5.3.2.2 WAC FM OPTO/MECHANICAL ALIGNMENT VERIFICATION

As reported in Reference 5.3.2.2-1

Reference 5.3.2.2-1 - DFM 506-EM-96-612, "WAC F/M Opto/Mechanical Alignment Verification", E. Motts, July 27, 1996

5.3.2.2.1 SUMMARY

A measurement of the WAC F/M opto/mechanical alignment was completed on May 16, 1996. Measured angles are reported and compared to the requirements of Document CAS-3-170, *Cassini Orbiter Functional Requirements Book, Accuracy Requirements and System Capabilities,* Section 4.6.1. The control requirement for angles from the boresight to the WAC mounting surface was met. The control requirement for boresight to alignment mirror angles was exceeded; a recommendation is made to waive the requirement if the knowledge requirement is met. The knowledge requirement was, in fact, met for both boresight to mounting surface and boresight to alignment mirror angles. There is no control requirement for CCD twist. However, CCD twist was measured and its uncertainty estimated; these results are reported to provide a complete characterization of the NAC.

5.3.2.2.2 DESCRIPTION OF TEST

The alignment measurement was performed according to DFM #506-EM-95-509, *ISS Wide Angle Camera- Opto/Mechanical Alignment Verification,* Preliminary Version, dated April 6, 1995. The WAC F/M was mounted on a tooling plate that simulated the Remote Sensing Pallet interface for purposes of measurement. Measurements of the WAC F/M were accomplished in building 169 room 109A and the tooling plate was characterized in building 11 room 121.

Determination of the direction of the WAC boresight was done by measuring the horizontal and vertical angles to four features on the CCD, using a theodolite. The four features observed lay outside the active area of the CCD and were chosen because the corners of the active area were not visible due to a coating. Horizontal angles were referenced to a porroprism and vertical angles were referenced to gravity.

After completion of the WAC E/M measurements in 1995, a CCD bearing identical markings was measured by John Bousman to determine the locations of the observed features. It was found that the features were symmetrical about the two axes of the CCD.

Therefore, it was possible to calculate the horizontal angle to the boresight as the mean of the horizontal angles to each of the four features. The vertical angle to the boresight was calculated as the mean of the vertical angles to each of the four features.

Angles in autocollimation to the WAC alignment mirror and to an optical cube on the tooling plate were measured, again in reference to the porroprism and to gravity.

To calculate the angles between the boresight, the alignment mirror and the camera mounting surfaces (datum -A- and -B-), the angles between the optical cube and the tooling plate were required. The angles were measured using an autocollimator on a granite surface plate, in reference to a plane-parallel mirror. The datum feature of the tooling plate was set parallel to the surface plate by shimming. The reference mirror was set perpendicular to the surface plate by rotating the mirror and observing its vertical angle with the autocollimator. The vertical angle to the cube face was then determined in comparison to the reference mirror. Data were recorded in E. Motts' Laboratory Notebook #5.

5.3.2.2.3 DATA REDUCTION

Calculation of the angles between the boresight, the alignment mirror, and the camera mounting surfaces was performed in spreadsheet "WACFMOM2.XLS" by subtracting the optical cube-to-tooling plate angles. In addition, the twist of the CCD about the optical axis was calculated from the vertical angles to two of the four features on the CCD and the actual distance between the features as measured by Bousman. The calculation was done twice, using features designated as CCD A and B, then with CCD C and D. The value reported is the mean of the two measured values. The equation used

$$a = (V_1 - V_2) * fl / L_{CCD}$$

was:

Where α = The twist angle
Vn = The vertical angle to a CCD feature
fl = The measured focal length of the WAC
L = The measured distance between the two features

The output of spreadsheet "WACFMOM2.XLS" is attached and includes each of the measured and calculated values (Table 5.3.2.2-1). Note that all angles are reported using the sign convention of the theodolite, not the traditional “right-hand rule.”

Estimating of the measurement uncertainties was done in the same spreadsheet. The size of each error source was estimated and identified as random (R) or systematic (S). The propagation of errors was determined by calculating the Root Sum Squared (RSS) of all random errors, then summing the systematic errors. Uncertainty of the boresight to alignment mirror and camera mounting surface is estimated on Table 5.3.2.2-2.

Uncertainty in the CCD twist was estimated by perturbing each of the variables in the equation above to determine the contribution of that error source. Again, random errors are RSS'ed and systematic errors are summed to find the total uncertainty. The uncertainty associated with the CCD twist is reported on Table 5.3.2.2-3.

Figure 5.3.2.2-1and Figure 5.3.2.2-2 are graphical representations of the reported angles. These are provided as an aid to interpretation of the measurement results.

