## 5.3.2 OPTICAL / MECHANICAL ALIGNMENT

### 5.3.2.1 NAC FM OPTO/MECHANICAL ALIGNMMENT VERIFICATION

*As reported in Reference 5.3.2.1-1*

**Reference 5.3.2.1-1 - DFM 506-EM-96-611, "NAC F/M Opto/Mechanical Alignment Verification", E. Motts, July 27, 1996**

#### 5.3.2.1.1 SUMMARY

A measurement of the Narrow Angle Camera Flight Model (NAC F/M) opto/mechanical alignment was completed on July 22, 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 NAC 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. The control requirement for CCD twist was met.

#### 5.3.2.1.2 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 procedure for measuring the NAC is identical to that used to measure the WAC. The NAC F/M was mounted on a tooling plate that simulated the Remote Sensing Pallet interface for purposes of measurement. Measurements of the NAC 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 NAC 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 of difficulty in observing the corners of the active area. The corners of the active area were measured, but the data were not used in calculating the results reported here. 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 NAC 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.

### 5.3.2.1.3 DATA REDUCTION

Calculation of the angles between the boresight, the alignment mirror, and the camera mounting surfaces was done in spreadsheet "NACFMOM.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

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

is the mean of the two measured values. The equation used was:

Where $\alpha$ = The twist angle
Vn = The vertical angle to a CCD feature
fl = The measured focal length of the NAC
L = The measured distance between the two features

The output of spreadsheet "NACFMOM.XLS" is attached and includes each of the measured and calculated values (Table 5.3.2.1-1). 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 5.3.2.1-2.

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 5.3.2.1-3.

Figure 5.3.2.1-1 and Figure 5.3.2.1-2 are graphical representations of the reported angles. These are provided as an aid to interpretation of the measurement results.

### 5.3.2.1.4 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 Narrow Angle Camera (NAC) boresight relative to its mounting surface (per axis) shall be within 0.3 mrad.” The actual angles are -0.17 mrad in the horizontal plane and 0.18 mrad in the vertical plane. This requirement has been met.

B. “Alignment knowledge of the ISS Narrow Angle Camera (NAC) boresight relative to its mounting surface (per axis) shall be within 0.05 mrad.” Knowledge (uncertainty) is estimated to be ±0.04 mrad, (three sigma). This requirement has been met.

C. “Alignment control of the ISS narrow Angle Camera (NAC) boresight relative to its reference mirror (per axis) shall be less than 0.3 mrad.” The actual angles are 5.61 mrad in the horizontal plane and 9.91 mrad in the vertical plane. This requirement has <u>not</u> been met.

D. "Alignment knowledge of ISS NAC B/S relative to its reference mirror (per axis) shall be less than 0.05 mrad.” The estimated knowledge (uncertainty) is ±0.03 mrad, (three sigma). This requirement has been met.

E. "NAC twist alignment control (about boresight) relative to the NAC mounting surface shall be less than 17.5 mrad per axis (3 sigma)." The measured value of the twist is -0.13 mrad relative to datum -A-, with an estimated uncertainty of ±3.0 mrad, three sigma. This requirement has been met.

### 5.3.2.1.5 RECOMMENDATIONS

Recommendations pertain to the requirements and conclusions above:

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

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

C. 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 NAC. The errors introduced are inversely proportional to the cosine of the deviation and the error is therefore very small for small deviations.

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

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

NACFMOM .XLS

ISS Narrow Angle Camera-- FLIGHT MODEL OptolMechanical Alignment Verification
Jobfile: NACFM4.job
DATE: July 22, 1996 4TH
DATA SET: AFTER MACHINING OF SHIM TO CORRECT ANGLE IN Y-Z PLANE
Note: Angles are expressed in theodolite angle convention.
Angles are in decimal decrees unless otherwise noted.

