FINAL REPORT

SOFT X-RAY TELESCOPE (SXT) FOCUS ERROR ANALYSIS

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SOFT X-RAY TELESCOPE (SXT) FINAL REPORT

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ABSTRACT

This report presents the analysis performed on the soft X-ray telescope (SXT) to determine the correct thickness of the spacer to position the CCD camera at the best focus of the telescope, and to determine the maximum uncertainty in this focus position due to a number of metrology and experimental errors, and thermal and humidity effects. This type of analysis has been performed by the SXT prime contractor, Lockheed Palo Alto Research Lab (LPARL). The SXT project office at MSFC formed an independent team of experts to review the LPARL work, and verify the analysis performed by them. Based on the recommendation of this team, the project office will make a decision if an end to end focus test is required for the SXT prior to launch.

The metrology and experimental data, and the spreadsheets provided by LPARL are used as the basis of the analysis presented in this report. The data entries in these spreadsheets have been verified as far as feasible, and the format of the spreadsheets has been improved to make these easier to understand. The results obtained from this analysis are very close to the results obtained by LPARL. However, due to the lack of organized documentation, the analysis uncovered a few areas of possibly erroneous metrology data, which may affect the results obtained by this analytical approach.

1. BACKGROUND

The Soft X-ray Telescope (SXT) is being built by Lockheed Palo Alto Research Laboratory (LPARL) for NASA Marshall Space Flight Center (MSFC). The mirror assembly of SXT has been built by United Technologies Optical Systems (UTOS). This telescope is scheduled to be launched on a Japanese satellite along with other instruments as part of Solar-A experiment.

The original plan was to do an end to end test of the SXT prior to launch at MSFC X-ray calibration facility. This facility is currently being modified for AXAF, and is consequently not available. The LPARL and MSFC project office personnel felt that the correct focus setting for the SXT can be determined analytically based on the metrology of the flight part, and the results of a previous X-ray test performed at MSFC in June 1989.

A review team consisting of MSFC Optics Branch personnel was formed at the end of November 1990 to evaluate the feasibility of setting the SXT focus analytically on the basis of metrology data and other documentation provided by LPARL. This review team was assisted by an optomechanical expert from the Center for Applied Optics (CAO) at University of Alabama at Huntsville (UAH). A meeting was held at Palo Alto, CA on December 3 & 4, 1990 with LPARL to review the documentation and metrology data for the flight parts as provided by LPARL.

The review team has made independent calculations of the error budget, and the thickness of the CCD spacer to position the camera at the best focus position based on the data provided by LPARL. The results obtained are quite close to the LPARL results, but due to the lack of organized documentation, and the metrology data that was not independently verified at Lockheed facilities, a significant uncertainty and doubts exist about the validity of the results obtained by this analytical approach.

This report consists of the spreadsheets for focus error analysis and calculation of the flight CCD spacer thickness. The issues relating to the accuracy of the data used in the spreadsheets are also discussed.

2. SXT FOCUS ERROR ANALYSIS

2.1 SOURCES OF FOCUS ERROR:

The major components of SXT are shown in figure 1. As it consists of a number of critical optical and mechanical parts fabricated to precision tolerance, it is important to determine the magnitude of the uncertainty in the focus position due to metrology and experimental errors. In this section, the major sources of focus error are identified, and the resulting uncertainty in the focus position is predicted.

The two major categories of errors are:

A. MSFC Test #2 Errors:

An end to end focus test was performed on SXT to determine the focal length at MSCF in June 1989. In this test, an engineering model metering tube and CCD camera were used. These errors determine the accuracy of the focal length calculated from MSFC Test #2 results.

B. Metrology errors in flight parts:

The SXT has been disassembled and reassembled several times since the June 1989 test. Most of the major parts were made new for the flight unit. The errors in these determine the accuracy of the desired focal length that will be achieved in the orbit.

2.2 FOCUS ERROR SPREADSHEET:

The data used in this spreadsheet was obtained directly from the documents supplied by LPARL. The spreadsheet supplied by LPARL was used as the baseline. The following list provides the reference for each entry in the spreadsheet.

