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AXAF-I CCD Imaging Spectrometer (ACIS)

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AXAF-I Alignment Report (AAR)

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1.0 Introduction

The ACIS instrument requires precise alignment to achieve its science objectives. The alignment tolerance budgets have been divided between the science instrument and the telescope optical bench, science instrument module (SIM) and high resolution mirror assembly (HRMA). This report describes the total instrument alignment of the ACIS science instrument. It does not, nor can it, make any determination of alignment when ACIS is mounted on the SIM or the telescope itself.

The methodology used was to transfer a set of reference surfaces from a tooling plate supplied by the ISIM contractor. The tooling plate contains an exact duplicate of the mounting features used by ACIS on the SIM. Additionally, the tooling plate contained a set of drill bushings to allow alignment pin holes to be drilled in the ACIS mounting shims and threaded holes to clamp the shims to the tooling plate. During alignment, the launch-lock position on the focal plane would be placed at the telescope focal point by adjusting these shims at the ACIS mounting interface. All six degrees of freedom were measured with reference to the tooling plate. All alignment numbers given in this document are with respect to the tooling plate with the mounting bolts torqued to specified values. It has been assumed that any differences between the tooling plate and the flight SIM are insignificant or are included in the ISIM error budgets.

There are two sources of error in the ACIS detector alignment, machining / assembly tolerances and the effects of cooling on the focal plane and detector assembly. Machining tolerances can be estimated using as built dimensions and subsequently measured on a Coordinate Measuring Machine (CMM). The thermal effects are more difficult to quantify and understand. Both the collimator and the detector housing have complex geometries making estimation fairly difficult even with modern finite element methods. Further, the collimator is made from titanium to reduce thermal conduction but the detector housing is aluminum to maintain uniform temperatures around the focal plane. This imparts a new source of strain from the differing coefficients of thermal expansion. Measurement of these thermally induce shifts is not possible because of the extremely cold temperatures and the extreme accuracies required by ACIS on orbit. In essence, the measuring machine, tooling plate and reference surfaces all undergo distortions that are larger than the shifts being measured.

The thermal distortions were, therefore, computed and verified using computer models developed during the design, building and verification of ACIS. Obviously, the output of a computer model is not an ideal source for critical alignment data but in this instance it is the best data available.

When alignment was performed, the CCDs were being installed on the flight focal plane, so a flight spare focal plane was used. This resulted in an additional set of corrections to take into account the minor differences between the flight and spare focal plane. Both the flight focal plane and the spare focal plane were precision machined and characterized so few differences were expected between the two. These adjustments were folded into the algorithm used to determine shim thickness and are presented in column 4 of Table 1a.

The alignment process was performed in two steps, first shim thickness was adjusted; second, alignment pin holes were drilled in the shims. Manufacturing tolerance stack-up was removed by adjustments in shim thickness and position on the tooling plate relative to the tooling plate reference surfaces. Similarly, the adjustments necessitated by the thermal shifts were added to these shim adjustments. Angular rotations, particularly about the Y axis, cause small shifts in the focal point position in the Y-Z plane at the focal surface 14 inches above the tooling plate, and these deltas were also added to the shim adjustments. With the composite position known the shims were ground to the required thickness, thus completing step one. The detector housing was again mounted to the tooling plate with the newly ground shims in place. Using the same set of reference surfaces, the location of the focal plane was again established, thus verifying the position had been correctly compensated for during step one. The mounting bolts were loosened and the detector housing and shims were gently moved in the Y-Z plane until the bore sight of the telescope intersected the focal plane at the launch-lock position. The mounting bolts were torqued, as required, and the measurements repeated to be sure no motion had occurred during the torquing process. The shims were clamped to the tooling plate and the detector assembly was removed from the shims and tooling plate. The shims, mounted to the tooling plate, were precision drilled using the drill bushing in the tooling plate. Table 1a lists these data for each of the corrections included in the shim adjustments, machining tolerance data are not included as they are not part of the final alignment position.

A Zeiss Coordinate Measuring Machine (CMM) was used to take all data used during this alignment procedure. Positional data was accurate to 0.00008" over the entire measurement volume. Machining was performed on a Moore Jig Grinder. Tolerances of 0.0001" were maintained during all alignment machining operations.

