4.1.4 STRAY LIGHT

As reported in Reference 4.1.4-1, augmented to include corrected rejection ratio plots and data

Reference 4.1.4-1 - DFM ISS-387-LAA-97-632, " CASSINI ISS NAC Stray Light Measurement", Lloyd Adams, August 25,1997

Reference 4.1.4-2 - Space Dynamics Laboratory, "Off-Axis Response of the Cassini Narrow Field Camera", John Kemp

4.1.4.1 INTRODUCTION

A stray light performance test of the CASSINI ISS flight spare Narrow Angle Camera (NAC) optical system was made by the Space Dynamics Laboratory (SDL) of the Utah State University (see Reference 4.1.4-2). This test measured the off-axis rejection factor of the NAC over a range of angles from the optical axis. The off-axis rejection factor is defined as the ratio of the total stray light flux reaching a CCD pixel from a “small” light source at an angle off the optical axis, to the total light flux reaching a pixel from the image of the same source when the source is in the field of view of the camera.

The test was performed in the SDL Off Axis Scatter Facility, which was re-built and enlarged for the Cassini task. The facility, which is described in detail in the SDL report, consists of a light source, 8 inch diameter 63.5 inch focal length collimator, black specular walled test chamber, rotating mount with angular position readout for the test optics, and detector system. Figure 4.1.4-1, from the SDL test report, shows a schematic drawing of the test set up. The specular wall is designed so that light that is reflected off the test optics onto the wall is not reflected back into the test optics aperture. Also, a clean room air filtration system was used to reduce particulates in the test chamber.

A tungsten halogen lamp was used as the source for the visible wavelength tests , and a deuterium lamp was used for the ultraviolet wavelength tests. The detector consisted of a photometer photomultiplier coupled to the focal plane with a fiber optics cable mounted in the NAC optics at the focal surface. A 1 (one) mm diameter plastic fiber cable was used for the visual wavelength tests and a 1 mm diameter fused silica fiber cable was used for the ultraviolet tests. The spectral response of the photomultiplier, output of the lamps, and transmission of the fiber optics cables are given in the SDL report.

For the first test runs, SDL had placed a relay lens in front of the fiber optics cable at the focus of the NAC to collect stray light over a larger area than the 1 mm fiber could cover. But, because of some uncertainty about whether the lens was coupling all of the light entering its aperture to the fiber, it was removed for the remainder of the runs. The data presented here is from the runs without the relay lens.

The detector design only allowed stray light measurements to be made at one field position. To allow measurements at more than one field position, the design would have had to be modified to allow repositioning of the fiber optics cable within the sensor head. Also, each field positioned measured would have required a separate test run, which would have increased cost and schedule considerably. For these reasons, only the center of the field was measured.

4.1.4.2 TEST ARTICLE CONFIGURATION

The test article consisted of the spare Narrow Angle Optical System (SN 005), spare Filter Wheel (SN 003) , spare Shutter (SN 005), the Engineering Model Sensor Head, and a CCD package with the CCD removed. The fiber optics cable was mounted in the sensor head at the center of the CCD with the end of the fiber optics about 2 mm behind the nominal focus position of the NAC optical system. The clear filter was selected for the visual wavelength band test and the 255W (233.6-276.1 nanometers band) filter was selected for the ultraviolet wavelength band test.

4.1.4.3 TEST DESCRIPTION

To perform the test, the camera is rotated in steps about a vertical axis in the collimated beam. The entrance aperture of the camera is centered on the pivot point of the table to insure that the aperture is fully illuminated by the source at all angles up to 90° from the optical axis. The photomultiplier signal is then read out for each angular position of the camera.

Due to the very large range of illumination on the detector over the full angular scan of the camera, it was necessary for SDL to utilize apertures placed in the focal plane of the collimator to limit the illumination range to the dynamic range of the photomultiplier. These apertures ranged from 0.0135 inch on axis to a maximum of 0.297 inch at 40 degrees off axis. The data was then adjusted to account for the different aperture sizes.

A detailed test description is given in the SDL report.

4.1.4.4 TEST RESULTS

Figure 4.1.4-2 and Figure 4.1.4-3 present plots of the off axis rejection measured for the visible band and ultraviolet band respectively. The numerical data is given in Table 4.1.4-1 and Table 4.1.4-2 (under the column labeled as “Rejection”).

Because the NAC off-axis rejection goals were stated at 6 degrees and 40 degrees off axis, the values for those angles from Table 4.1.4-1 and Table 4.1.4-2 are given below:

	6°	40°
Visible	1.7×10^{-8}	2.8×10^{-12}
Ultraviolet	5.8×10^{-9}	5.2×10^{-10}

The visible data bottomed out (noise floor) at 36 degrees and the ultraviolet data bottomed out at 16 degrees off axis. The noise floor is the limitation of the test room due to scattering off the walls, dust in the air, and molecular scattering in the air.

SDL was unable to provide error bars for the data. But, because of the various sources of scattering from the test equipment, which are impossible to eliminate completely, the test data tends to make the off-axis performance of an optical system look worse than it is. In addition, the 1 millimeter diameter fiber optics cables were of marginal size to collect all of light from the on axis image due to aberrations in the collimator. The fiber optics cables were only able to cover approximately 90% of the image area, if the alignment were perfect. To quote John Kemp of SDL “It is our strong conviction that the off-axis rejection of Cassini is at least as good and potentially could be a factor of two better than the measurements reported.”

Because the test set-up differs from the flight camera in the size of the test "pixel" (the fiber optics collector) versus a CCD pixel, and in the size of the light source, the test data has to be multiplied by a correction factor to obtain the off-axis rejection factor for the camera.

The off-axis rejection factor “$K_{(\theta)}$” for the flight camera is defined as:

$$K_{(\theta)} = R_{(\theta)}/R_{(0)}$$

Where: $R_{(0)}$ = Total amount of light reaching a CCD pixel from an on axis source.

$R_{(\theta)}$ = Total amount of stray light reaching a CCD pixel from a source at angle "θ".

This definition of the off-axis rejection factor is valid for a point source or a very “small” source.

The measured off-axis rejection factor “$C_{(\theta)}$” is defined as:

$$C_{(\theta)} = I_{(\theta)}/I_{(0)}$$

Where: $I_{(0)}$ = Total amount of light reaching the test pixel from an on-axis source.

$I_{(\theta)}$ = Total amount of stray light reaching the test pixel from a source at angle "θ".

$$K_{(\theta)} = J\ C_{(\theta)}$$

Where: J = The correction factor.

If the illumination in the camera is such that the image of the scene source in the camera is smaller than a CCD pixel and the image of the test source is smaller than the test pixel (1 mm dia. fiber optics probe), then:

$$J = A_{(CCD)}/A_{(TP)}$$

(The derivation of “J” for the above illumination case is given in the Appendix.)

and $K_{(\theta)} = C_{(\theta)}\ A_{(CCD)}/A_{(TP)}$ Where: $A_{(CCD)}$ = Area of a CCD pixel.
$A_{(TP)}$ = Area of the test pixel.