A. MSFC TEST #2 ERRORS:

1. Error in focus location by Hartmann test. Used LPARL number.

2. Focal length correction for the source @ finite distance. Used LPARL number.

3. Effective focal length correction. Used LPARL number.

4. Temperature uncertainty in calibration/metrology of MSFC assembly.

   - Refer to Design Notes: 36, P:1 & 2
     45, P:1

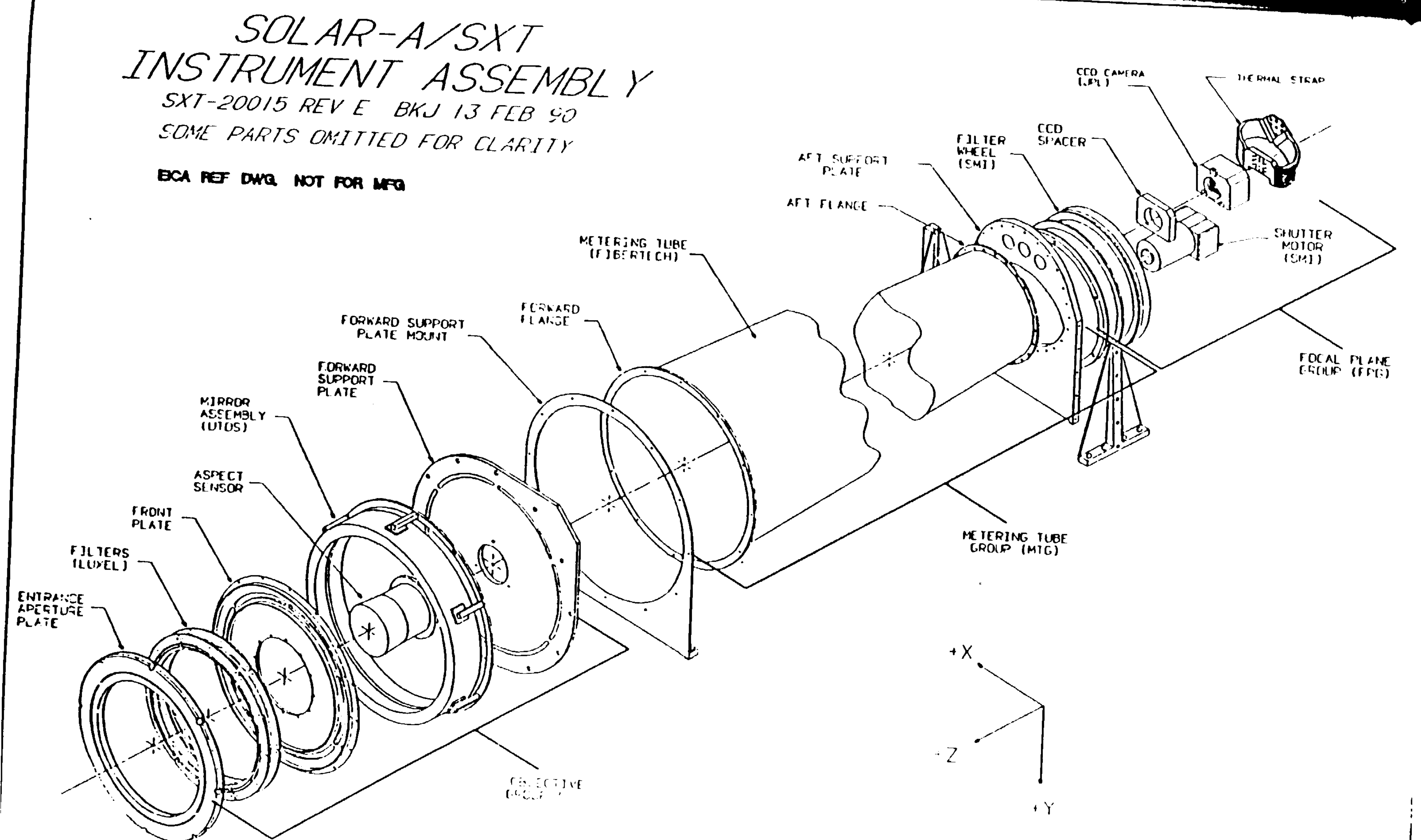
SOLAR-A/SXT
INSTRUMENT ASSEMBLY
SXT-20015 REV E BKJ 13 FEB 90
SOME PARTS OMITTED FOR CLARITY
BCA REF DWG. NOT FOR MFG
CCD CAMERA (JPL)
THERMAL STRAP
CCD SPACER
FILTER WHEEL (SMI)
AFT SUPPORT PLATE
AFT FLANGE
SHUTTER MOTOR (SMI)
METERING TUBE (FIBERTECH)
FORWARD FLANGE
FORWARD SUPPORT PLATE MOUNT
FORWARD SUPPORT PLATE
MIRROR ASSEMBLY (UTOS)
ASPECT SENSOR
FRONT PLATE
FILTERS (LUXEL)
ENTRANCE APERTURE PLATE
FOCAL PLANE GROUP (FPG)
METERING TUBE GROUP (MTG)
+X
+Z
+Y

Figure 1

5. Length of beamline. Used LPARL number.

6. "Best focus" spacer thickness.

- Cannot find ref: JRL note of 9/15/90. Used LPARL number.

7. Uncertainty in CCD focal plane inset from the mounting feet.

- P: 2 of CCD Camera Metrology report, dated 10/2/89 (SXT8E056)

8. Tube #2 hydration uncertainty.

- Design Note: 50, P:1 & Table:1

9. "Wire pinch" problem.

- Design Note: 50, Fig:5

10. Flatness error in forward support plate.

- Design Note: 50, P:1 & 2, Table:2 & Fig:6

11. Metrology accuracy in metering tube group (July 1989)

- Cannot find MEB 9/17/90 reference.

12. Mounting pads to mirror joint distance.

- Original UTOS drawing indicates ±0.020" tolerance, LWA memo of 11/16/90 (items #9 & 10) indicates that actual tolerance may be better than ±0.005".

