SXT CALIBRATION NOTE 14

SEMI-EMPIRICAL SXT MIRROR FIGURE AND FINITE DISTANCE CORRECTION

J. R. Lemen
18 December 1990, Rev A

This note describes a very simple meridional ray trace model of the SXT mirror based on the originally specified hyperboloid-hyperboloid parameters, and modified semi-empirically to agree with the measured cone angles and with the focus results from the June 1989 tests at MSFC (MSFC2).

A. CORRECTIONS TO MIRROR FIGURE

The equation for each hyperboloid surface and the parameters are given on UTOS drawing number 5966-01 entitled "Final Optical Configuration Flight Mirror." My copy of the drawing was plotted on 28 October 1988.

The equation for the hyperboloid surface is given by:

$$R = SQRT(\{(e-1)^2+2(e-1)\}\{(z+z\_o+a)^2-a^2\})$$

where for the forward (H1) and aft (H2) mirrors the parameters are given as:

	H1	H2
(e-1)	3.0626e-5	1.36008e-3
z_o (cm)	323.89282382	152.535523820
a (cm)	3167.195019322	82.806461072

This description results in cone angles at the center of each uncut mirror equal to Cone(H1)=1.063739 (deg) and Cone(H2)=3.193143 (deg). The UTOS report states that these cone angles were not achieved and that in addition there is an average radius offset error. These are reported in Tables 6 and 7 of the UTOS final report. These corrections have been treated as a linear correction to the equation for the hyperboloid surfaces (given above). When such corrections are applied, we find that the model still does not quite predict the image distance obtained in the MSFC2 tests. The cone angle of H1 was adjusted to agree with the MSFC2 focus. A summary of the cone angles follows:

SURFACE	DESIGN ANGLE (deg)	MEASURED ANGLE (deg)	ADJUSTED ANGLE (deg)	ADJUSTED-MEASURED (arcsec)
H1	1.031474	1.0321	1.03147363	2.2549
H2	3.193143	3.1821	-	

Note that the adjusted angle differs from the measured angle by only 2.2549 arcsec. This is substantially less than the 21 arcsec measurement error quoted in the UTOS report.

Therefore, for the calculations reported here we use:

H1 = 1.03147363 deg
H2 = 3.1821 deg

The corresponding linear corrections to the hyperboloid surfaces are given by (all quantities in inches):

$$R1(Z)' = R1(Z) - 0.00056333 * (Z - 0.6003935) - 0.000182$$
$$R2(Z)' = R2(Z) - 0.00019334 * (Z + 0.6003935) + 0.000182$$

B. FINITE SOURCE DISTANCE CORRECTION

The ray trace program was run twice, once with the source at infinity and once with the source at the distance of the MSFC source. The corresponding mirror joint to image distance is given as:

Source Distance	Joint to image distance
1017.7946 ft	1539.7864 mm
Infinity	1532.1471 mm

Finite Distance Correction from adjusted mirror figure = 7.6393 mm
WAB Finite Distance Correction = 7.6209 mm
Difference = 18.4 microns

As a check, this correction was also determined by setting the cone angle of H1 to the value reported in the UTOS final report (H1=1.0321) and adjusting the cone angle of H2 to agree with the MSFC 2 image distance. This resulting finite source distance correction varied from the above result by only 0.1 micron.

C. ENTRANCE APERTURE RADII

The ray trace model was used to compute the entrance aperature. This was taken by determining the rays which struck the extreme edges of the CUT mirror. The geometry of the cut mirror is as follows:

	Z Front (in)	Z Back (in)
H1	0.886811	0.095984
H2	-0.086457	-0.890669

From this the entrance aperture is determined to be:

R1 = 4.526138 in @ Z = 0.095984 in
R2 = 4.540382 in @ Z = 0.886811 in

Aperture = 0.014244 in = 0.36179 mm

D. THIN LENS FOCAL LENGTH

The thin lens equation states that:

$$1/f = 1/o + 1/i$$

If we let:
$f = f/j + \text{delta}(z)$
$o = o/j - \text{delta}(z)$
$i = i/j + \text{delta}(z)$

and

$\text{delta}(z)$ = infinity focus - joint focal length
o/j = mirror joint to object distance
i/j = mirror joint to image distance.

f/j is determined by putting the source at infinity.
i/j is determined by putting the source at MSFC2 source distance = o/j

Then, solve for delta(z) and compute f.

