4.1.3.2 WAC FM FOCAL LENGTH AND DISTORTION MEASUREMENT RESULTS

As reported in Reference 4.1.3.2-1

Reference 4.1.3.2-1 - IOM DQA # 95-1047, "WAC F/M Focal Length And Distortion Measurement Results", Edward Motts, October 26, 1995

4.1.3.2.1 Scope

This report describes a measurement of the Cassini Wide Angle Camera Flight Model (WAC F/M). The objective of the measurement was to determine focal length and field distortion of the camera optics. The accuracy requirement for the focal length is defined in Cassini document 699-CAS-5-2036-CAL, *Imaging Science Subsystem (ISS) Instrument Calibration Requirements Document, Component Level Calibrations* as ±0.5 mm. No requirement is established for field distortion at the component level. Measurements were performed in accordance with ISS ELM-506-001-6.10.3.0, Preliminary Version dated August 14, 1995.

4.1.3.2.2 Description of Test Method

Measurements of the angles between the NAC/WAC tooling plate optical cube and the WAC grid target were performed using electronic optical theodolites. The theodolites measured angles in a horizontal plane in reference to a porroprism. Angles in a vertical plane were measured with respect to local gravity. Theodolite angles were recorded using a portable computer running the Leica ManCAT software. Refer to Figure 4.1.3.2-1 for the instrument layout.

Determinations of the tooling plate optical cube -X and +Z face normals were performed by autocollimation to those faces. Determination of the grid target locations was performed by superimposing the theodolite telescope reticle over the intersection. Refer to Figure 4.1.3.2-2 for grid intersection locations.

Database file “WACFL1.dbf” containing all measured angles was exported to Excel spreadsheet “ISSDIST.xls” sheet 2 for data reduction.

4.1.3.2.3 Data Reduction

Database files were imported into the Excel spreadsheet “ISSDIST.xls” as described above. Refer to Table 4.1.3.2-1 for raw data.

Angle φ (the angle in the plane containing a given grid intersection and the center grid intersection) was calculated as the RSS of the two component angles:

$$\mathrm{j} = \sqrt{\left(\Delta Hz^2 + \Delta V^2\right)}$$

Table 4.1.3.2-2 contains calculated values of angle φ for each grid intersection. Radial distances “h’ ” to each grid intersection were calculated from drawing dimensions and are also contained in Table 4.1.3.2-2.

The effective focal length (EFL) was calculated using h’ and φ for each grid intersection:

$$EFL = \frac{h'}{\tan \mathrm{j}}$$

Finally, the percentage distortion to a grid target intersection is calculated as the percent deviation from the minimum focal length:

$$\%Distortion = \frac{EFL_n - EFL_{\min}}{EFL_{\min}} * 100\%$$

The twist, or rotation about Z, of the grid target is determined as follows. The twist of the grid target with respect to local gravity is calculated by the following equation:

$$Twist = \arctan \frac{Hz_2 - Hz_1}{V_2 - V_1}$$

Where: Hz_n = the horizontal angle to point n of the target
V_n = the vertical angle to point n of the target.

The rotation with respect to gravity of the optical cube -X face normal is then subtracted from the twist, as shown in Table 4.1.3.2-3. The difference is the rotation of the grid target with respect to the cube -X face normal. This information will be used to map the field distortion to the CCD after optomechanical characterization of the WAC F/M.

4.1.3.2.4 Uncertainty Estimate

The calculated measurement uncertainty in the measured focal length is ±0.251 mm (three σ). Estimation of the uncertainty (error) in the reported angles was accomplished in spreadsheet "ISSDIST.xls" sheet 2.

Random error was estimated by calculating the standard deviation of the theodolite observations. The equation for EFL was then perturbed by the calculated standard deviation to determine the effect on EFL. Then, the EFL equation was perturbed by the stated uncertainty of the grid target, ±25 μm. The two random error contributions were then combined by the Root Sum Square (RSS) method. Finally, the RSS was multiplied times three to give a ± three σ uncertainty estimate. Refer to Table 4.1.3.2-4 for calculation of the measurement uncertainty.