NOTE:

Errors # 1,2,3,5 & 12 are optical in nature & must be verified by MSFC personnel.

B. ERRORS IN FLIGHT PARTS:

1. Temperature uncertainty in metrology of metering tube group.

- Refer to Design Notes: 36, P:1 & 2
45, P:1

2. Uncertainty in the value of coefficient of thermal expansion of structure.

- Design Note: 45, P:1

3. Orbit temperature uncertainty.

- Design Note; 45, P:1

4. Uncertainty in CCD focal plane inset from the mounting feet.

- P: 4 of CCD Camera Metrology report, dated 08/27/89 (SXT8E065)

5. Tube #5 hydration uncertainty.

- P:3 of Feinstein handout at 12/3/90 meeting.

6. Metrology accuracy of metering tube group (September 1990).

- Cannot find any reference.

7. Mounting pads to mirror joint distance.

- Same as Error #12 of section A.

8. Metrology of flight CCD spacer.

- Loren's spreadsheet dated 9/15/90.

9. Metrology of fiberglass (G-10) washers (compressed).

- Loren's spreadsheet of 9/15/90.

10. Lapping of flight CCD spacers.

- Flatness tolerance on the drawing per Bruce. Drawing not available.

SPREADSHEET FOR ESTIMATING THE FOCUS ERROR

SXT FOCUS ERROR ANALYSIS

SOURCE OF ERROR	ERROR	FOCUS ERROR (MICRONS)	SQ. OF FOCUS ERR	% OF TOTAL ERROR
A. MSFC TEST #2 ERRORS:				
1. Error in focus location by Hartmann test	11.00 um	11.00	121.00	17
2. F/L correction for source @ finite distance	0.000039 units	0.60	0.36	1
3. Effective focal length correction	0.000670	10.24	104.86	15
4. Temp. uncertainity in metrology of MSFC assy	2 C	2.87	8.26	4
5. Error in the length of beamline.	0.3 in	0.16	0.03	0
6. "Best focus" spacer thickness	70 u in	1.78	3.16	3
7. CCD focal plane inset from mounting feet	402 u in	10.21	104.26	15
8. Tube #2 hydration uncertainity	'250 u in	6.35	40.32	10
9. "Wire pinch" problem	165 u in	4.19	17.56	6
10. Flatness error in forward support plate	550 u in	13.97	195.16	21
11. Metrology accuracy of metering tube group.	5 u m	5.00	25.00	8
12. Mounting pads to mirror joint distance.	'0.0005 in	0.13	0.02	0
Total error for MSFC Test #2		66.50	619.99	100.00
RSS defocus for MSFC Test #2			24.90	

SPREADSHEET FOR ESTIMATING THE FOCUS ERROR

B. ERRORS IN FLIGHT PARTS:

SOURCE OF ERROR	ERROR	FOCUS ERROR (MICRONS)	SQ. OF FOCUS ERR	% OF TOTAL ERROR
1. Metrology temperature uncertainity	2 C	2.87	8.26	6
2. Error in spacer thk due to uncertainity in CTE	30 %	5.70	32.49	12
3. Orbit temperature uncertainity	5 C	7.18	51.62	15
4. Uncertainity in CCD focal plane inset	31.00 u in	0.80	0.63	2
5. Tube #5 hydration uncertainity	'360 u in	9.14	83.61	19
6. Metrology accuracy of metering tube group.	1 u m	1.00	1.00	2
7. Mounting pads to mirror joint distance.	'0.0005 in	0.13	0.02	0
8. Metrology error for flight CCD spacer	6.714 u m	6.71	45.08	14
9. Metrology error for fiberglass (G-10) washers	2.8 u m	2.80	7.84	6
10. Grinding error for flight CCD spacer	500 u in	12.70	161.29	26
Total error for Flight parts		49.04	391.84	100.00
RSS defocus for Flight parts			19.80	
GRAND TOTAL		115.54	1011.83	
GRAND TOTAL RSS DEFOCUS			31.81	

3. FLIGHT CCD SPACER THICKNESS

3.1 SPREADSHEET DATA:

The calculations in the spreadsheet are based on a number of metrology measurements of the parts used in MSFC test#2, and the flight parts that were fabricated subsequently. The machining and measurements of the parts used in MSFC test#2 were done in less than ideal conditions as compared to the flight parts. Moreover, a number of analytical formulas were used in the focal length calculations. The validity & the accuracy of these formulas needs to be verified. Some of the metrology data is open to interpretation, so judgement calls had to be made about the signs, etc. All these factors must be considered in judging the accuracy of the thickness of the flight spacer as predicted by the spreadsheet.

Some brief comments about the various calculations and measurements used in this spreadsheet are as follows:

1. Length of MSFC X-ray beam (source to mirror joint) has changed slightly because the pads to mirror joint distance has changed from 2.035" to 2.05372". Moreover, this length is composed of 5 measurements, so it's accuracy depends on how accurately those 5 measurements were made at the time of test (Cells F9-F11).