5.3.2.2.4 CONCLUSIONS

The following requirements of CAS-3-170, *Cassini Orbiter Functional Requirements Book, Accuracy Requirements and System Capabilities, Section 4.6.1,* are addressed:

A. "Alignment control of the ISS WAC boresight relative to its reference mirror (per axis) shall be within 1.0 mrad, (3 sigma)." The actual measurements are 2.0 milliradians (mrad) in the horizontal plane and 24.1 mrad in the vertical plane. This requirement has <u>not</u> been met.

B. "Alignment knowledge of the ISS WAC B/S relative to its reference mirror (per axis) shall be within 0.05 mrad (3 sigma)." Knowledge (uncertainty) is estimated to be ±0.04 mrad, (three sigma). This requirement has been met.

C. "WAC boresight alignment control relative to the WAC mounting surface shall be better than 1.0 mrad per axis." The actual measurements are 0.38 mrad in the horizontal plane and 0.65 mrad in the vertical plane. The requirement has been met.

D. "WAC boresight alignment knowledge relative to the WAC mounting surface shall be less than 0.1 mrad per axis." Knowledge (uncertainty) is estimated to be ±0.05 mrad, (three sigma). This requirement has been met.

5.3.2.2.5 RECOMMENDATIONS

Recommendations pertain to the requirements and conclusions above:

A. Waive the requirement, providing the knowledge requirement is met (it was). The measured angles are not sufficiently large to introduce significant error into the alignment of the WAC. The errors introduced are inversely proportional to the cosine of the deviation and the error is therefore very small for small deviations.

B. No recommendation-- the requirement has been met.

C. No recommendation-- the requirement has been met.

D. No recommendation-- the requirement has been met.

Cube Z face to Boresight
WAC Mounting Surface to Cube
ISS Wide Angle Camera-- FLIGHT MODEL
Opto/Mechanical Alignment Verification Jobfile: WACFM2.job DATE: May 16, 1996 Second data set-- tooling plate moved Note: Angles are expressed in theodolite angle convention. Angles are in decimal degrees unless otherwise noted

	Horizontal Angle	Vertical Angle
	Angle in the X-Z plane:	In the Y-Z plane:
	0.00267	0.04819
	0.01908	-0.01106
WAC Mounting Surface to Boresight	**0.02175**	0.03713
In Milliradians:	0.38	0.65
Requirement:	< 1.0 mrad	<1.0 mrad
Cube Z face to Mirror	0.11756	1.43160
WAC Mounting Surface to Cube	0.02372	-0.01106
WAC Mounting Surface to Mirror	0.14128	1.42054
(milliradians}	2.47	24.79
Boresight to Mirror	0.11458	1.38341
In Milliradians:	2.00	24.14
Requirement:	< 1.0 mrad	< 1.0 mrad

Twist CCD A to CCD B	
Distance A to B (mm)	9.734
Nominal Focal Length (mm)	200.22
Alpha A to B	-0.03735
Fixture roll	0.03383
Cube mounting error	-0.00858
Twist A-B to datum -A	-0.06261
Twist CCD C to CCD D	
Distance C to D (mm)	9.734
Nominal Focal Length (mm)	200.22
Alpha C to D	0.03489
Fixture roll	0.03383
Cube mounting error	-0.00858
Twist C-D to datum -A	0.00963
Twist-WAC Mounting Surface to CCD	-0.02649
In Milliradians:	-0.46
Requirement:	< 17.5 mrad

WACFMOM2.XLS

Table 5.3.2.2-1 - Measured and Calculated Alignment Values

ISS Wide Angle Camera-- Flight Model
Opto/Mechanical Alignment Verification
Uncertainty Estimate-- Horizontal and Vertical Angles

Error Source	Decimal degrees	Contribution Milliradians
Cube to WAC Mounting Surface:		
Determination of datum: arctan (.0001/16.0) (R)	0.00036	0.006
Cube sighting: 0.3 arcsec (R)	0.00008	0.001
Reference Mirror determination: 0.2 arcsec (R)	0.00006	0.001
Autcollimator calibration errors: 0.5 arcsec (S)	0.00014	0.002
RSS of random errors	0.00037	0.006
RSS + systematic errors	0.00051	0.009
Boresight Angle Determination:		
Theodolite pointing to CCD: 2.0 arcsec (R)	0.00056	0.010
Theodolite pointing to porroprism 0.2 arcsec (R)	0.00005	0.001
Theodolite calibration errors: 0.2 arcsec (S)	0.00006	0.001
Porroprism or leveling error 0.2 arcsec (S)	0.00006	0.001
RSS of random errors	0.00056	0.010
RSS + systematic errors	0.00068	0.012
Cube Z face or Alignment Mirror Angles:		
Theodolite pointing to mirror : 0.2 arcsec (R)	0.00006	0.001
Theodolite pointing to porroprism 0.1 arcsec (R)	0.00004	0.001
Theodolite calibration errors: 0.2 arcsec (S)	0.00006	0.001
Porroprism or leveling error 0.2 arcsec (S)	0.00005	0.001
RSS of random errors	0.00007	0.001
RSS + systematic errors	0.00018	0.003
Propagation of Errors:		
Boresight to WAC Mounting Surface:		
Boresight random errors	0.00056	0.010
Boresight systematic errors	0.00012	0.002
Camera CQordinate System random errors	0.00037	0.006
Camera Coordinate System systematic errors	0.00014	0.002
RSS of random errors	0.00067	0.012
RSS +systematic Errors	0.00093	0.016
Three Sigma Uncertainty (Knowledge}	**0.00280**	**0.049**
Requirement:	< 0.00286	0.1
Boresight to Alignment Mirror:		
Boresight random errors	0.00056	0.010
Boresight systematic errors	0.00012	0.002
Alignment Mirror random errors	0.00007	0.001
Alignment Mirror systematic errors	0.00011	0.002
RSS of random errors	0.00057	0.010
RSS +systematic errors	0.00080	0.014
Three Sigma **Uncertainty** (Knowledge)=	**0.00239**	**0.042**
Requirement	< 0.0029	< 0.05