Please note that for simplicity the estimation of uncertainty was performed for one grid intersection only, at point "A1." The actual error would probably be greater for a point closer to the center of the target, and less for a point further away. The estimate is still a useful approximation of the measurement accuracy, however.

4.1.3.2.5 Test Results

The calculated focal lengths are shown in Table 4.1.3.2-2, along with the percent distortion. Figure 4.1.3.2-3 graphically represents the measured values. The best fit curve of Figure 4.1.3.2-3 crosses the vertical axis at approximately 200.22 mm, a value close to the expected paraxial focal length of 200 mm.

The maximum focal length measured was at the ends of the grid targets diagonals, at the maximum radial distance. The largest value was 201.1 mm, which differs from the minimum by 0.45%.

The estimated measurement uncertainty of ±0.251 mm (three σ) meets the Component Level Calibrations requirement of ±0.5 mm accuracy.

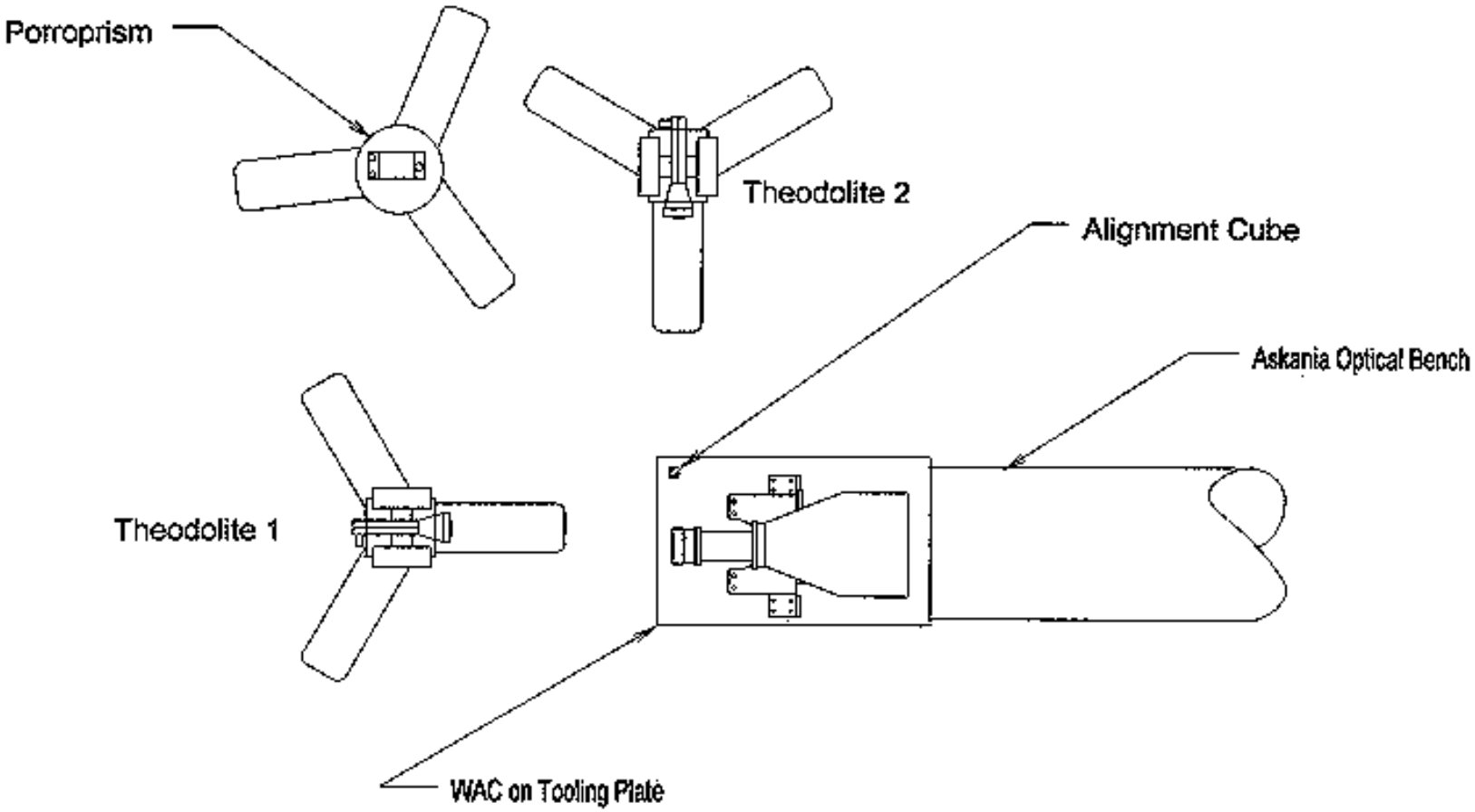
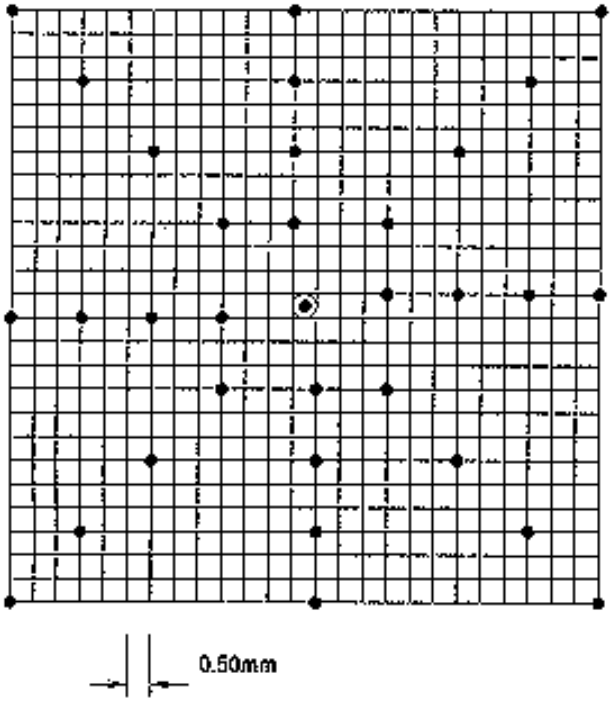
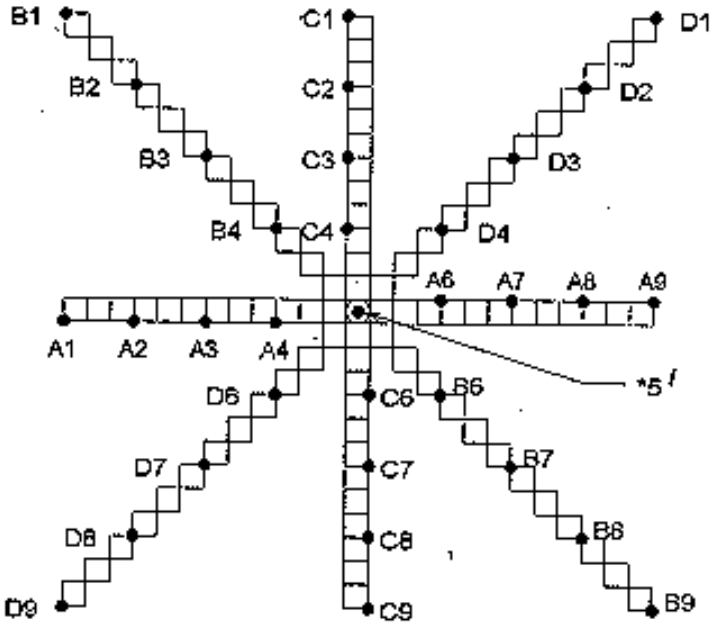


