4.1.3 FOCAL LENGTH AND DISTORTION

4.1.3.1 NAC FM FOCAL LENGTH AND DISTORTION MEASUREMENTS

As reported in Reference 4.1.3.1-1

Reference 4.1.3.1-1 - IOM , "NAC Flight Model Focal Length And Distortion Measurement Results", Edward Motts, August 26, 1998

4.1.3.1.1 SCOPE

This report describes a measurement of the Cassini Narrow Angle Camera Flight Model (NAC F/M) performed on November 9, 1995. The objective of the measurement was to determine Effective Focal Length (EFL) and field distortion of the camera optics. Measurement results were apparently not distributed at the time of the test; this memorandum is therefore intended as the final test report.

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.

The measured EFL is 2000 mm, ±4 mm (3 σ). Field distortion is less than can be measured by this technique.

4.1.3.1.2 DESCRIPTION OF TEST METHOD

Measurements of the angles between the NAC/WAC tooling plate optical cube and the NAC 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 4.1.3.1-1 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 each grid target location was performed by superimposing the theodolite telescope reticle over the grid intersection. Each data point recorded was the mean of ten individual observations. Refer to Figure 4.1.3.1-2 for grid intersection locations.

Database file “NACFL2.dbf” containing all measured angles was exported to Excel spreadsheet “ISSDIST.xls” sheet 4 for data reduction.

4.1.3.1.3 DATA REDUCTION

Database files were imported into the Excel spreadsheet “ISSDIST.xls” as described above. Refer to Table 4.1.3.1-1 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:

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

Table 4.1.3.1-2 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 4.1.3.1-2.

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

The effective focal length (EFL) was calculated using h’ and φ for each grid intersection: Finally, the percentage distortion to a corner target intersection (such as point B1) is calculated as the percent deviation from the paraxial focal length:

$$\%distortion = \frac{EFL_{B1} - EFL_{parax.}}{EFL_{parax.}} * 100\%$$

4.1.3.1.4 UNCERTAINTY ESTIMATE

Random error was estimated by calculating the standard deviation of the theodolite observations. The value of angle _ was then perturbed by the standard deviation to determine the effect on EFL. Then, the EFL equation was perturbed by the stated uncertainty of the grid target, ±0.25 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.

The measurement uncertainty in EFL is inversely proportion to the radial distance h`. Please note that the uncertainty value reported is for the greatest value of h`, at the ends of the diagonal lines.

The calculated measurement uncertainty in the measured focal length is ±4.4 mm (3 σ). Estimation of the uncertainty (error) in the reported angles was accomplished in spreadsheet "ISSDIST.xls" sheet 4 and is shown in Table 4.1.3.1-3 of this report.

4.1.3.1.5 TEST RESULTS

The calculated focal lengths are shown in Table 4.1.3.1-2. Figure 4.1.3.1-3 graphically represents the measured values. The best fit line of Figure 3 crosses the vertical axis at 2000 ± 4 mm (three σ), the expected paraxial focal length. The EFL at point B1 is 2000.8. The calculated field distortion is 0.04%. In other words, the field distortion is less than can be measured by this method.

Note that the estimated measurement uncertainty of ± 4.4 mm (three σ) does not meet the Component Level Calibrations requirement of ±0.5 mm accuracy.