2. The length of metering tube used in MSFC test #2 was measured twice because of the wire pinch problem. The second set of numbers (without pinched wire) has been used by LPARL in the spreadsheet. It is possible that wire was pinched at the time of test. In that case, the first set of numbers should be used (cell D14).

3. The change in mirror joint to mounting pads distance affects the mirror joint to image distance (cells D21 & D22), the finite conjugate correction (cell A28), and the location of the best infinity axial focus with respect to the mirror pads (cell D33).

4. The source of mirror remount correction number (cell C42) is not known. There was also an uncertainty about its sign at the time of December 3-4, 1990 meeting.

5. The CCD inset from the mounting feet for the flight camera (cell C45) is calculated by making the measurements using a rather tedious method (LPARL report SXT8E065), and then fitting the best planes to the two sets of data. This approach is prone to sign and magnitude errors.

6. An average thickness of the insulating washers (cell C48) is used. The three washers, that will actually be used, can be of different thickness and, therefore, can introduce tilt errors.

7. The desired metering structure length (cell F53) is 0.000185" shorter than the previous value because of the change in mirror joint to pads distance.

8. The number used by LPARL for the measured length of the flight tube (cell C76) can not be verified by the metrology data sheets dated 9/14/90.

9. The desired length is about 0.037547" shorter than the measured length (cell B82) due to the reason mentioned in item 7 above.

10. The slope error calculations are open to a lot of interpretation as far as the signs and the calculations of coefficients of the best fitting plane equations. The coefficient B & C for the spacer (cells C94 & D94) were calculated by LPARL by offsetting the actual X values by 0.1 (supposedly to keep the solution stable).

11. The numbers in cells F117 & F118 indicate the amount material to be removed from the existing spacer.

12. The required thickness of the flight CCD spacer is 0.98420" at upper screw holes & 0.99000" at the lower screw holes (cells F132 & F133). As the "as built" spacer is too short by about 0.0005" (cells C138 & C139), a new spacer must be fabricated.

SPREADSHEET FOR CALCULATING CCD SPACER THICKNESS

	A	B	C	D	E	F	G
1	"2/22/1991	CALCULATION OF FLIGHT CCD SPACER THICKNESS					
2							
3	Conversion factor:		25400 µm/inch				
4							
5	Length of MSFC x-ray beam, source to mirror joint:						
6							
7	Target to pivot	Pivot to table	Table to mount	Mount to pad	Pad to joint	Answer =	
8	1013.68	41.75	10	0.34	2.05372		
9	12164.16	41.75	10	-0.34	-2.05372	12213.5163 inches	
10	30896.9664	106.045	25.4	-0.8636	-5.2164488	31022.3314 cm	
11						1017.79302 feet	
12	MSFC "system" length, mirror pads to spacer face (DESIGN NOTE:50, FIG:5).						
13	Pos on Spacer		Avg bottom	Hole			
14	I1	58.30158		58.30062056 inches			
15	I2	58.29962	58.30001				
16	I3	58.3004					
17							
18	"Best focus" image distance at MSFC-2 (mirror joint to image) , REF: SXT8E056, P: 2 &						
19	Joint-pad	Structure	CCD inset	"Defocus"		LWA'S MEMO OF 12/11/90	
20	2.05372	58.3006206	0.2632	0.004370079 inches			
21			Answer =	60.62191063 inches			
22			or	153.979653 cm			
23	Joint f/l	**153.2191**					
24	Joint/Effective ratio (WAB)		1.001345				
25	Effective f/l	153.425228 cm =		60.40363307 inches			
26							
27	Finite conjugate correction for MSFC pipe (M. BRUNNER NOTES OF 9/12/90, P: 4)						
28	0.762557004 cm =		0.300219293 inches				
29							
30	Location of best infinity axial focus w/t x-ray mirror pads						
31	Structure	CCD inset	"Defocus"	Conjugate corr			
32	58.30062056	0.2632	0.004370079	-0.300219293 inches			
33			Answer =	58.26797134 inches			
34			or	**148.00065** cm			
35	Wide field defocus						
36	-100 µm =		-0.003937008 inches				
37							