If the image of the test source is larger than the test pixel then:

$$J = A_{(CCD)}/A_{(TS)}$$

Where $A_{(TS)}$ = The area of the test source image.

This is valid if the energy distribution in the test source image is uniform.

Because the collimator used by SDL for the measurements produced a highly aberrated image in the focal plane of the NAC, it was necessary to determine if the test pixel collected all of the light from the image of the test source. To do this, the collimator and NAC combination was modeled in codeV. The only difference between the codeV model and the actual collimator configuration is in the angle of the fold mirror. This difference was not significant for the analysis. The SDL collimator utilized a 63.5 inch (1612.9 mm) focal length, 8 inch diameter spherical mirror used 7.5 degrees off axis. Table 4.1.4-3 gives the CodeV model and Figure 4.1.4-6 shows an optical schematic of the test set up.

Figure 4.1.4-7 gives the spot diagram of the image, from a point source, at the focus of the NAC. Because the source in the collimator was a 0.0135 inch (0.343 mm) dia aperture rather than a point source, the image spot has to be overlaid on the geometrical image of the aperture in the NAC to determine the image size. The geometrical image of the aperture in the NAC is 0.425 mm in diameter. The overlay is shown in Figure 4.1.4-8 in relation to the 1 mm diameter fiber optics test probe.

The 1 mm diameter test probe was able to cover about 90% of the image area, however due to the non uniform energy distribution in the image, it probably collected more than 90% of the energy. Because the exact energy distribution in the image is unknown, the assumption is made that the probe was able to collect close to 100% of the energy in the image. This gives a slightly conservative number for the off-axis rejection factor, however, as stated above, there are other factors in the measurement that also make the number conservative.

Using the equation for the correction factor: $J = A_{(CCD)}/A_{(TP)}$

$A_{(CCD)} = 1.44 \times 10^{-4}$ mm $A_{(TP)} = 7.85 \times 10^{-1}$ mm

$J = 1.83 \times 10^{-4}$

and applying "J" to the measured off-axis rejection factor for 6° and 40° gives:

	6°	40°
Visible	3.1×10^{-12}	5.1×10^{-16}
Ultraviolet	1.1×10^{-12}	9.5×10^{-14}

for the off-axis rejection factor in the camera for a small source. The numerical data is given in Table 4.1.4-1 and Table 4.1.4-2 under the "Corrected Rejection" column, and plotted in Figure 4.1.4-3 and Figure 4.1.4-4.

It is not clear why the off-axis rejection should be better in the ultraviolet band than in the visible band at 6°. However, I suspect that SDL was achieved a better alignment of the image on the fiber probe for the on-axis measurement in the ultraviolet band test.

The off-axis rejection factor goal (not the spec.) stated in the ISS functional requirements document is:

6°	40°
$\leq 1.03 \times 10^{-12}$	$\leq 3.68 \times 10^{-15}$

over the entire wavelength band of the camera.

Off-axis rejection requirements for the NAC given in the Design Requirements Document are:

6°	40°
$\leq 10^{-4}$	$\leq 10^{-10}$

The off-axis performance of the NAC is considerably better than the specification requirement at both 6° and 40°, and it comes close to meeting the goal at 6° in the ultraviolet band. Also, I think the performance at 6° in the visible band is probably better than the number indicates due to the difficulty that SDL had in aligning the system for the on-axis measurements and from the other error sources in the measurements. At 40° it exceeds the goal in the visible band, while the 40° performance in the ultraviolet band is limited by increased scattering in test chamber at the shorter wavelengths.

4.1.4.5 ELECTRONIC DATA

The original electronic files from SDL augmented with the corrected data are electronically archived (see Appendix E).

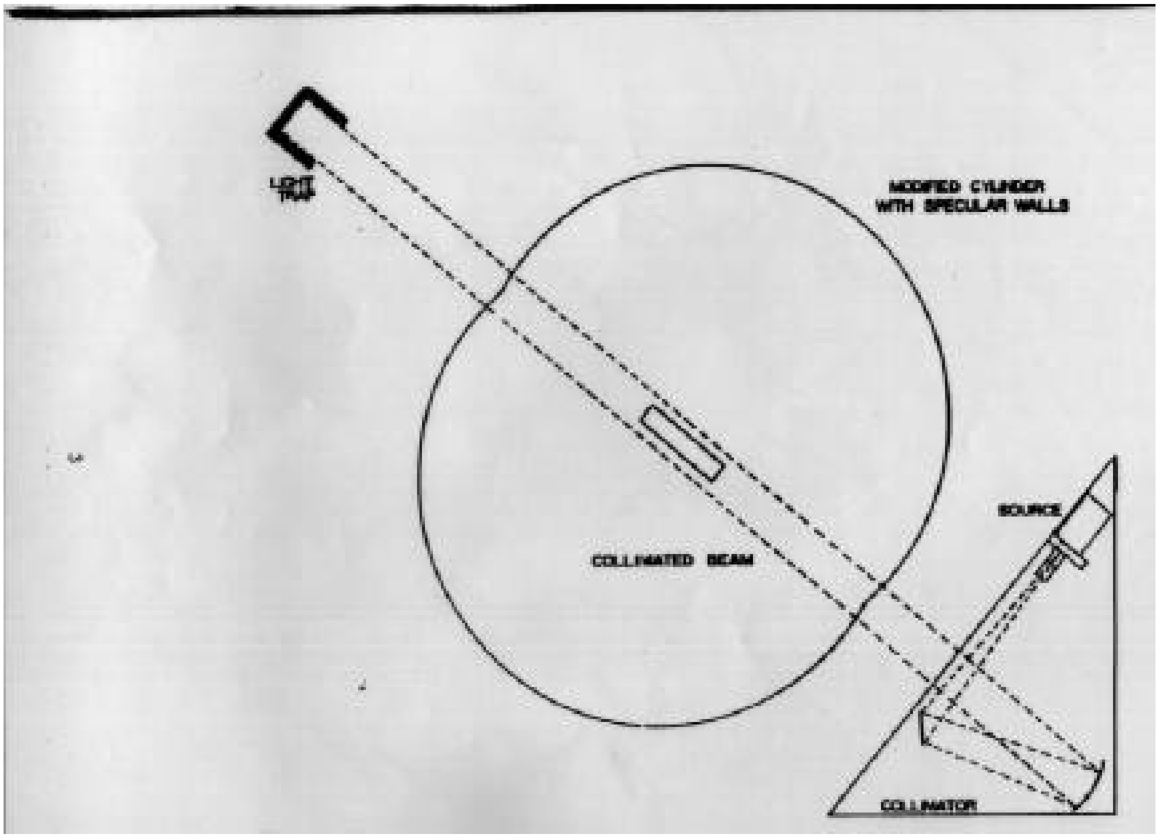
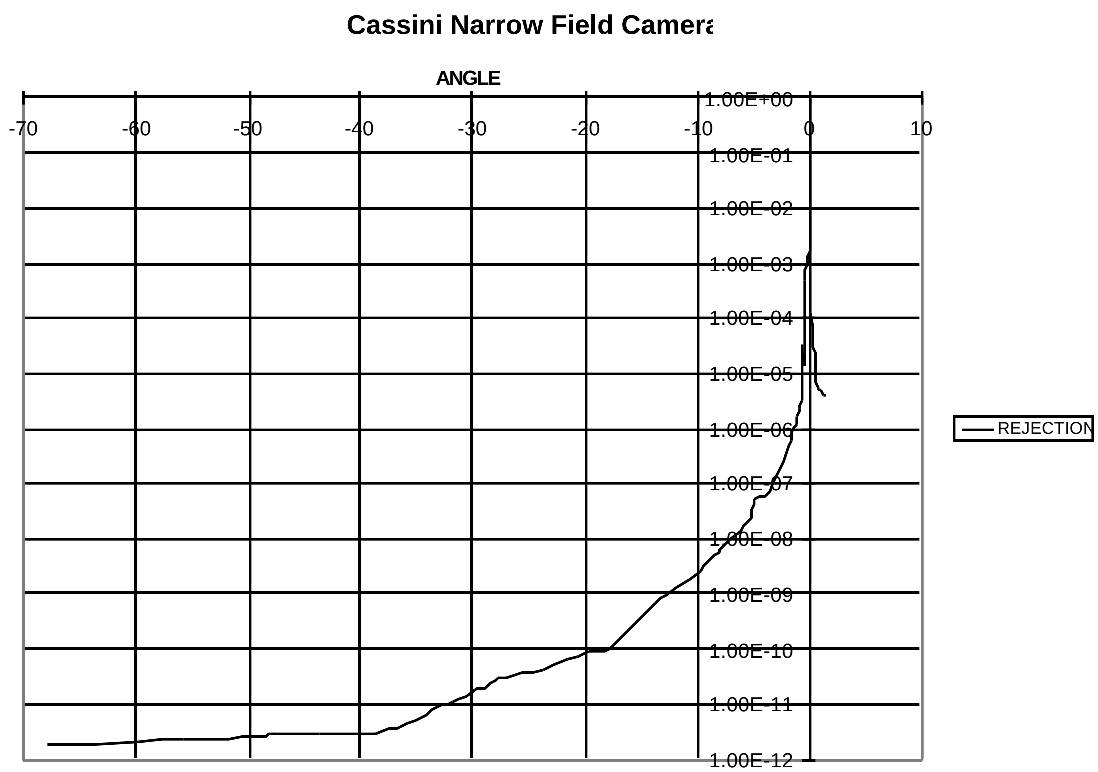