WACFMOM2.XLS

Table 5.3.2.2-2 - Uncertainty Estimate - Horizontal and Vertical Axes

ISS Wide Angie Camera-- Flight Model
Opto/Mechanical Alignment Verification
Uncertainty Estimate-- CCD Twist

Error Source	degrees	Contribution Milliradians
Angle Alpha		
Error in vertical angles-- 1.0 arcsec*FI/L (R)	0.00576	0.101
Error in distance L-- .05 mm (R)	0.00019	0.003
Error in focal length--0.25 mm (R)	0.00005	0.001
RSS of random errors	0.00576	0.101
RSS + systematic errors		0.101
Cube X face:		
Theodoiite pointing-- 0.3 arcsec (R)	0.00008	0.001
Theodolite calibration errors: 0.2 arcsec (S)	0.00006	0.001
RSS of random errors	0.00008	0.001
RSS + systematic errors	0.00014	0.002
Cube X face to WAC Mounting Surface:		
Determination of datum: arctan (.0001/16.0) (R)	0.00036	0.006
Cube sighting: 0.3 arcsec (R)	0.00008	0.001
Reference Mirror determination: 0.2 arcsec (R)	0.00006	0.001
Autcollimator calibration errors: 0.5 arcsec (S)	0.00014	0.002
RSS of random errors	0.00037	0.006
RSS + systematic errors	0.00051	0.009
Propagation of Errors:		
Angle Alpha random errors	0.00576	0.101
Angle Alpha systematic errors	0.00000	0.000
Cube X face anale random errors	0.00008	0.001
Cube X face angle systematic errors	0.00006	0.001
Cube X to Camera Coordinate System Random Errors	0.00037	0.006
Cube X to Camera Coordinate System Systematic Errors	0.00014	0.002
RSS of random errors	0.00578	0.101
RSS + systematic errors	0.00598	0.104
Three Sigma Uncertainty {Knowledge) =	**0.01793**	**0.31**
Requirement :	< 0.00286	< 0.05