SPREADSHEET FOR CALCULATING CCD SPACER THICKNESS

	A	B	C	D	E	F	G
38	On-orbit temperature correction (DESIGN NOTE:45, P:1)						
39	19 µm	=	0.000748031	inches			
40							
41	Mirror re-mount correction (M. BRUNNER NOTES OF 9/12/90, P:4)						
42	-6.858 µm	=	-0.00027	inches			
43							
44	FM CCD INSET FROM MOUNTING PADS (METROLOGY REPORT SXT 8E065, P: 4)						
45	6832.7016 µm	=	0.269004	inches			
46							
47	Insulating washer thickness (compressed to 8 inch #) , REF: 9/15/90 WORKSHEET BY L. ACTON						
48	536.1624 µm	=	0.021108756	inches			
49							
50	Desired metering structure length (mirror pads to spacer pads), REF: MEB NOTES OF 9/12/90, P: 5						
51	Pads to inf focus	Defocus	Temp corr	Remount	Insul. washers	CCD inset	
52	58.26797134	-0.00393701	0.000748031	-0.00027	-0.021108756	-0.269004	inches
53					Answer =	57.9743996	inches
54					or	147.254975	cm
55							
56	Length of reference bar (REF: M. BRUNNER NOTES OF 9/12/90, P:5A)						
57	Meter bar	61.512981	inches				
58	Riser blocks	3.500001	inches				
59	Difference	58.01298	inches =	Href			
60							
61	Gauge reading (positive number means structure longer than meter bar), REF: M. BRUNNER NOTES 0F						
62	Pos 1		8.15 µm =	0.000320866	inches	9/12/90, P: 5	
63	Pos Href		6.23 µm =	0.000245276	inches		
64							
65	Length of FM metering structure (mirror pads to spacer pads), REF: MEB NOTES OF 9/12/90, P: 6						
66	Pos 1	58.0130556	inches				
67		147.353161	cm				
68							
69	Correction for tilt of spacer, REF: M. BRUNNER NOTES OF 9/13/90, P: 6						
70	Relative ht pos 1		9.43 µm	=	0.00037126	inches	
71	Relative ht hole center		-18.74 µm	=	-0.000737795	inches	
72							
73	Structure length at center of exit hole , REF: M. BRUNNER NOTES OF 9/13/90, P: 6						
74	Ref bar	Gauge diff	Pos 1 to hole				

SPREADSHEET FOR CALCULATING CCD SPACER THICKNESS

	A	B	C	D	E	F	G
75	58.01298	7.5591E-05	-0.001109055	inches			
76		Answer =	58.01194654	inches			
77		or	147.3503442	cm			
78							
79	**Amount to thin spacer at center of hole**						
80	Meas length	Desired length					
81	58.01194654	-57.9743996	inches		Value using joint f/l		Difference
82		**0.037547**	**inches**		0.03805014	inch	-0.000503213
83		0.09536919	cm				
84							0.000807463
85						Orbit T sign switch	0.001310676
86	CALCUTLATION OF SLOPE ERRORS:						
87							
88	Metrology of CCD in CCDH and tilt of spacer (Z = A + BX + CY), REF: FM CCD METROLOGY REPORT, P: 5						
89	Item	A	B	C			
90	Feet	1.9048415	-0.000185	0.0005911	inch units		
91	CCD	1.6339198	-0.000127	0.0024868	inch units		
92	Difference	0.2709217	-0.000058	-0.0018957	inch units		
93			-1.4732	-48.15078	μm/inch		
94	Spacer		-5.82085	18.951925	μm/inch	REF: MEB' S WORKSHEET	
95						DATED 9/13/90	
96	According to LWA Figure 1 B-slopes compensate and C-slopes add.						
97	Resulting Tilt of CCD wrt optical axis if no tilt compensation added to spacer lap operation.						
98			[Ignore sign]				
99			-4.34765	67.10271	μm/inch		
100			-3.19987	49.38759	μm across 0.737 inch CCD		
101	So, tilt about Y axis must be compensated in spacer.						
102							
103							
104	SETTING OF SINE PLATE FOR MACHINING THE SPACER (M. BRUNNER'S NOTES OF 9/13/90, P: 9)						
105							
106	Slope to be taken out in lapping			0.00264	in/in =	0.1514 deg or 9.08 arcmin	
107	Shim to set 10 inch sine plate at angle			0.02642	inch		
108							
109							
110	AMOUNT OF MATERIAL TO BE REMOVED (M. BRUNNER'S NOTES 0F 9/13/90, P:10)						
111							

SPREADSHEET FOR CALCULATING CCD SPACER THICKNESS

	A	B	C	D	E	F	G
112	In order to move center		0.03755	inches and achieve 9.08 arcmin tilt			
113							
114	Screw holes in upper pads are				1.33	inches above hole center	
115	Likewise, lower pads (wings) are				0.867	inches below hole center	
116							
117	**Lap off upper pads at center of screw hole**					**0.04106**	**inch**
118	**Lap off lower pads at center of screw hole**					**0.03526**	**inch**
119		**Difference**				**0.00580**	**inch**
120							
121							
122	Spacer Metrology						
123	{Looking down on 4-pad side of spacer with bevelled corners on top.}						
124		Gauge reading at pads					
125	Pad	(μm)	Thick (mm)	Thick (in)	Delta (in)		
126	UL	41.6	26.0512	1.02564	0.00062		
127	UR	30.1	26.0397	1.02519	0.00017		
128	LL	25.9	26.0355	1.02502	0.00000		
129	LR	30.5	26.0401	1.02520	0.00018		
130	Average thickness of spacer		26.0416	1.02526			
131							
132	**Final spacer thickness at center of upper screw hole**					**0.98420**	**inch**
133	**Final spacer thickness at center of lower screw hole**					**0.99000**	**inch**
134	**Final spacer thickness at center of camera mounting hole**					**0.98771**	**inch**
135							
136	**"As Built" 10/01/90**						
137	Average (in)		Short (in)	Short (μm)			
138	0.98377 Upper holes		0.00043	10.87			
139	0.98950 Lower holes		0.00050	12.82			
140							
141	NOTE: AS THE EXISTING FM CCD SPACER IS TOO SHORT, A NEW SPACER MUST BE FABRICATED.						
142							