Figure 4.1.4-1 - SDL Test Floor Plan

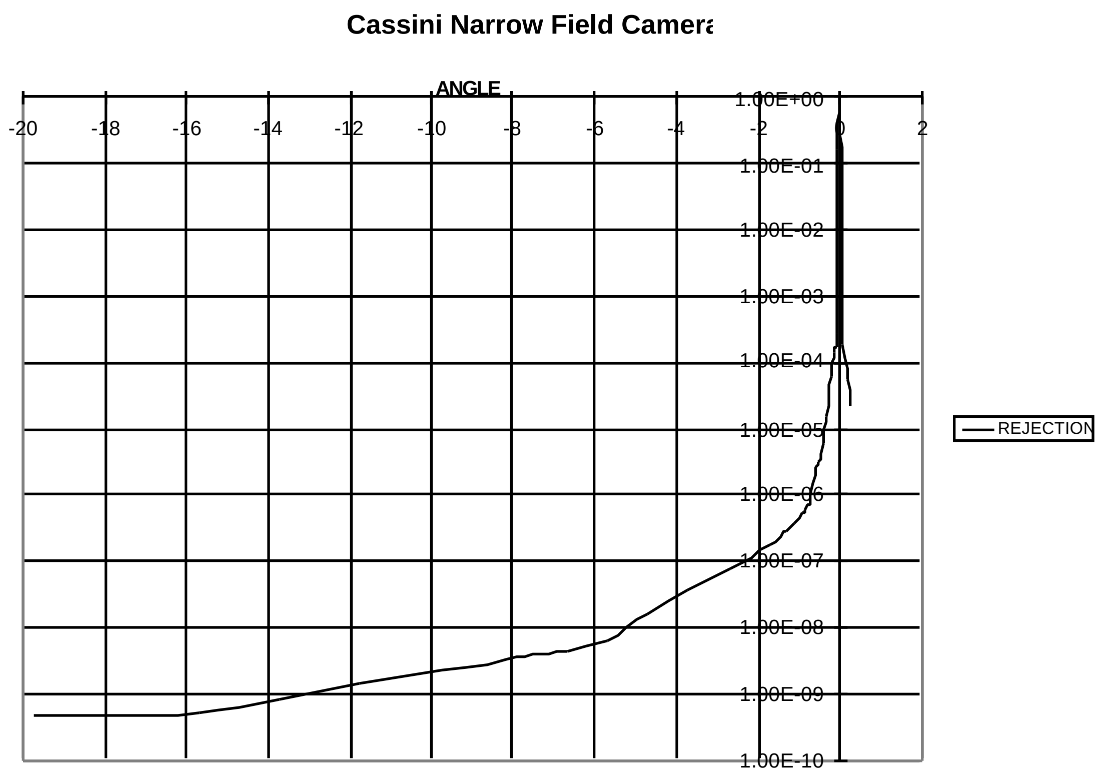


Off-axis Test Facility, Space Dynamics Laboratory, Utah State University

CFOV6.XLS

Visible Band Test
Source : Tungsten halogen lamp
Fiber : 1 mm diameter plastic
NAC filter : Clear

Figure 4.1.4-2 - SDL Visible Band Data (Uncorrected)



Off-axis Test Facility, Space Dynamics Laboratory, Utah State University

CFOV7.XLS

UV Band Test
Source : Deuterium lamp
Fiber : 1 mm diameter fused silica
NAC filter : 255W

Figure 4.1.4-3 - SDL UV Data (Uncorrected)