2.0 Thermal Modeling

As described above, thermal shifts were estimated using a finite element model of the ACIS hardware. Temperatures obtained from detailed SINDA85 thermal math models were input in the Algor Finite Element Analysis (FEA) model which included the collimator, detector housing, thermal standoffs, focal plane paddle, and shims (Filename: CAMASY3N dated 6/4/96). Algor is a PC based Finite Element Analysis Tool. Output from the model included translational, as well as rotational shifts in position of the focal surface. As a verification of the calculated shim thicknesses, an additional FEA model was created using the specified shim thicknesses. Resulting thermal distortions put the focal plane at the correct location and thus verified that the shims were properly machined (Filename: CAMASY3O dated 6/5/96). The SINDA85 and the Algor models for this analysis will be kept in the ACIS software archives. Additional information about the Alignment analysis can also be found in verification report ACIS-110-A-24VR dated 3/29/1997.

3.0 Test Results

During the thickness grinding on the flight shims a sign error in the algorithm caused the theta-Y angle to be doubled. Even though an extra 0.005" in thickness had been provided to accommodate for such a mishap, this cushion proved to be inadequate, so the flight spare shims were used. When the sign error was detected the flight detector housing was located in the Zeiss CMM room with clean filtered air maintained at 40% RH. Once the sign error had been corrected the second measurements, made after shim thickness grinding, still had an 0.004" discrepancy in the X location. This 0.004" shift in the X location occurred between the first and second Zeiss measurements. After all other causes were eliminated the only possible remaining cause of the shift was the Torlon standoffs absorbing moisture and expanding.

Water absorption by Torlon and the attendant increase in volume is a known property of Torlon and was expected. During manufacturing and fit checking this property of water absorption and expansion by Torlon caused several precision surfaces to bind after atmospheric water was absorbed. Since all other candidate materials also exhibit this tendency, Torlon was chosen because of its strength and high toughness. To ameliorate the difficulties caused by this the standoffs were baked prior to alignment to remove absorbed water and restore the material to its dry dimensions. Since water absorbed by the Torlon would be desorbed during long term vacuum exposure, the shims were to be ground based on the original X measurements and the 0.004" growth would be discounted during subsequent measurements.

Torlon growth was to cause difficulty during the grinding of the second (flight spare) set of shims. When the new shims were first measured and adjustments computed, the new shim thicknesses included the 0.004" growth discussed above. Now, somewhat gun-shy from the first grinding attempt, and down to the last set of shims, a cushion of 0.030" was used instead of 0.005". This, it was felt, would allow for a second grind, no matter what unforeseen difficulty may have remained in the algorithms. Of course, the only error had been discovered during the first alignment attempt and so these precautions proved unnecessary

After the shims were thickness ground, the second step in the procedure was performed and the alignment holes were drilled. At this time 0.026" was removed from the shim thickness to bring the focal plane to the correct X location with dry standoffs at their on-orbit length. This requires some thought and explanation, however. When the second set of shims were measured, it was the focal plane that was measured. Therefore the 0.030" added to the proper X-axis location included the 0.004" growth in the standoffs. In order to compensate for the Torlon expansion the 0.004" was subtracted from the 0.030" margin and a total of 0.026" was removed from each shim. The final alignment values and adjustments are tabulated in Table 1a. The first column shows the combined movements of the focal plane from thermal contraction of the standoffs, collimator and shims at operational temperatures. The next column shows the change in size of the focal plane. Next, the measured differences between the flight focal plane and the spare focal plane are shown. Last, the shifts in Y and Z caused by angular changes are shown. Table 1b shows the final results of the alignment activity. Table 2 shows the alignment tolerances from the PTS Spec and the ISIM to SI ICD.

Table 1a. Alignment corrections for the ACIS detector housing

	Collimator, Detector Housing & Shim Offsets at -120 C	Cold Paddle Thermal Offsets at -120 C	Deltas between Flight and Test Cold Paddles	Derived Translations From angle Corrections	Units
X	0.00979	-0.00063	-0.00021	0.00000*	Inches
Y	-0.00005	0.00000	0.00023	0.00015	Inches
Z	-0.00324	0.00000	0.00028	0.00239	Inches
θ_X	-2.2	0.0	0.0	-	Arcsec
θ_Y	-36.1	0.0	0.0	-	Arcsec
θ_Z	2.2	0.0	0.0	-	Arcsec

* X corrections were not computed because they are too small to adjust for.