Thin lens focal length = f = 1535.6222 mm ✓ 3/10/91
Joint focal length = f/j = 1532.1471 mm (source at infinity)

Thin lens focal length / joint focal length = f / f/j
= 1535.6222 / 1532.1471
= 1.002268 ✓

E. EXPLANATION FOR CALCULATIONS

Page 1: Calculated mirror figure for design (uncorrected) parameters.
Z1 is position from joint on H1 (+z towards the Sun)
R1 is the radius of the mirror at Z1
T1 is the slope (deg) at Z1, R1.
Focus is the distance from the mirror joint to the image.

Page 1 was calculated with:
Source at infinity
Design mirror figure:
Cone(H1) = 1.063739 deg; Cone(H2) = 3.193143 deg

Page 2: Source at MSFC2 distance = 1017.7946 ft
Adjusted mirror figure:
Cone(H1) = 1.03147363 deg; Cone(H2) = 3.1821 deg

Page 3: Source at infinity
Adjusted mirror figure:
Cone(H1) = 1.03147363 deg; Cone(H2) = 3.1821 deg

Page 4: Linear corrections for adjusted mirror figure.

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18-Dec-1990 18:21:18.00

Calculated focus for Design (uncorrected) Mirror Figure

Z1 (in)	R1 (in)	Z2 (in)	R2 (in)	T1 (deg)	T2 (deg)	Focus (mm)
0.019685	4.525293	-0.019785	4.523824	1.0658254	3.1902920	1547.1273
0.059055	4.526025	-0.059335	4.521619	1.0656835	3.1904843	1547.1341
0.098425	4.526757	-0.098840	4.519417	1.0655416	3.1906767	1547.1409
0.137795	4.527490	-0.138302	4.517217	1.0653999	3.1908691	1547.1477
0.177165	4.528222	-0.177720	4.515019	1.0652582	3.1910616	1547.1546
0.216535	4.528954	-0.217093	4.512824	1.0651165	3.1912542	1547.1613
0.255906	4.529686	-0.256424	4.510631	1.0649749	3.1914468	1547.1681
0.295276	4.530418	-0.295710	4.508441	1.0648334	3.1916395	1547.1749
0.334646	4.531149	-0.334953	4.506252	1.0646920	3.1918322	1547.1817
0.374016	4.531881	-0.374152	4.504066	1.0645506	3.1920251	1547.1884
0.413386	4.532612	-0.413307	4.501883	1.0644093	3.1922180	1547.1952
0.452756	4.533344	-0.452419	4.499701	1.0642681	3.1924109	1547.2019
0.492126	4.534075	-0.491487	4.497522	1.0641269	3.1926039	1547.2087
0.531496	4.534806	-0.530513	4.495345	1.0639859	3.1927970	1547.2154
0.570866	4.535538	-0.569495	4.493171	1.0638448	3.1929902	1547.2221
0.610236	4.536269	-0.608433	4.490998	1.0637039	3.1931834	1547.2288
0.649606	4.537000	-0.647329	4.488828	1.0635630	3.1933767	1547.2355
0.688976	4.537730	-0.686182	4.486660	1.0634222	3.1935700	1547.2422
0.728346	4.538461	-0.724991	4.484495	1.0632814	3.1937635	1547.2488
0.767717	4.539192	-0.763759	4.482332	1.0631407	3.1939569	1547.2555
0.807087	4.539922	-0.802483	4.480171	1.0630001	3.1941505	1547.2622
0.846457	4.540653	-0.841165	4.478012	1.0628596	3.1943441	1547.2688
0.885827	4.541383	-0.879803	4.475855	1.0627191	3.1945378	1547.2754
0.925197	4.542113	-0.918400	4.473701	1.0625787	3.1947315	1547.2821
0.964567	4.542844	-0.956953	4.471549	1.0624383	3.1949254	1547.2887
1.003937	4.543574	-0.995465	4.469399	1.0622980	3.1951192	1547.2953
1.043307	4.544304	-1.033934	4.467252	1.0621578	3.1953132	1547.3019
1.082677	4.545034	-1.072360	4.465107	1.0620177	3.1955072	1547.3085
1.122047	4.545763	-1.110745	4.462964	1.0618776	3.1957013	1547.3151
1.161417	4.546493	-1.149087	4.460823	1.0617376	3.1958954	1547.3216
1.181102	4.546858	-1.168242	4.459753	1.0616676	3.1959925	1547.3249

Focus for ray intersecting middle of uncut H1 at R = 4.536086 in

0.600394	4.536086	-0.598703	4.491541	1.063739	3.193135	1547.2271

Focus for ray intersecting middle of CUT H1 at R = 4.534062 in

0.491398	4.534062	-0.490765	4.497562	1.064130	3.192600	1547.2085

Source at infinity
Cone(H1) = 1.06373906 deg; Cone(H2) = 3.19314335 deg

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Calculated focus for Adjusted Mirror Figure: Slope(H1)= 1.03147363