USU OFF-AXIS REJECTION PROGRAM						CF0V6COR.XLS	
	1/17/97	1:28 PM					
	Enter on-axis voltage into cell B4						
	7.928						
	Enter peak response into cell C6						
		6.25E+07	1.26E+10	4.93E+12	3.63E+14	1.23E+15	1.25E+15
ANGLE	**VOLTAGE**	**RESPONSE**	**REJECTION**			**CORRECTED REJECTION**	
1.488	8.3	2.47E+02	3.95074E-05			7.22985E-09	
1.328	8.26	2.56E+02	4.08989E-05			7.48450E-09	
1.088	8.2	3.02E+02	4.83045E-05			8.83973E-09	
0.968	8.17	3.33E+02	5.32630E-05			9.74712E-09	
0.888	8.15	3.18E+02	5.08637E-05			9.30806E-09	
0.688	8.1	4.29E+02	6.86180E-05			1.25571E-08	
0.488	8.05	8.90E+02	1.42354E-04			2.60509E-08	
0.288	8	2.71E+03	4.33461E-04			7.93234E-08	
0.248	7.99	2.05E+04	0.000327895			6.00048E-07	
0.228	7.985	3.38E+04	0.000540627			9.89347E-07	
0.188	7.975	5.24E+04	0.000838132			1.53378E-06	
0.168	7.97	6.71E+04	0.001073257			1.96406E-06	
0.128	7.96	6.42E+04	0.001026871			1.87917E-06	
0.088	7.95	6.86E+04	0.001096449			2.00650E-06	
0.048	7.94	5.20E+05	0.008317338			1.52207E-05	
0.008	7.93	4.36E+07	0.697376839			0.00012762	
-0.004	7.927	5.82E+07	0.930902111			0.000170355	
-0.012	7.925	5.79E+07	0.926103647			0.000169477	
-0.032	7.92	5.05E+07	0.807741523			0.000147817	
-0.04	7.918	3.12E+07	0.498240563			9.11780E-04	
-0.048	7.916	1.03E+07	0.163947537			3.00024E-04	
-0.052	7.915	3.78E+05	0.006046065			1.10643E-05	
-0.072	7.91	9.83E+04	0.001571497			2.87584E-06	
-0.092	7.905	7.72E+04	0.001234805			2.25969E-06	
-0.112	7.9	7.80E+04	0.001247601			2.28311E-06	
-0.152	7.89	7.41E+04	0.001185221			2.16895E-06	
-0.192	7.88	6.52E+04	0.001042147			1.90713E-06	
-0.192	7.88	1.31E+07	0.001042195	Normalize to Cell D6		1.90722E-06	
-0.232	7.87	6.35E+06	0.000503648			9.21677E-07	
-0.292	7.855	9.80E+05	7.77284E-04			1.42243E-07	
-0.312	7.85	5.22E+05	4.14023E-04			7.57662E-08	
-0.352	7.84	3.45E+05	2.73636E-04			5.00753E-08	
-0.392	7.83	2.45E+05	1.94321E-04			3.55608E-08	
-0.472	7.81	1.63E+05	1.28886E-04			2.35862E-08	
-0.552	7.79	4.50E+05	3.56916E-04			6.53157E-08	
-0.632	7.77	6.96E+04	5.51634E-05			1.00949E-08	
-0.792	7.73	3.83E+04	3.03775E-05			5.55909E-09	
-0.912	7.7	2.91E+04	2.30885E-05			4.22520E-09	

Table 4.1.4-1 - SDL/USU Visible Data (Original and Corrected)

ANGLE	VOLTAGE	RESPONSE	REJECTION			CORRECTED REJECTION	
-0.912	7.7	1.14E+07	2.30897E-05	Normalize to Cell E6		4.22542E-09	
-1.032	7.67	8.68E+06	1.75976E-05			3.22035E-09	
-1.152	7.64	6.98E+06	1.41510E-05			2.58964E-09	
-1.312	7.6	5.92E+06	1.19919E-05			2.19452E-09	
-1.512	7.55	4.00E+06	8.09934E-06			1.48218E-09	
-1.712	7.5	3.03E+06	6.14293E-06			1.12416E-09	
-2.112	7.4	1.74E+06	3.51749E-06			6.43700E-10	
-2.712	7.25	7.95E+05	1.61176E-06			2.94952E-10	
-3.712	7	3.17E+05	6.41662E-07			1.17424E-10	
-4.712	6.75	2.55E+05	5.16979E-07			9.46072E-11	
-5.712	6.5	9.05E+04	1.83376E-07			3.35577E-11	
-8.112	5.9	2.79E+04	5.64825E-08			1.03363E-11	
-8.112	5.9	2.05E+06	5.64973E-08	Normalize to Cell F6		1.03390E-11	
-9.712	5.5	9.31E+05	2.56206E-08			4.68856E-12	
-11.712	5	4.74E+05	1.30442E-08			2.38709E-12	
-13.712	4.5	2.50E+05	6.87985E-09			1.25901E-12	
-15.712	4	1.01E+05	2.76570E-09			5.06123E-13	
-17.712	3.5	3.77E+04	1.03666E-09			1.89708E-13	
-19.684	3.007	3.16E+04	8.69613E-10			1.59139E-13	
-21.688	2.506	2.27E+04	6.24690E-10			1.14318E-13	
-23.68	2.008	1.44E+04	3.96279E-10			7.25191E-14	
-25.68	1.508	1.25E+04	3.42617E-10			6.26988E-14	
-27.68	1.008	1.02E+04	2.79322E-10			5.11159E-14	
-27.68	1.008	3.43E+04	2.79358E-10	Normalize to Cell G6		5.11225E-14	
-31.68	0.008	1.40E+04	1.14090E-10			2.08785E-14	
-33.712	-0.5	9.47E+03	7.71738E-11			1.41228E-14	
-35.712	-1	5.07E+03	4.13169E-11			7.56100E-15	
-39.712	-2	3.48E+03	2.83595E-11			5.18980E-15	
-43.68	-2.992	3.31E+03	2.69742E-11			4.93627E-15	
-47.712	-4	329	2.68112E-11			4.90645E-15	
-47.712	-4	335.8	2.68361E-11	Normalize to Cell H6		4.91100E-15	
-51.712	-5	295	2.35755E-11			4.31431E-15	
-55.712	-6	275	2.19771E-11			4.02182E-15	
-59.712	-7	258	2.06186E-11			3.77320E-15	
-63.712	-8	242	1.93399E-11			3.53920E-15	
-67.712	-9	224	1.79014E-11			3.27595E-15	
	-9.5	67.7	5.41037E-12	Noise Level		9.90098E-16	
Corrected Rejection : USU data corrected by factor of CCD pixel area divided by test pixel area.							

Visible Band Data

Source : Tungsten halogen lamp

Fiber : 1 mm diameter plastic
NAC filter : Clear

Table 4.1.4-1 - SDL/USU Visible Data (Original and Corrected) (cont'd)