Figure 4.1.3.2-1 - Instrument Layout



GRID TARGET
WITH INTERSECTION POINTS



IDENTIFICATION OF
GRID INTERSECTION POINTS

Figure 4.1.3.2-2 - Grid Target and Intersection Point Identification

A1	197.59811	90.07299
A2	198.02491	90.07284
A3	198.45308	90.07268
A4	198.88201	90.07278
A5	199.38233	90.00086
A6	l99.88328	89.92913
A7	200.31204	89.92889
A8	200.74022	89.92870
A9	201.16683	89.92847
B1	197.60112	88.22235
B2	198.02600	88.64600
B3	198.45315	89.07289
B4	198.88155	89.50078
B5	199.38241	90.00109
B6	199.88369	90.50121
B7	200.31233	90.92935
B8	200.73980	91.35561
B9	201.16438	91.77912
C1	199.31016	88.21701
C2	199.31039	88.64382
C3	199.31057	89.07177
C4	199.31063	89.50054
C5	199.38236	90.00105
C6	199.45414	90.50167
C7	199.45455	90.93030
C8	199.45487	91.35810
C9	199.45505	91.78523
D1	201.16209	88.22046
D2	200.73825	88.64442
D3	200.31099	89.07180
D4	199.88305	89.50015
D5	199.38244	90.00100
D6	198.88217	90.50195
D7	198.45416	90.93013
D8	198.02736	91.35687
D9	197.60280	91.78132
PORROB1	109.16174	101.18848
PORROC1	0.99998	91.42705
CUBEX1	257.33065	89.99270
CUBEZ1	91.22379	89.99795

Table 4.1.3.2-1 - Raw Data : WAC Flight Focal length and Field Distortion Measurements

Grid Point	h' (mm)	phi (radians)	EFL (mm)	% Distortion
A1	-6.25	0.03117	200.6	0.25
A2	-4.76	0.02372	200.5	0.15
A3	-3.26	0.01627	200.4	0.11
A4	-1.77	0.00882	200.4	0.12
A6	1.77	0.00883	200.1	0.00
A7	3.26	0.01627	200.3	0.06
A8	4.76	0.02373	200.4	0.12
A9	6.25	0.03117	200.6	0.23
B1	-8.84	0.04394	201.0	0.45
B2	-6.72	0.03346	200.7	0.26
B3	-4.60	0.02292	200.5	0.16
B4	-2.47	0.01236	200.3	0.07
B6	2.47	0.01236	200.2	0.05
B7	4.60	0.02293	200.4	0.12
B8	6.72	0.03347	200.6	0.25
B9	8.84	0.04394	201.0	0.45
C1	-6.25	0.03116	200.7	0.26
C2	-4.76	0.02372	200.5	0.17
C3	-3.26	0.01627	200.4	0.11
C4	-1.77	0.00882	200.3	0.09
C6	1.77	0.00883	200.3	0.06
C7	3.26	0.01627	200.4	0.11
C8	4.76	0.02372	200.5	0.18
C9	6.25	0.03117	200.6	0.25
D1	-8.84	0.04394	201.0	0.45
D2	-6.72	0.03347	200.6	0.23
D3	-4.60	0.02293	200.4	0.15
D4	-2.47	0.01236	200.2	0.05
D6	2.47	0.01236	200.3	0.07
D7	4.60	0.02292	200.5	0.16
D8	6.72	0.03346	200.7	0.28
D9	8.84	0.04393	201.1	0.45

Table 4.1.3.2-2 - WAC Flight : Calculation of Focal Length and Field Distortion

ROTATION ABOUT Z	
	arctan (Hz2-Hz1)/V2-V1) =
Gridline B	45.0521614
Gridline C	-44.987302
Minus rotation of Cube	89.99270
Gridline B	-44.94054
Gridline C	-134.98000

Table 4.1.3.2-3 - WAC Flight : Calculation of Twist about Optical Axis

UNCERTAINTY ESTIMATE		
The effect on EFL of perturbing	BY	EFFECT
Horizontal and Vertical Angles	0.0002 °	0.023 mm
Distance h′	25 micrometer	0.1 mm
RSS of above		0.084
RSS x 3		0.251