| | Horizontal Angle<br>Angle in the X-Z plane: | Vertical Angle<br>Angle in the Y-Z plane: |
|---|---|---|
| Cube Z face to Boresight | | |
| NAC Mounting Surface to Boresight | -0.00963 | 0.01008 |
| | -0.17 | 0.18 |
| | <0.3 mrad | <0.3 mrad |
| Cube Z face to Mirror | 0.28811 | 0.58881 |
| NAC Mounting Surface to Cube | 0.02372 | -0.01106 |
| NAC Mounting Surface to Mirror | 0.31183 | 0.57775 |
| (milliradians) | 5.44 | 10.08 |
| **Boresight to Mirror** | 0.32122 | 0.56767 |
| In Milliradians: | 5.61 | 9.91 |
| Requirement: | <0.3 mrad | <0.3 mrad |

| | |
|---|---|
| Twist CCD A to CCD B | |
| Distance A to B (mm) | 9.734 |
| Nominal Focal Length (mm) | 2000.0 |
| Alpha A to B | 0.01192 |
| Fixture roll | -0.01300 |
| Cube mounting error | -0.00858 |
| Twist A-B to datum -A | 0.03350 |
| Twist CCD C to CCD D | |
| Distance C to D (mm) | 9.734 |
| Nominal Focal Length (mm) | 2000.0 |
| Alpha C to D | -0.06986 |
| Fixture roll | -0.01300 |
| Cube mounting error | -0.00858 |
| Twist C-D to datum -A | -0.04828 |
| **Twist-NAC Mounting Surface to CCD** | -0.00739 |
| In Milliradians: | -0.13 |
| In Milliradians: | <17.5 mrad |

NACFMOM.XLS

**Table 5.3.2.1-1 - Measured and Calculated Alignment Values**

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

| Error Source | Contribution Decimal degrees | Contribution Milliradians |
|---|---|---|
| **Cube to NAC 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 |
| Aliterollim::ltor rnlihr:ltir~~n orrrlrc n E nrr<Pr 1Ru | 0.00014 | 0.002 |
| RSS of random errors | 0.00037 | 0.006 |
| RSS + systematic errors | 0.000510 | 0.009 |
| | | |
| **Boresight Angle Determination:** | | |
| Theodolite pointing to CCD: 1.0 arcsec (R) | 0.00026 | 0.005 |
| 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 | 0.00017 | 0.003 |
| RSS + systematic errors | 0.00029 | 0.005 |
| | | |
| **Cube Z face or Alignment Mirror Angles:** | | |
| Theodolite pointing to Mirror: 0.4 arcsec (R) | 0.00012 | 0.002 |
| Theodolite pointing to porroprism 0.4 arcsec (R) | 0.00012 | 0.002 |
| 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 | 0.00017 | 0.003 |
| RSS + systematic errors | 0.00029 | 0.005 |
| | | |
| **Propagation of Errors:** | | |
| **Boresight to NAC Mounting Surface:** | | |
| Boresight random errors | 0.00026 | 0.005 |
| Boresight systematic errors | 0.00012 | 0.002 |
| Camera Coordinate System random errors | 0.00037 | 0.006 |
| Camera Coordinate System systematic errors | 0.00014 | 0.002 |
| RSS of random errors | 0.00046 | 0.008 |
| RSS + systematic errors | 0.00072 | 0.013 |
| | | |
| **Three Sigma Uncertainty (Knowledge) =** | **0.00215** | **0.04** |
| Requirement : | **<0.00286** | <0.05 |
| | | |
| **Boresight to Alignment Mirror:** | | |
| Boresight random errors | 0.00026 | 0.005 |
| Boresight systematic errors | 0.00012 | 0.002 |
| Alignment Mirror random errors | 0.00017 | 0.003 |
| Alignment Mirror systematic errors | 0.00012 | 0.002 |
| RSS of random errors | 0.00031 | 0.005 |
| RSS + svstematic errors | 0.00055 | 0.01 |
| | | |
| **Three Sigma Uncertainty (Knowledge) =** | **0.00166** | 0.03 |
| Requirement : | 0.0029 | <0.05 |