USU OFF-AXIS REJECTION PROGRAM						**CFOV7COR.XLS**
	1/18/97	5:10 PM				
	Enter on-axis voltage into cell B4					
	7.93					
	Enter peak response into cell C6					
		4.81E+07	8.42E+09	8.65E+11		
ANGLE	**VOLTAGE**	**RESPONSE**	**REJECTION**			**CORRECTED REJECTION**
0.28	8	1.03E+03	2.13173E-04			3.90106E-08
0.2	7.98	2.52E+03	5.22543E-04			9.56254E-08
0.08	7.95	8.95E+03	0.000185955			3.40297E-07
0	7.93	4.81E+07	1			0.000183
-0.012	7.927	4.61E+07	0.957199252			0.000175167
-0.02	7.925	3.54E+07	0.735507999			0.000134598
-0.04	7.92	7.67E+06	0.159360066			2.91629E-04
-0.06	7.915	2.48E+04	0.000515271			9.42946E-07
-0.08	7.91	1.30E+04	0.000270933			4.95807E-07
-0.08	7.91	2.28E+06	0.000271025	Normalize to Cell D6		4.95975E-07
-0.12	7.9	1.45E+06	0.000172211			3.15146E-07
-0.16	7.89	1.32E+06	0.000156771			2.86892E-07
-0.18	7.885	1.17E+06	0.000138957			2.54290E-07
-0.24	7.87	5.48E+05	6.50839E-04			1.19104E-07
-0.32	7.85	1.37E+05	1.62116E-04			2.96672E-08
-0.42	7.825	5.15E+04	6.11646E-05			1.11931E-08
-0.52	7.8	2.52E+04	2.99588E-05			5.48246E-09
-0.52	7.8	2.59E+06	2.99586E-05	Normalize to Cell E6		5.48243E-09
-0.6	7.78	2.14E+06	2.47296E-05			4.52552E-09
-0.72	7.75	7.06E+05	8.15845E-06			1.49300E-09
-0.84	7.72	5.27E+05	6.08417E-06			1.11340E-09
-0.92	7.7	4.49E+05	5.18281E-06			9.48455E-10
-1.12	7.65	3.12E+05	3.60544E-06			6.59795E-10
-1.32	7.6	2.47E+05	2.85430E-06			5.22338E-10
-1.72	7.5	1.55E+05	1.79116E-06			3.27783E-10

-2.72	7.25	6.39E+04	7.38421E-07			1.35131E-10
-3.72	7	3.12E+04	3.60081E-07			6.58949E-11
-4.72	6.75	1.38E+04	1.58893E-07			2.90775E-11
-5.72	6.5	5.49E+03	6.34418E-08			1.16099E-11
-6.72	6.25	3.90E+03	4.50679E-08			8.24743E-12
-7.72	6	3.17E+03	3.66322E-08			6.70368E-12
-9.72	5.5	1.92E+03	2.21873E-08			4.06028E-12
-11.72	5	1.16E+03	1.34048E-08			2.45308E-12
-13.72	4.5	6.90E+02	7.97356E-09			1.45916E-12
-15.72	4	4.50E+02	5.20015E-09			9.51627E-13
-17.72	3.5	4.00E+02	4.62235E-09			8.45891E-13
-19.72	3	4.20E+02	4.85347E-09			8.88185E-13
Corrected Rejection : USU data corrected by factor of CCD pixel area divided by test pixel area.						

UV Band Test

Source : Deuterium lamp, Fiber : 1 mm diameter fused silica, NAC filter : 255W

Table 4.1.4-2 - SDL/USU UV Data (Original and Corrected)

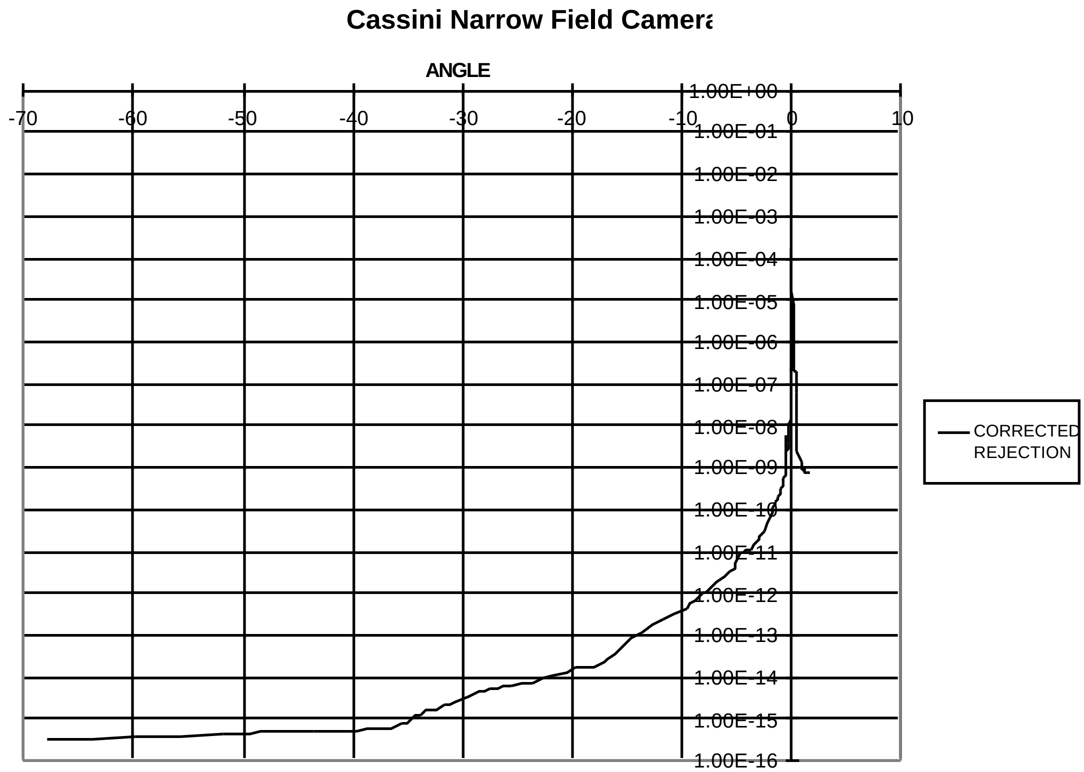
CASSINI NAC STRAY LIGHT TEST SET UP PRESCRIPTION

```
   CASSINI 2000 + SDL COLL 7.5 deg  defocus 2 mm

          RDY          THI     RMD      GLA        CCY   THC   GLC
 > OBJ:      INFINITY       0.000000                    100   100
    1:     INFINITY     399.947216                    100     0
           XDE:   0.000000   YDE:   0.000000   ZDE:   0.000000
           XDC:     100       YDC:     100       ZDC:     100
           ADE:   0.000000   BDE:   0.000000   CDE:   0.000000
           ADC:     100       BDC:     100       CDC:     100

    2:     INFINITY    -1202.175000  REFL               100   100
           XDE:   0.000000   YDE:   0.000000   ZDE:   0.000000   DAR
           XDC:     100       YDC:     100       ZDC:     100
           ADE:   3.750000   BDE:   0.000000   CDE:   0.000000
           ADC:     100       BDC:     100       CDC:     100

    3:      0.1e12       0.000000                    100   100
           XDE:   0.000000   YDE: -158.270000   ZDE:   0.000000
           XDC:     100       YDC:     100       ZDC:     100
           ADE:   0.000000   BDE:   0.000000   CDE:   0.000000
           ADC:     100       BDC:     100       CDC:     100

    4:    3225.80000     1240.000000  REFL               100   100
           XDE:   0.000000   YDE:   0.000000   ZDE:   0.000000   DAR
           XDC:     100       YDC:     100       ZDC:     100
           ADE:   3.750000   BDE:   0.000000   CDE:   0.000000
           ADC:     100       BDC:     100       CDC:     100

  STO:     -862.95630    -326.795712  REFL               100   100
     CON:
     K :  -1.052460   KC :     100

    6:    -269.12310     386.887417  REFL               100   100
     CON:
     K :  -2.934466   KC :     100

    7:     314.98540       2.755521     'fusil'        100   100
    8:    1215.39000       5.092950                    100   100
    9:     -63.29680       2.689914     'CAFL'         100   100
   10:     -66.70040      10.566400                    100   100
   11:      INFINITY       2.719646     'fusil'        100   100
   12:      INFINITY      12.939266                    100   100
   13:      INFINITY       2.375088     'fusil'        100   100
   14:      INFINITY      12.522200                    100   100
   15:      INFINITY      18.013702                    100   100
   16:    -109.44860      10.000000     'fusil'        100   100
   17:     152.90800       5.311165                    100   100
   18:      INFINITY       2.540000     'fusil'        100   100
   19:      INFINITY       1.270000                    100   100
  IMG:      INFINITY       2.000000                    100   100

 SPECIFICATION DATA
  EPD    825.26923
  DIM         MM
  WL       959.43    799.52    616.78    403.76    235.74
  REF          3
  WTW          11        72        99        40        15
  XIM     0.00000
  YIM     0.00000
  VUX     0.00000
  VLX     0.00000
  VUY     0.00000
  VLY     0.00000
```