Table 4.1.3.2-4 - WAC Flight : Estimate of Uncertainty in Measured EFL

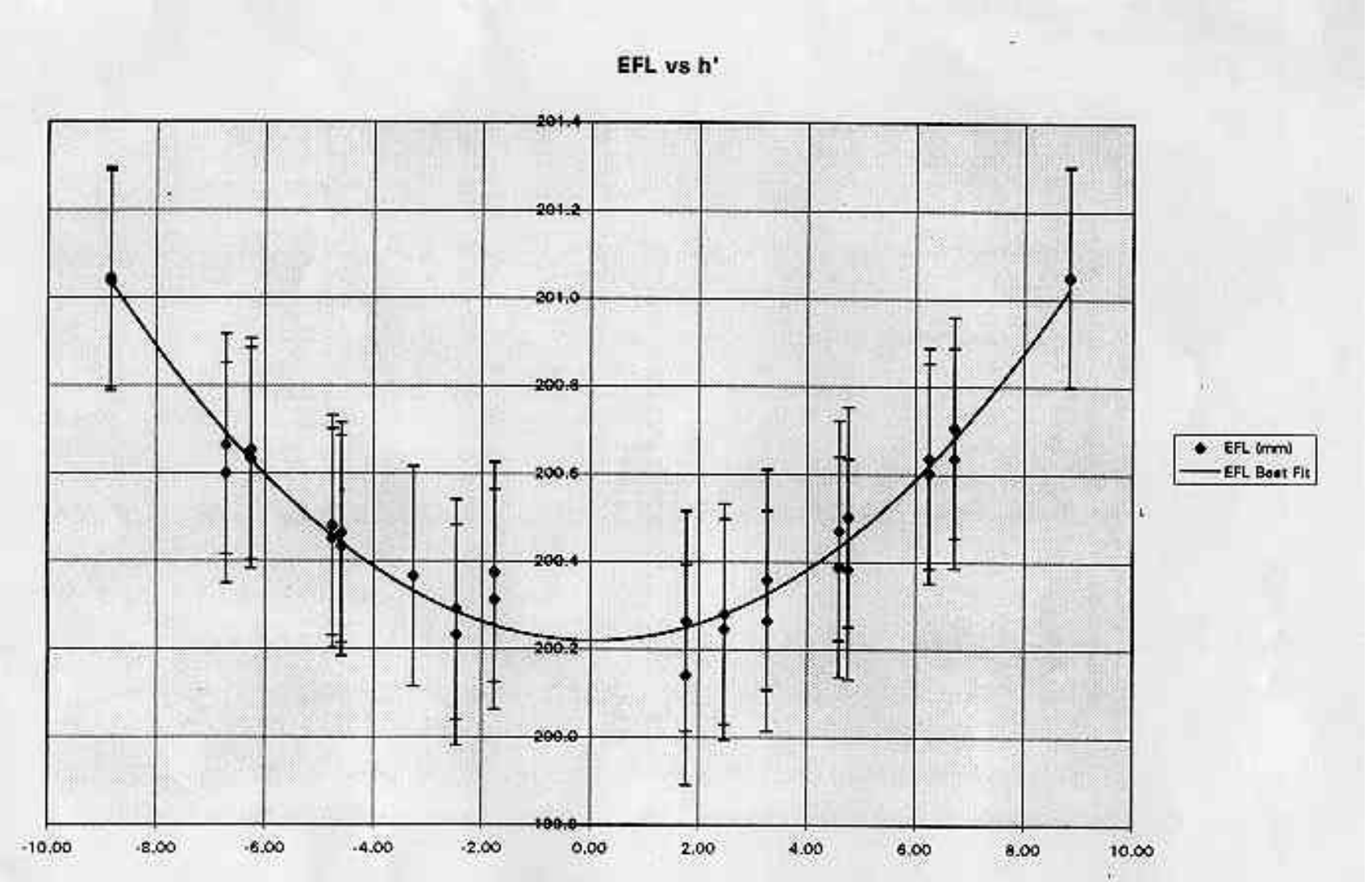


Figure 4.1.3.2-3 - WAC FM Effective Focal Length Measurements