Z1 (in)	R1 (in)	Z2 (in)	R2 (in)	T1 (deg)	T2 (deg)	Focus (mm)
0.019685	4.524761	-0.061883	4.521787	1.0335600	3.1794532	1539.6427
0.059055	4.525472	-0.099849	4.519678	1.0334180	3.1796381	1539.6547
0.098425	4.526182	-0.137774	4.517571	1.0332762	3.1798230	1539.6668
0.137795	4.526892	-0.175657	4.515466	1.0331344	3.1800080	1539.6788
0.177165	4.527602	-0.213500	4.513364	1.0329927	3.1801931	1539.6908
0.216535	4.528312	-0.251303	4.511263	1.0328511	3.1803782	1539.7029
0.255906	4.529021	-0.289065	4.509165	1.0327095	3.1805634	1539.7149
0.295276	4.529731	-0.326786	4.507069	1.0325680	3.1807486	1539.7268
0.334646	4.530441	-0.364466	4.504975	1.0324265	3.1809339	1539.7388
0.374016	4.531150	-0.402106	4.502883	1.0322852	3.1811193	1539.7508
0.413386	4.531859	-0.439705	4.500793	1.0321439	3.1813047	1539.7627
0.452756	4.532569	-0.477264	4.498706	1.0320026	3.1814901	1539.7747
0.492126	4.533278	-0.514783	4.496620	1.0318615	3.1816757	1539.7866
0.531496	4.533987	-0.552261	4.494537	1.0317204	3.1818613	1539.7985
0.570866	4.534696	-0.589700	4.492455	1.0315794	3.1820469	1539.8105
0.610236	4.535405	-0.627098	4.490376	1.0314384	3.1822326	1539.8224
0.649606	4.536113	-0.664456	4.488299	1.0312975	3.1824184	1539.8342
0.688976	4.536822	-0.701774	4.486224	1.0311567	3.1826042	1539.8461
0.728346	4.537531	-0.739053	4.484151	1.0310159	3.1827901	1539.8580
0.767717	4.538239	-0.776292	4.482080	1.0308752	3.1829761	1539.8698
0.807087	4.538947	-0.813491	4.480012	1.0307346	3.1831621	1539.8817
0.846457	4.539656	-0.850650	4.477945	1.0305941	3.1833482	1539.8935
0.885827	4.540364	-0.887769	4.475881	1.0304536	3.1835343	1539.9053
0.925197	4.541072	-0.924849	4.473818	1.0303132	3.1837205	1539.9171
0.964567	4.541780	-0.961890	4.471758	1.0301728	3.1839068	1539.9289
1.003937	4.542488	-0.998891	4.469699	1.0300325	3.1840931	1539.9407
1.043307	4.543196	-1.035852	4.467643	1.0298923	3.1842794	1539.9525
1.082677	4.543903	-1.072775	4.465589	1.0297522	3.1844659	1539.9642
1.122047	4.544611	-1.109658	4.463537	1.0296121	3.1846524	1539.9760
1.161417	4.545319	-1.146502	4.461487	1.0294721	3.1848389	1539.9877
1.181102	4.545672	-1.164909	4.460463	1.0294021	3.1849322	1539.9936

Focus for ray intersecting middle of uncut H1 at R = 4.535227 in

0.600394	4.535227	-0.617752	4.490896	1.031474	3.182186	1539.8194

Focus for ray intersecting middle of CUT H1 at R = 4.533265 in

0.491398	4.533265	-0.514089	4.496659	1.031864	3.181672	1539.7864

H1 = 0.095984 in to 0.886811 in; Delta= 0.790827 in (CUT dimension)
Average focus @ Z= 0.492126 in = 1539.7864 +/- 0.074003 mm (21)

Source distance = 1017.7946 ft
Cone(H1) = 1.03147363 deg; Cone(H2) = 3.18210000 deg

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Calculated focus for Adjusted Mirror Figure: Slope(H1)= 1.03147363