FORMULAS FOR CALCULATING CCD SPACER THICKNESS

	A	B	C	D
1	"2/22/1991	CALCULATION OF FLIGHT		
2				
3	Conversion factor:		=25.4*1000	µm/inch
4				
5	Length of MSFC x-ray beam, source			
6				
7	Target to pivot	Pivot to table	Table to mount	Mount to pad
8	1013.68	41.75	10	0.34
9	=12*A8	41.75	10	-0.34
10	=2.54*A9	=2.54*B9	=2.54*C9	=2.54*D9
11				
12	MSFC "system" length, mirror pads tc			
13	Pos on Spacer		Avg bottom	Hole
14	l1	58.30158		=(0.875/2.25)*(B14-C15)+C15
15	l2	58.29962	=(B15+B16)/2	
16	l3	58.3004		
17				
18	"Best focus" image distance at MSFC			
19	Joint-pad	Structure	CCD inset	"Defocus"
20	2.05372	=D14	=0.2632	=111/C3
21			Answer =	=SUM(A20:D20)
22			or	=D21*2.54
23	Joint f/l	**=1/((1/F10)+(1/D22))**		
24	Joint/Effective ratio (WAB)		1.001345	
25	Effective f/l	=B23*C24	cm =	=B25/2.54
26				
27	Finite conjugate correction for MSFC			
28	=B25^2/(F10-B25)	cm =	=A28/2.54	inches
29				
30	Location of best infinity axial focus w/			
31	Structure	CCD inset	"Defocus"	Conjugate corr
32	=D14	=C20	=D20	=-C28
33			Answer =	=SUM(A32:D32)
34			or	**=D33*2.54**
35	Wide field defocus			
36	-100	µm =	=A36/$C$3	inches
37				

FORMULAS FOR CALCULATING CCD SPACER THICKNESS

	A	B	C	D
38	On-orbit temperature correction (DES			
39	19	µm =	=A39/$C$3	inches
40				
41	Mirror re-mount correction (M. BRUN			
42	=C42*$C$3	µm =	-0.00027	inches
43				
44	FM CCD INSET FROM MOUNTING			
45	=C45*$C$3	µm =	0.269004	inches
46				
47	Insulating washer thickness (compres			
48	536.1624	µm =	=A48/C3	inches
49				
50	Desired metering structure length (mi			
51	Pads to inf focus	Defocus	Temp corr	Remount
52	=D33	=C36	=C39	=C42
53				
54				
55				
56	Length of reference bar (REF: M. BR			
57	Meter bar	61.512981	inches	
58	Riser blocks	3.500001	inches	
59	Difference	=B57-B58	inches =	Href
60				
61	Gauge reading (positive number m			
62	Pos 1	8.15	µm =	=B62/$C$3
63	Pos Href	6.23	µm =	=B63/$C$3
64				
65	Length of FM metering structure (mir			
66	Pos 1	=B59+(D62-D63)	inches	
67		=B66*2.54	cm	
68				
69	Correction for tilt of spacer, REF: M. I			
70	Relative ht pos 1		9.43	µm =
71	Relative ht hole center		-18.74	µm =
72				
73	Structure length at center of exit hole			
74	Ref bar	Gauge diff	Pos 1 to hole	

FORMULAS FOR CALCULATING CCD SPACER THICKNESS

	A	B	C	D
75	=B59	=D62-D63	=-(E70-E71)	inches
76		Answer =	=A75+B75+C75	inches
77		or	=C76*2.54	cm
78				
79	**Amount to thin spacer at cen**			
80	Meas length	Desired length		
81	=C76	=-F53	inches	
82		**=A81+B81**	**inches**	
83		=B82*2.54	cm	
84				
85				
86	CALCUTLATION OF SLOPE ERROF			
87				
88	Metrology of CCD in CCDH and tilt o			
89	Item	A	B	C
90	Feet	1.9048415	-0.000185	0.0005911
91	CCD	1.6339198	-0.000127	0.0024868
92	Difference	=B90-B91	=C90-C91	=D90-D91
93			=$C$3*C92	=$C$3*D92
94	Spacer		-5.82085	18.951925
95				
96	According to LWA Figure 1 B-slopes			
97	Resulting Tilt of CCD wrt optical axis			
98			[Ignore sign]	
99			=C94-C93	=D94-D93
100			=0.736*C99	=0.736*D99
101	So, tilt about Y axis must be compens			
102				
103				
104	SETTING OF SINE PLATE FOR MA			
105				
106	Slope to be taken out in lapping			=D99/C3
107	Shim to set 10 inch sine plate at ar			=D106*10
108				
109				
110	AMOUNT OF MATERIAL TO BE REI			
111				