Table 1b. Final aligned values for the ACIS detector housing

	Shimmed Position at 20 C	Required Position at 20 C	Error	Units
X	-0.00880	-0.00895	-0.00015	Inches
Y	0.00016	-0.00033	0.00049	Inches
Z	0.00367	0.00057	0.00310	Inches
θ_X	23.4	2.2	21.2	Arcsec
θ_Y	18.9	36.1	-17.2	Arcsec
θ_Z	-12.3	-2.2	-10.1	Arcsec

Table 2. Alignment error budgets and actual performance.

	PTS Specification	ISIM to SI ICD	Measured Error	Units
X	±0.002	±0.003	0.00015	Inches
Y	±0.007	±0.009	0.00049	Inches
Z	±0.007	±0.009	0.00310	Inches
θ_X	±424	±600	21.2	Arcsec
θ_Y	±60	±83.2	-17.2	Arcsec
θ_Z	±60	±83.2	-10.1	Arcsec

Once the alignment had been performed it was decided that an X-location verification should be performed after MSFC-SPEC-1238 certification of the detector housing at Lockheed Martin had removed the absorbed water from the standoffs. This was performed at MIT after recipt of the detector housing. These results are tabulated in Table 3. The measurements made at MIT were performed with the mounting bolts snug but not torqued to required values. The measurements made on the Zeiss were with the bolts fully torqued or with the bolts loose. The torqued values are probably the most accurate with the discrepancy being generated by water absorption in the Torlon during shipping and disassembly at MIT.

Table 3. Results of post alignment X location measurement.

Cold Paddle Mount	Post Align Measurement at MIT	Predicted X Location Bolts loose	Predicted X Location Bolts torqued	Discrepancy Bolts loose	Discrepancy Bolts torqued
-Y, -Z	14.0097	14.0092	14.0085	0.0005	0.00118
+Y, +Z	14.0106	14.0099	14.0093	0.0007	0.00129
-Y, +Z	14.0102	14.0094	14.0086	0.0008	0.00163
+Y, +Z	14.0099	14.0092	14.0083	0.0007	0.00157
Average	14.0101	14.0095	14.0087	0.0007	0.00142

3.1 Discussion of Results

3.1.1 X-Axis

Thermal analysis indicated the focal plane would shift 0.00916" in the +X direction (toward the HRMA) on orbit, at temperature. The flight focal plane was 0.00021" thinner than the spare so the total compensated motion was 0.00895" in the -X direction (away from the HRMA). The alignment procedure resulted in a shift of 0.0088" in -X leaving an uncompensated error of 0.00015" in +X. Angular motion corrections for X were not performed because they were computed to be too small.

3.1.2 Y-Axis

Thermal analysis indicated that the focal plane would shift 0.00005" in the -Y direction. This is an insignificant amount. The difference between the two focal planes causes a shift of 0.00023 in +Y. At cold temperatures, the angular rotation of the collimator in the θz direction (θz is rotation about the Z-axis according to the right hand rule) causes a 0.00015" shift in the +Y direction. The final compensated Y position is -0.00033" along the Y-axis. The alignment procedure positioned the launch-lock position on the focal plane at 0.00016 for a total error of 0.00049" in the +Y direction.

3.1.3 Z-Axis

Thermal analysis showed a -0.00324" shift along the Z-axis. The difference between the two focal planes was 0.00028" in Z. The shift in Z caused by θy accounted for a shift of 0.00239". The compensated Z position is therefore 0.00057" in the +Z direction. The alignment procedure placed the launch-lock position on the focal plane at 0.00367" for a total error of 0.00310" along the Z-axis. This is the largest alignment error.

3.1.4 Theta-X

Theta X measurements were based on an edge surface on the focal plane itself. Thermal modeling predicted a shift in θx of 2.2 arcseconds. The accuracy of positioning the detector housing on the collimator yielded a final θx position of 23.4 seconds of arc, for a final positioning error of 21.2 arcseconds.

3.1.5 Theta-Y

Theta-Y measurements are based upon probing multiple points on the back of the focal plane using a CMM. The CMM then determines a best fit plane through these points giving tip and tilt from a predefined reference plane. Thermal analysis showed a rather large shift of 36 arcseconds in θy at -120 C. After compensation the focal plane was left with a θy of 18.9 seconds of arc for a net error of -17.2 arcseconds.

3.1.6 Theta-Z

Theta-Z was measured in exactly the same way as θy. The required tilt from thermal analysis was -12.3 arcseconds. After compensation the focal plane had a θz of -2.2 seconds of arc for a net error of -10.1 arcseconds.