Z1 (in)	R1 (in)	Z2 (in)	R2 (in)	T1 (deg)	T2 (deg)	Focus (mm)
0.019685	4.524761	-0.060328	4.521873	1.0335600	3.1794456	1532.0025
0.059055	4.525472	-0.096820	4.519846	1.0334180	3.1796233	1532.0146
0.098425	4.526182	-0.133272	4.517821	1.0332762	3.1798011	1532.0267
0.137795	4.526892	-0.169685	4.515798	1.0331344	3.1799788	1532.0388
0.177165	4.527602	-0.206059	4.513777	1.0329927	3.1801567	1532.0509
0.216535	4.528312	-0.242394	4.511759	1.0328511	3.1803345	1532.0630
0.255906	4.529021	-0.278690	4.509742	1.0327095	3.1805125	1532.0751
0.295276	4.529731	-0.314946	4.507727	1.0325680	3.1806904	1532.0871
0.334646	4.530441	-0.351163	4.505714	1.0324265	3.1808684	1532.0992
0.374016	4.531150	-0.387342	4.503704	1.0322852	3.1810465	1532.1112
0.413386	4.531859	-0.423481	4.501695	1.0321439	3.1812246	1532.1233
0.452756	4.532569	-0.459581	4.499689	1.0320026	3.1814028	1532.1353
0.492126	4.533278	-0.495643	4.497684	1.0318615	3.1815810	1532.1473
0.531496	4.533987	-0.531666	4.495682	1.0317204	3.1817592	1532.1593
0.570866	4.534696	-0.567650	4.493681	1.0315794	3.1819375	1532.1713
0.610236	4.535405	-0.603596	4.491683	1.0314384	3.1821159	1532.1833
0.649606	4.536113	-0.639503	4.489687	1.0312975	3.1822943	1532.1952
0.688976	4.536822	-0.675372	4.487692	1.0311567	3.1824727	1532.2072
0.728346	4.537531	-0.711202	4.485700	1.0310159	3.1826512	1532.2192
0.767717	4.538239	-0.746995	4.483710	1.0308752	3.1828298	1532.2311
0.807087	4.538947	-0.782749	4.481721	1.0307346	3.1830084	1532.2430
0.846457	4.539656	-0.818464	4.479735	1.0305941	3.1831870	1532.2549
0.885827	4.540364	-0.854141	4.477751	1.0304536	3.1833657	1532.2668
0.925197	4.541072	-0.889781	4.475769	1.0303132	3.1835444	1532.2787
0.964567	4.541780	-0.925382	4.473789	1.0301728	3.1837232	1532.2906
1.003937	4.542488	-0.960945	4.471810	1.0300325	3.1839020	1532.3025
1.043307	4.543196	-0.996471	4.469834	1.0298923	3.1840809	1532.3144
1.082677	4.543903	-1.031958	4.467860	1.0297522	3.1842598	1532.3262
1.122047	4.544611	-1.067408	4.465888	1.0296121	3.1844388	1532.3381
1.161417	4.545319	-1.102820	4.463917	1.0294721	3.1846178	1532.3499
1.181102	4.545672	-1.120512	4.462933	1.0294021	3.1847073	1532.3558

Focus for ray intersecting middle of uncut H1 at R = 4.535227 in

0.600394	4.535227	-0.594613	4.492182	1.031474	3.182071	1532.1803

Focus for ray intersecting middle of CUT H1 at R = 4.533265 in

0.491398	4.533265	-0.494976	4.497721	1.031864	3.181578	1532.1471

H1 = 0.095984 in to 0.886811 in; Delta= 0.790827 in (CUT dimension)
Average focus @ Z= 0.492126 in = 1532.1471 +/- 0.074500 mm (21)

Source at infinity
Cone(H1) = 1.03147363 deg; Cone(H2) = 3.18210000 deg

FINITE SOURCE DISTANCE CORRECTION

Finite Distance Correction = 1539.7864 - 1532.1471 = 7.6393 mm
WAB Finite Distance Correction result = 7.6209 mm
Difference = 18.4 microns

LINEAR CORRECTION TO MIRROR FIGURE

(Assume all quantities in inch)

R1(Z)' = R1(Z) +-0.00056333 * (Z- 0.6003935) + -0.000182
R2(Z)' = R2(Z) +-0.00019334 * (Z--0.6003935) + 0.000182

Effective Linear Corrections:

H1: Slope =-0.00056333, Offset =-0.0005202
H2: Slope =-0.00019334, Offset = 0.0002981

Assume the following mirror angles:

H1 = 1.03147363 deg (adjusted)
H2 = 3.18210000 deg (measured)

Entrance Aperture Radii

Assume the following mirror angles:

H1 = 1.03147363 deg (adjusted)
H2 = 3.18210000 deg (measured)

R1 = 4.526138 in @ Z = 0.095984 in
R2 = 4.540382 in @ Z = 0.886811 in
Aperture = 0.014244 in = 0.36179 mm

Thin lens focal length = 1535.6222 mm; 1.002268
Cone angles for MSFC source = 4.2718, 4.2849