Table 4.1.4-3 - Code V Model

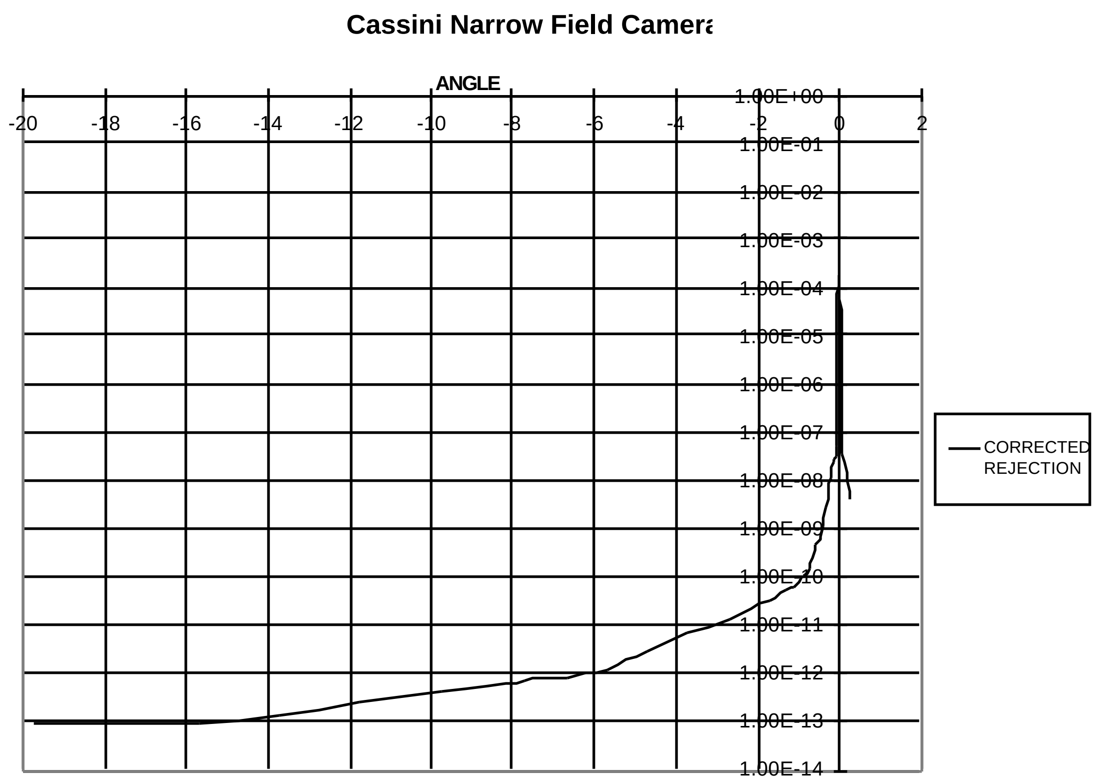
```
                              APERTURE DATA/EDGE DEFINITIONS
  CA
  CIR S5              95.223000
  CIR S5   OBS          37.630000
  CIR S6              25.353000
  CIR S6   OBS           6.931000
  CIR S7              13.601500
  CIR S8              13.601500
  CIR S9              13.601500
  CIR S10             13.601500
  CIR S11             14.503500
  CIR S12             14.503500
  CIR S13             14.503500
  CIR S14             14.503500
  CIR S15             16.614200
  CIR S16             12.700000
  CIR S17             11.379000

PRIVATE CATALOG
  PWL         1100.00      656.27      587.56      486.13      365.48      265.36      202.54
  'fusil'    1.449261    1.456370    1.458470    1.463140    1.474880    1.499940    1.547170

  PWL         1100.00      766.53      587.58      486.15      280.00      190.00
  'CAFL'     1.428340    1.430930    1.433880    1.437040    1.458410    1.505000

REFRACTIVE INDICES
   GLASS CODE            959.43      799.52      616.78      403.76      235.74
  'fusil'             1.450774    1.453178    1.457519    1.469888    1.515887
  'CAFL'              1.429173    1.430557    1.433254    1.441503    1.472832

No solves defined in system

No pickups defined in system


      This is a decentered system.  If elements with power are
      decentered or tilted, the first order properties are probably
      inadequate in describing the system characteristics.

INFINITE CONJUGATES
  EFL       104.6030
  BFL      -128.4496
  FFL        73.5613
  FNO         0.1268
AT USED CONJUGATES
  RED         1.4220
  FNO        12.0229
  OBJ DIS     0.0000
  TT        588.6598
  IMG DIS     3.2700
  OAL       585.3898
  PARAXIAL IMAGE
   HT         0.0000
   THI       20.2942
  ANG         0.0000
  ENTRANCE PUPIL
   DIA      825.2692
   THI     6965.4797
  EXIT PUPIL
   DIA       12.5256
   THI     -130.0372
CODE V>
```

Table 4.1.4-3 - Code V Model (cont'd)



Visible Band Test
Soource : Tungsten halogen lamp
Fiber : 1 mm diameter plastic
NAC filter : Clear

Figure 4.1.4-4 - Corrected Visible Rejection Ratio



<u>UV Band Test</u>
Source : Deuterium lamp
Fiber : 1 mm diameter fused silica
NAC filter : 255 W