NACFMOM.XLS

**Table 5.3.2.1-2 - Uncertainty Estimate - Horizontal and Vertical Axes**

ISS Narrow Angle Camera-- Flight Model
Opto/Mechanical Alignment Verification
Uncertainty Estimate-- CCD Twist

| Error Source | Decimal degrees | Contribution Milliradians |
|---|---|---|
| **Angle Alpha:** | | |
| Error in vertical angles-- 1.0 arcsec*FI/L (R) | 0.05753 | 1.004 |
| Error in distance L-- .05 mm (R) | 0.00006 | 0.001 |
| Error in focal length--4.4 mm (R) | 0.00003 | 0.000 |
| RSS of random errors | 0.05753 | 1.004 |
| RSS + systematic errors | 0.05753 | 1.004 |
| | | |
| Cube X face: | | |
| Theodolite pointing-- 0.4 arcsec (R) | **0.00012** | **0.002** |
| Theodolite calibration errors: 0.2 arcsec (S) | **0.00006** | **0.001** |
| RSS of random errors | **0.00012** | **0.002** |
| RSS + systematic errors | **0.00018** | **0.003** |
| | | |
| **Cube X face to NAC 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** |
| Autcoilimator 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 | **0.05753** | **1.004** |
| Angle Alpha systematic errors | **0.00000** | **0.000** |
| Cube X face angle random errors | **0.00012** | **0.002** |
| 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 | **0.05753** | 1.004 |
| RSS + systematic errors | **0.05773** | 1.008 |
| | | |
| Three Sigma Uncertainty {Knowledge) = | 0.17320 | 3.023 |