FORMULAS FOR CALCULATING CCD SPACER THICKNESS

	A	B	C	D
112	In order to move center		=B82	inches and achieve 9.08 arcm
113				
114	Screw holes in upper pads are			
115	Likewise, lower pads (wings) are			
116				
117	**Lap off upper pads at center**			
118	**Lap off lower pads at center**			
119		**Difference**		
120				
121				
122	Spacer Metrology			
123	{Looking down on 4-pad side of spac			
124		Gauge reading at pads		
125	Pad	(µm)	Thick (mm)	Thick (in)
126	UL	41.6	26.0512	1.0256377952755
127	UR	30.1	26.0397	1.0251850393700
128	LL	25.9	26.0355	1.0250196850393
129	LR	30.5	26.0401	1.0252007874015
130	Average thickness of spacer		26.041624999999	1.0252608267716
131				
132	**Final spacer thickness at cen**			
133	**Final spacer thickness at cen**			
134	**Final spacer thickness at cen**			
135				
136	**"As Built" 10/01/90**			
137	Average (in)		Short (in)	Short (µm)
138	0.98377230971129	Upper holes	=F132-A138	=C138*$C$3
139	0.98949967191601	Lower holes	=F133-A139	=C139*$C$3
140				
141	NOTE: AS THE EXISTING FM CCD			

FORMULAS FOR CALCULATING CCD SPACER THICKNESS

	E	F	G	H
1				
2				
3				
4				
5				
6				
7	Pad to joint	Answer =		
8	2.05372			
9	-2.05372	=SUM(A9:E9)	inches	MFSC-2 (with "best defocus"
10	=2.54*E9	=SUM(A10:E10)	cm	Spacer thickness
11		=F9/12	feet	Length (pads to rear of FWA
12				
13				FM structure (Unfinished spa
14	inches			Spacer thickness
15				Length (pads to rear of FWA
16				
17				
18				
19		LWA'S MEMO OF 12/11/90		
20	inches			
21	inches			
22	cm			
23				
24				
25	inches			
26				
27				
28				
29				
30				
31				
32	inches			
33	inches			
34	cm			
35				
36				
37				

FORMULAS FOR CALCULATING CCD SPACER THICKNESS

	E	F	G	H
38				
39				
40				
41				
42				
43				
44				
45				
46				
47				
48				
49				
50				
51	Insul. washers	CCD inset		
52	=-C48	=-C45	inches	
53	Answer =	=SUM(A52:F52)	inches	
54	or	=F53*2.54	cm	
55				
56				
57				
58				
59				
60				
61				
62	inches	9/12/90, P: 5		
63	inches			
64				
65				
66				
67				
68				
69				
70	=C70/$C$3	inches		
71	=C71/$C$3	inches		
72				
73				
74				

FORMULAS FOR CALCULATING CCD SPACER THICKNESS

	E	F	G	H
75				
76				
77				
78				
79				
80				
81	Value using joint f/l		Difference	
82	0.038050139688572	inch	=B82-E82	
83			0.00080746282158373	
84		Orbit T sign switch	=G83-G82	
85				
86				
87				
88				
89				
90	inch units			
91	inch units			
92	inch units			
93	µm/inch			
94	µm/inch	REF: MEB' S WORKSHEET		
95		DATED 9/13/90		
96				
97				
98				
99	µm/inch			
100	µm across 0.737 inch CCD			
101				
102				
103				
104				
105				
106	in/in =	0.1514 deg or 9.08 arcmin		
107	inch			
108				
109				
110				
111				

FORMULAS FOR CALCULATING CCD SPACER THICKNESS

	E	F	G	H
112				
113				
114	1.33	inches above hole center		
115	0.867	inches below hole center		
116				
117		=C112+E114*D106	inch	
118		=C112-E115*D106	inch	
119		=F117-F118	inch	
120				
121				
122				
123				
124				
125	Delta (in)			
126	0.0006181102362206			
127	0.00016535433070874			
128	0			
129	0.0001811023622047			
130				
131				
132		=$D$130-F117	inch	
133		=$D$130-F118	inch	
134		=D130-B82	inch	
135				
136				
137				
138				
139				
140				
141				

4. REVIEW OF LOCKHEED METROLOGY PROCEDURES

The accuracy of the metrology data for the flight parts is crucial for predicting the correct thickness of the CCD spacer that must be installed on SXT prior to launch. The calculation of the correct CCD spacer thickness is based on the five measurements listed below. Most of these measurements were made by one person using one set of tools. These measurements were not independently verified by another person, or by the same person using another set of tools or another metrology method. Some of the measurements were made with uncontrolled equipment in an uncontrolled environment by the LPARL engineering personnel, rather than by the qualified inspectors.

The specific comments about these five critical measurements are as follows:

4.1 METERING STRUCTURE LENGTH:

The graphite epoxy metering tube used in the MSFC test #2 was measured seven times on different occasions as shown in table 1. In all cases, the high and low readings, as well as their difference was found to be different. We can disregard the first 4 measurements and only consider the measurements 5 through 7, which are critical to the results obtained from MSFC test #. Even these three readings vary from a low of 53.30686" to a high of 53.31446", i.e. a difference of 0.0076". Some of the causes of this variation are hydration uncertainty, wire pinch problem and metrology errors.