WACFMOM2.XLS

Table 5.3.2.2-3 - Uncertainty Estimate - CCD Twist

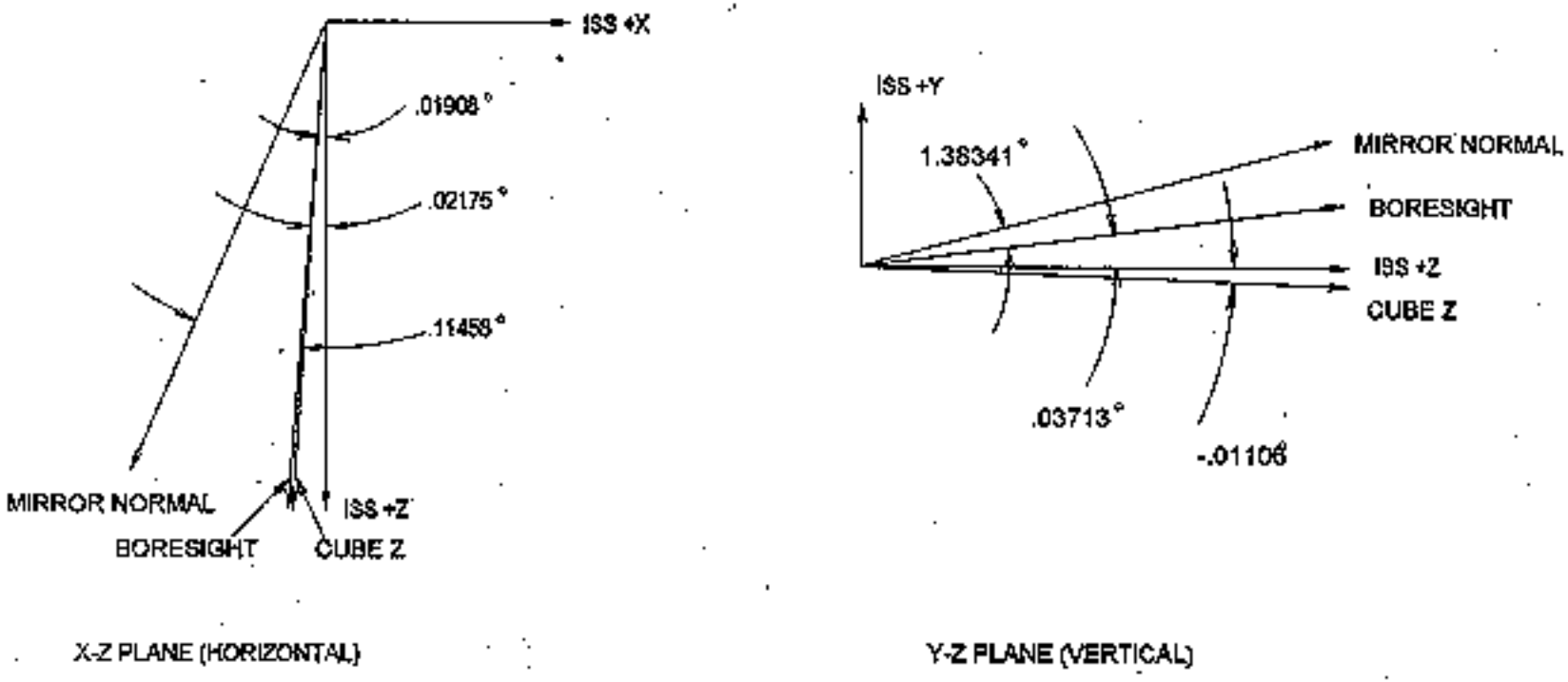

Figure 5.3.2.2-1 - Angular Offset

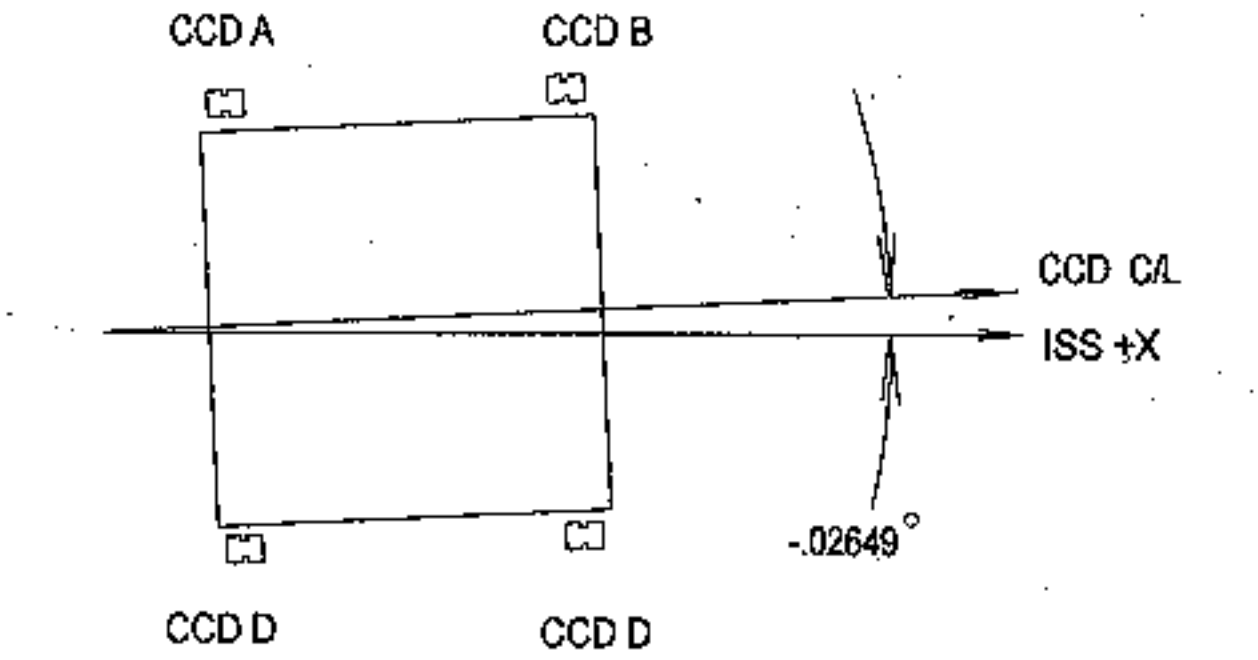

Figure 5.3.2.2-2 - CCD Twist (as Viewed from Object Space)