219</td>
<td>.217</td>
<td>.218</td>
<td>.006</td>
</tr>
<tr>
<td>A2U</td>
<td>.216</td>
<td>.216</td>
<td>.216</td>
<td>.006</td>
</tr>
<tr>
<td>A3L</td>
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<td>.047</td>
<td>.048</td>
<td>.002</td>
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<td>A3U</td>
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<td>.047</td>
<td>.047</td>
<td>.002</td>
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<td>A4L</td>
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<td>.0057</td>
<td>.0057</td>
<td>.0003</td>
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<td>A4U</td>
<td>.0057</td>
<td>.0056</td>
<td>.0057</td>
<td>.0003</td>
</tr>
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<td>C1L</td>
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<td>.89</td>
<td>.90</td>
<td>.02</td>
</tr>
<tr>
<td>C1U</td>
<td>.91</td>
<td>.90</td>
<td>.91</td>
<td>.02</td>
</tr>
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<td>C2</td>
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<td>.31</td>
<td>.01</td>
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<td>C4</td>
<td>.72</td>
<td>.71</td>
<td>.72</td>
<td>.02</td>
</tr>
</tbody>
</table>

(1) Areas in square arcsec.

(2) Error in arcsec for average (see text for description of computation).

(3) Sizes normalized to this aperture, set to 1.432 x 4.3 = 6.158 square arcsec.
FIGURE CAPTIONS

Figure 1: Contour plots of the 4.3 arc sec aperture maps. Contour levels are at 88, 90, 92, 94, 96 and 98% of the maximum data value. Each tick mark on the X and Y axes represents 20 steps of 12.5 microns in X and 11.29 microns in Y.

Figure 2: Computation of the correction for uneven illumination. Crosses show a vertical cross-section through the center of the 4.3 aperture. The solid line is a linear fit to illumination function. Plots are scaled to 1.0 at the center of the aperture.

Figures 3 - 8: Vertical profiles of the FOS entrance apertures. Data was summed over all 120 pixels for each Y-step. There are 11.29 microns (0.081 arcsec) between Y-steps.

Figures 9 - 10: Photocathode granularity for the central Y-step of the aperture maps as a function of relative diode location in X. Data was normalized to an average of 1.0. Repeatable variations are assumed to be blemishes. The large slope in Figure 9 is caused by the "ion bump." The lack of repeatability at the left of Figure 10 is associated with a noisy diode channel. The location of the 4.3 arcsec aperture is marked.
Figure 9

- - - - - JULY 84
--- August 84

Slope resulting from "ion bump"

\[ \text{Area covered by 4.3 aperture} \]

\[ \text{one sigma counting error} \]