Figure 4.1.4-5 - Corrected UV Rejection Ratio

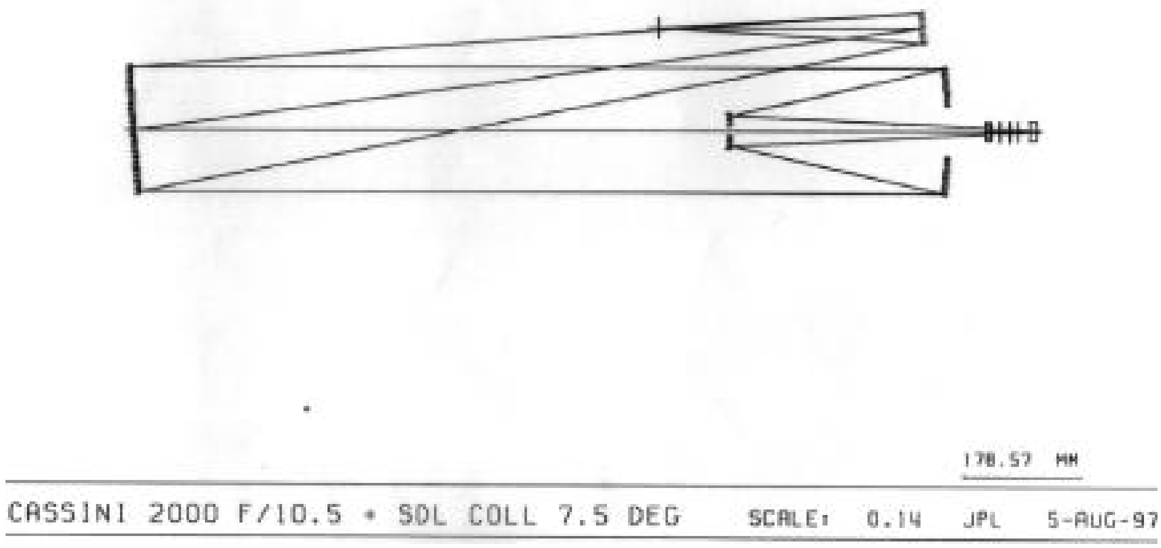


Figure 4.1.4-6- Optical Schematic of Test Set-up

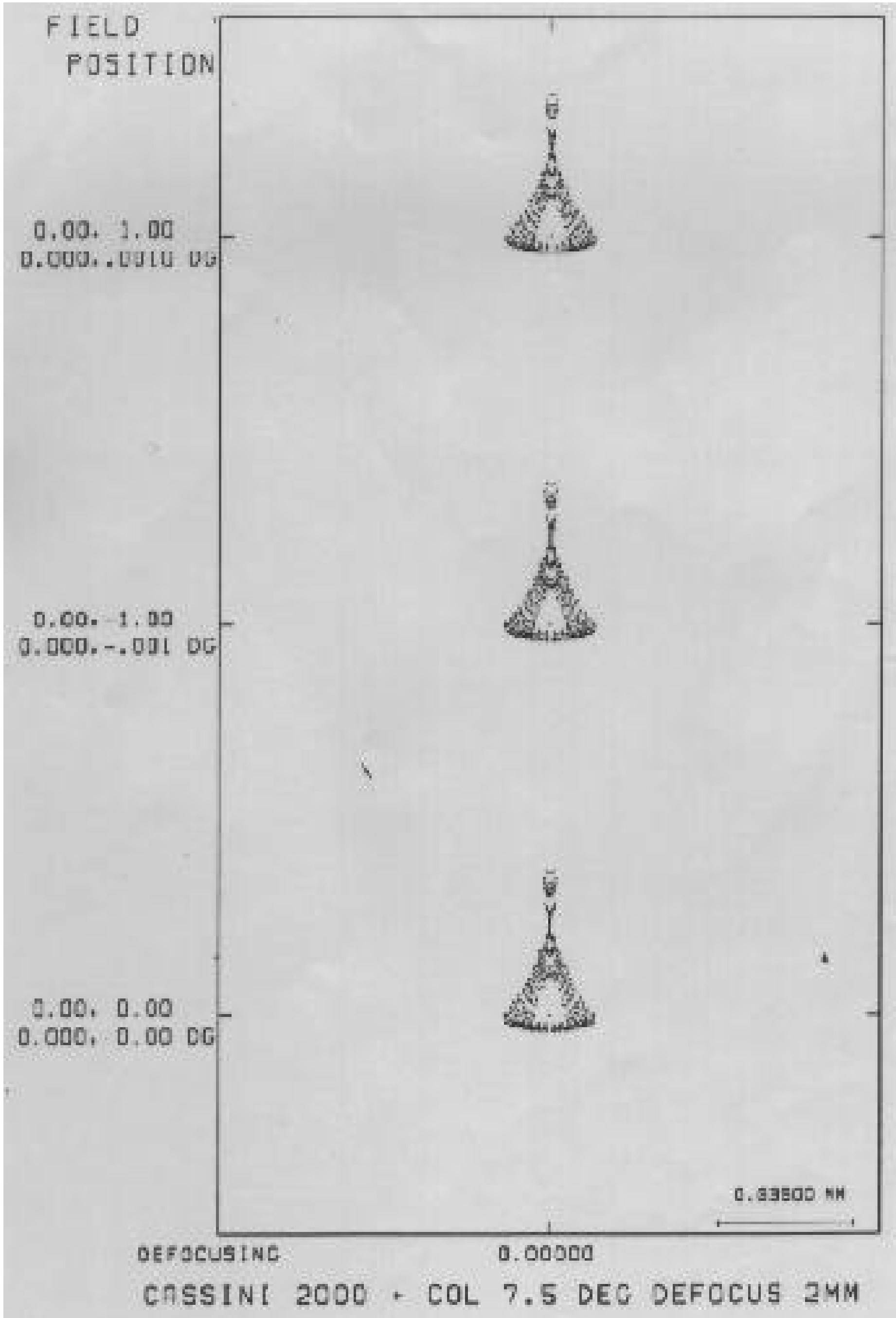
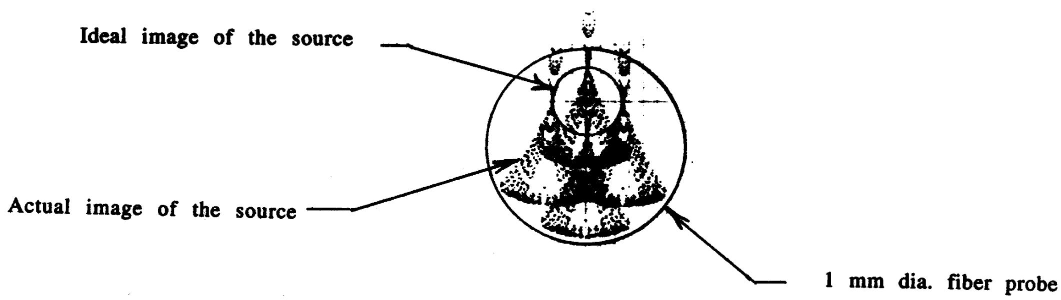


Figure 4.1.4-7 - Spot Diagram of Image

On Axis Image Of the Source in the NAC Focal Plane



Drawing scale: 1 inch = 0.71 mm

L. Adams

8/5/97

Figure 4.1.4-8 - Image Spot Overlay in Relation to 1mm Diameter Fiber Optics Test Probe

4.1.4.6 DERIVATION OF "J"

The derivation of "J" for the illumination case stated in Section 4.1.4.4, where the image of the scene source in the camera is smaller than a CCD pixel and the image of the test source is smaller than the test pixel (1 mm dia. fiber optics probe) is presented here. For this derivation the CCD pixel and the test pixel are both on the camera optical axis.