The flight tube was measured five times, again all of the measurements were different. The measurements #9 and 11 are both pre-bakeout readings, but the highs were different by about 0.003" and lows were different by about 0.002". Similar differences exist in the post-bakeout readings. One possible explanation for these variations is that metrology tools or environment may not have been well controlled.

4.2 CCD FOCAL PLANE INSET FROM MOUNTING PADS:

The details of these measurements are discussed in LPARL's CCD Metrology report SXT8E065 dated 27 August, 1990. A tool makers microscope, which did not have long enough travel to cover the mounting pads fully, was used. The data was taken in a non-certified environment by engineering personnel using an uncalibrated tool. Also, the data is not documented properly, and is therefore, hard to understand. The distance and slope between the focal plane and the mounting pads was computed analytically, and not measured directly.

The CCD focal plane is mounted on a fiberglass sleeve. The temperature and hydration effects were not taken into account by LPARL for calculating this inset.

TABLE 1

Metering Tube Height Measurements Summary

1. Before lapping began MT 2 9 March, 1989	High Low Difference	53.32140 53.31995 0.00145
2. After lapping MT 2 4 April, 1989	High Low Difference	53.31528 53.31506 0.00022
3. After rework due to MT2 vibration failure 5 May, 1989	High Low Difference	53.31762 53.30910 0.00852
4. After relapping MT2 9 May, 1989	High Low Difference	53.31480 53.30884 0.00596
5. After bakeout MT2 25 May, 1989	High Low Difference	53.31322 53.30686 0.00636
6. Post MSFC X-Ray test MT2 5 July, 1989	High Low Difference	53.31386 53.30784 0.00602
7. Additional metrology MT2 11 Aug,1989	High Low Difference	53.31446 53.30911 0.00535
8. Initial metrology MT 5 13 Nov, 1989	High Low Difference	53.3130 53.1668 0.00462
9. Pre-bakeout MT 5 18 Dec, 1990	High Low Difference	53.31965 53.31170 0.00795
10 Post-Bakeout MT 5 4 Jan, 1990	High Low Difference	53.31939 53.30968 0.00971
11 Pre-final bakeout MT 5 25 July, 1990	High Low Difference	53.31688 53.313606 0.003275
12 Post-final bakeout MT5 14 Sept,1990	High Low Difference	53.31717 53.31229 0.00488

4.3 THICKNESS OF FLIGHT SPACER.

The required thickness of the flight spacer is computed in the spreadsheet presented in section 3. A slightly oversized spacer was made and measured. To calculate the slope of the pads on the "as made" spacer, a spreadsheet (MEB, dated 9/13/90) was used to best fit a plane through the 4 pads. LPARL personnel claim that the actual metrology values had to be offset by 0.1" to obtain the solution. Moreover, thermal effects due to the difference in metrology temperature of 25°C and the actual orbit temperature were neglected.

The 4 pads of the spacer were then ground to achieve the required thickness and the correction of the slope errors. The spacer was measured again, and was found to be about 0.0005" too short compared to the desired thickness.

4.4 THICKNESS OF G-10 WASHERS:

The insulating washers between the CCD camera and the spacer are made from G-10 (fiberglass reinforced plastic). A number of washers were measured by LPARL engineering personnel, and the average thickness was computed. This number was used to determine the CCD spacer thickness. In actual practice, the four washers will be of different thicknesses, and may introduce small slope errors.

4.5 MOUNTING PADS TO MIRROR JOINT DISTANCE:

This measurement was made by UTOS after the mirror had been assembled to its mounting ring. The procedure used by UTOS for this measurement is not known, but it is an indirect measurement because the mirror joint is an imaginary plane. As a result of a vibration problem , the mirror was removed from its mounting ring and rebonded afetr the June 1989 test at MSFC. Initially, UTOS reported this number to be 2.05372" ± 0.005", but later on changed it to 2.035" ± 0.0005", i.e. a change of about 0.019". This results in a change of about 0.0002" in the spacer thickness.

5. RECOMMENDATIONS

Based on the information presented in this report, it is highly desirable that an end to end focus test be performed on SXT prior to launch, to eliminate some of the uncertainties mentioned in section 4. The reasons for this recommendation are once again summarized below.

1. Lack of formal and organized documentation on part of LPARL because it was not a contractual requirement, and their engineering personnel were planning on a focus test prior to launch.

2. All the critical flight parts are different from the ones used in MSFC test#2.

3. The metrology of parts used in MSFC test#2, and some flight parts was performed by engineering personnel with non-certified tools in uncontrolled environment.

4. The determination of the best focus is based on metrology of a large number of parts, and fairly extensive analyses involving a number of assumptions. There were uncertainties about the interpretation of the signs of some measurements and the slope errors. In some cases, the thermal and hydration effects were neglected. This type of approach is usually susceptible to human errors, and can not have the same high degree of confidence as a full-up test.

5. Generally, all the metrology on critical flight parts was performed by one person using one set of tools, and was not independently verified.