NACFMOM.XLS

## Table 5.3.2.1-3 - Uncertainty Estimate - CCD Twist

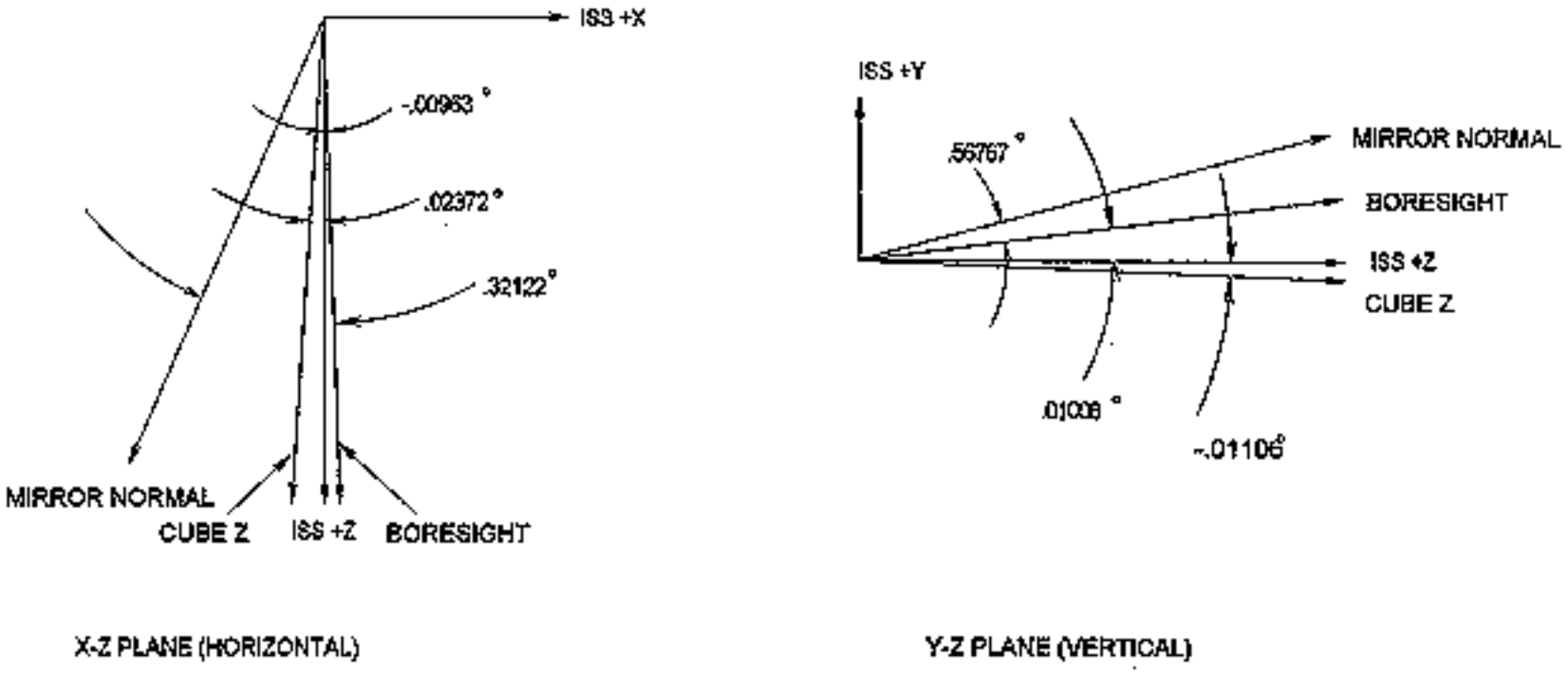


**Figure 5.3.2.1-1 - Angular Offset**

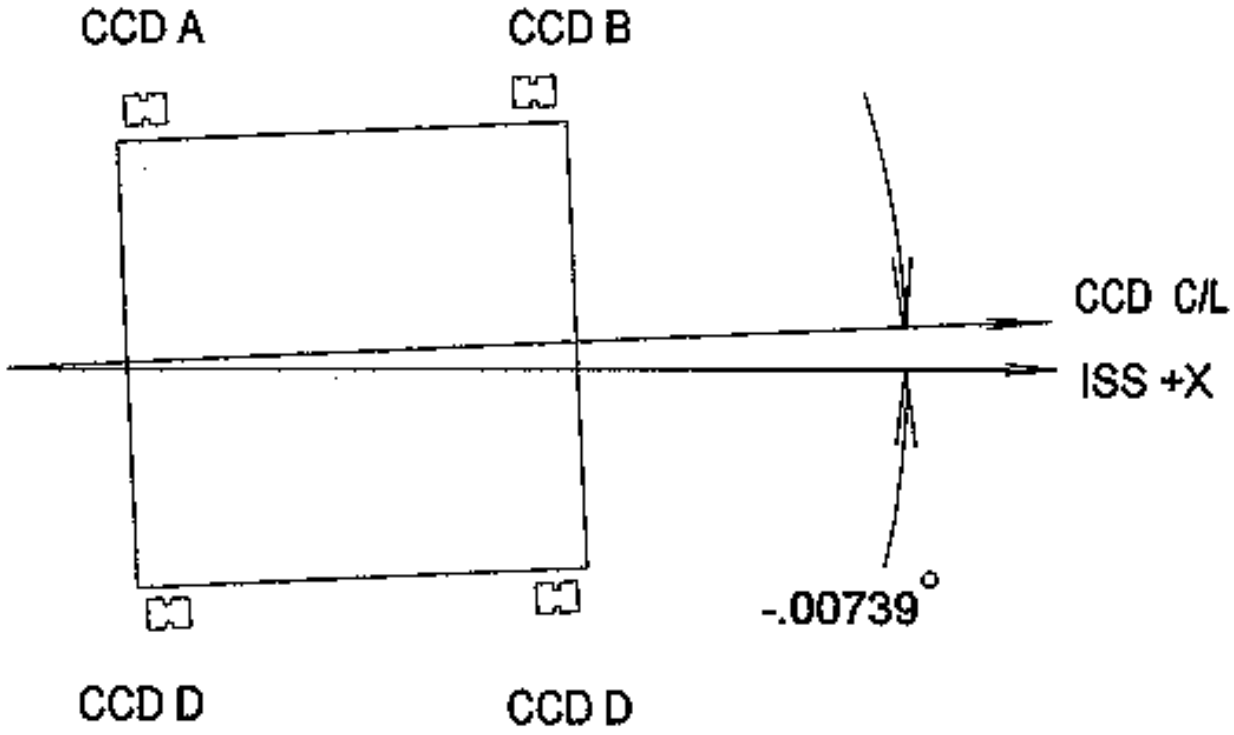


**Figure 5.3.2.1-2 - CCD Twist (as Viewed from Object Space)**