The off-axis rejection factor in the flight camera is defined as:

$K_{(\theta)} = R_{(\theta)}/R_{(0)}$ where: $R_{(\theta)} =$ Total amount of stray light reaching a CCD pixel from a source at angle "θ".

and: $R_{(0)} =$ The total amount of image light plus stray light reaching a CCD pixel from a source on axis.

$R_{(\theta)} = E_{S(SS)}\, A_{(CCD)}$

$R_{(0)} = E_{I(SS)}\, A_{(SS)} + E_{S(SS)(0)}\, A_{(CCD)}$

where: $E_{S(SS)} =$ Illuminance of the off axis stray light on the CCD from the scene source.

$E_{S(SS)(0)} =$ Illuminance of the on axis stray light on the CCD from the scene source.

$E_{I(SS)} =$ Illuminance of the on axis image of the scene source on the CCD.

$A_{(CCD)} =$ Area of a CCD pixel.

$A_{(SS)} =$ Area of the image of the scene source in the focal plane of the NAC.

then $K_{(\theta)} = E_{S(SS)}\, A_{(CCD)} / E_{I(SS)}\, A_{(SS)} + E_{S(SS)(0)}\, A_{(CCD)}$

In the stray light test the off-axis rejection factor is:

$C_{(\theta)} = I_{(\theta)}/I_{(0)}$

and

$I_{(\theta)} = E_{S(TS)}\, A_{(TP)}$

$I_{(0)} = E_{I(TS)}\, A_{(TS)} + E_{S(TS)(0)}\, A_{(TP)}$ Where: $E_{S(TS)} =$ Illuminance of the off axis stray light on the test pixel from the test source.

$E_{I(TS)} =$ Illuminance of the image of the test source on the test pixel.

$E_{S(TS)(0)} =$ Illuminance of the on axis stray light on the test pixel from the test source.

$A_{(TP)} =$ Area of test pixel.

$A_{(TS)}$ = Area of the image of the test source.

then $C_{(\theta)} = E_{S(TS)}\, A_{(TP)} / E_{I(TS)}\, A_{(TS)} + E_{S(TS)(0)}\, A_{(TP)}$

The illuminance of the image is given by:

$E_I = T\ B\ \pi\ \mathrm{Sin}^2 u'$ Where: E_I = Illuminance of the image in lumens/cm2

T = Transmission of the optical system.

B = Brightness of the source in lumens ster $^{-1}$ cm^{-2}.

u' = Half angle subtended by the pupil of the optical system at the image surface.

The illuminance of the stray light on the detector from a source at angle θ is given by:

$E_S = T\ F_S\, E_P\ \pi\ \mathrm{Sin}^2 u'$ Where: E_S = Illuminance of the stray light on the detector in lumens/cm2.

F_S = Fraction of the light entering system pupil from a source at angle θ that is scattered into the image area.

E_P = Illuminance of the pupil by the source.

$E_P = B\ \pi\ \mathrm{Sin}^2\alpha\ \mathrm{Cos}\ \theta$ Where: α = Half angle subtended by the source at the system pupil.

θ = Angle that the source makes with the camera optical axis.

Therefore

$$E_S = T\ F_S\ B\ (\pi\ \mathrm{Sin}^2\alpha)(\mathrm{Cos}\ \theta)(\pi\ \mathrm{Sin}^2 u')$$

For the flight camera scene source

$$E_{S(SS)} = T\ F_S\ B_{(SS)}\ (\pi\ \mathrm{Sin}^2\alpha_{(SS)})(\mathrm{Cos}\ \theta)(\pi\ \mathrm{Sin}^2 u')$$

$$E_{S(SS)(0)} = T\ F_{S(0)}\ B_{(SS)}\ (\pi\ \mathrm{Sin}^2\alpha_{(SS)})(\pi\ \mathrm{Sin}^2 u')$$

$E_{I(SS)} = T\ B\ \pi\ \mathrm{Sin}^2 u'$ Where: $\alpha_{(SS)}$ = Half angle subtended by the scene source at the system pupil.

$F_{S(0)}$ = Fraction of the light entering the system pupil from an on axis source that is scattered into the image area.

$B_{(SS)}$ = Brightness of the scene source.

$$R_{(\theta)} = T\ F_S\ B\ (\pi\ \mathrm{Sin}^2\alpha_{(SS)})(\mathrm{Cos}\ \theta)(\pi\ \mathrm{Sin}^2 u')A_{(CCD)}$$

$$R_{(0)} = T\ B\ (\pi\ \mathrm{Sin}^2 u')\ A_{(SS)} + T\ F_{S(0)}\ B\ (\pi\ \mathrm{Sin}^2\alpha_{(SS)})(\pi\ \mathrm{Sin}^2 u')A_{(CCD)}$$

Then

$$K_{(\theta)} = T\ F_S\, B(\pi\, Sin^2\alpha_{(SS)})(Cos\ \theta)\ (\pi\, Sin^2u')A_{(CCD)}$$
$$/\ TB(\pi\, Sin^2u')A_{(SS)} + T\ F_{S(0)}\ B(\pi\, Sin^2\alpha_{(SS)})\ (\pi\, Sin^2u')A_{(CCD)}$$

$$K_{(\theta)} = F_S\ (\pi\, Sin^2\alpha_{(SS)})(Cos\ \theta)A_{(CCD)}/A_{(SS)} + F_{S(0)}\ (\pi\, Sin^2\alpha_{(SS)})\ A_{(CCD)}$$

For small angular size sources

$\pi\, Sin^2\alpha_{(SS)} = A_{(SS)} / L^2$ Where: L = Image distance.

$A_{(SS)}$ = Area of the image of the scene source.

then

$$K_{(\theta)} = F_S\ A_{(SS)}\ (Cos\ \theta)A_{(CCD)} / L^2(A_{(SS)} + F_{S(0)}\ A_{(SS)}\ A_{(CCD)} / L^2)$$

$$[K_{(\theta)} = F_S\ A_{(CCD)}\ (Cos\ \theta) / L^2\ (1 + F_{S(0)}\ A_{(CCD)} / L^2)]$$

$(F_{S(0)}\ A_{(CCD)} / L^2)$ is a small enough to be negligible.

then

$$[K_{(\theta)} = F_S\ A_{(CCD)}\ (Cos\ \theta) / L^2\ ]$$

and for the test run

$$[C_{(\theta)} = F_S\ A_{(TP)}\ (Cos\ \theta) / L^2]$$

$$K_{(\varnothing)} = J\ C_{(\varnothing)}$$

$$J = K_{(\varnothing)}/C_{(\varnothing)}$$

$$J = F_S\ A_{(CCD)}\ (Cos\ \theta)L^2/\ F_S\ A_{(TP)}\ (Cos\ \theta)L^2$$

$$[\ J = A_{(CCD)} / A_{(TP)}\ ]$$