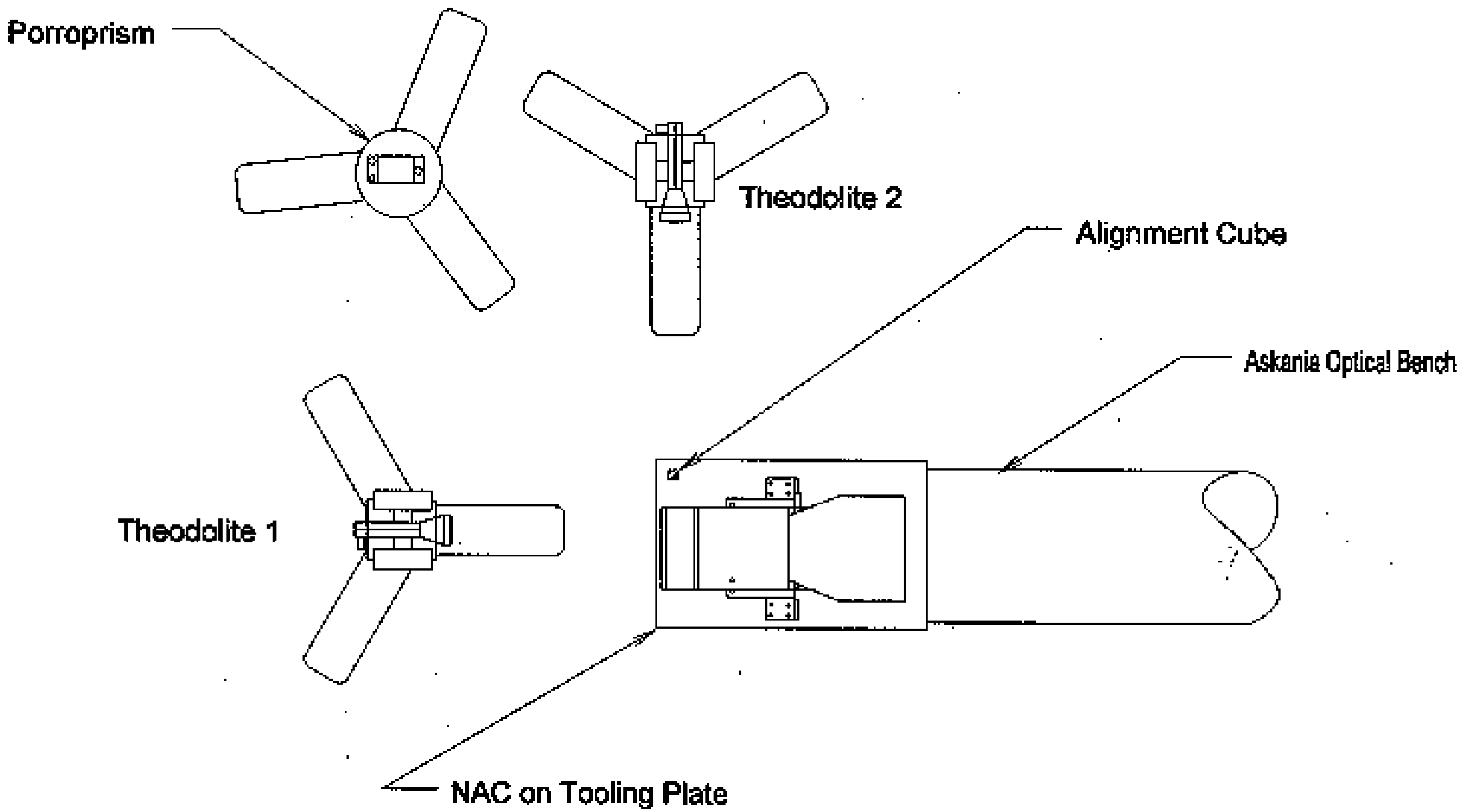
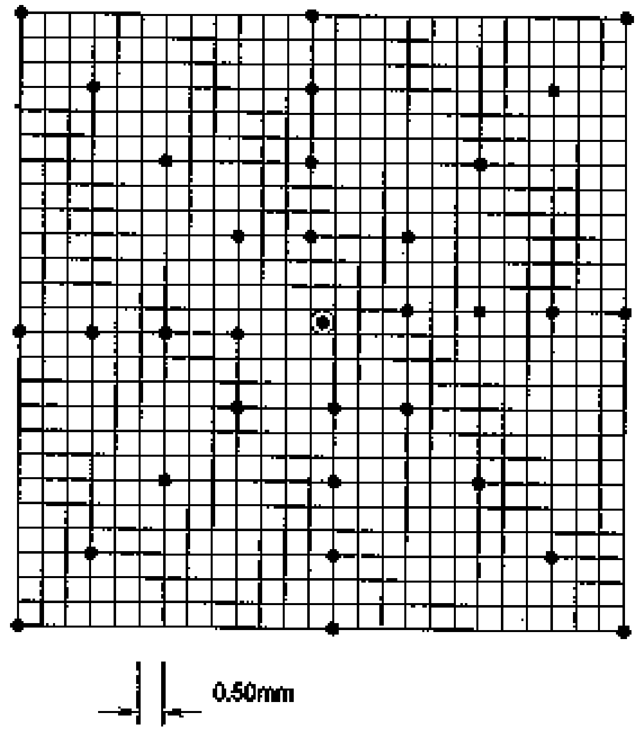
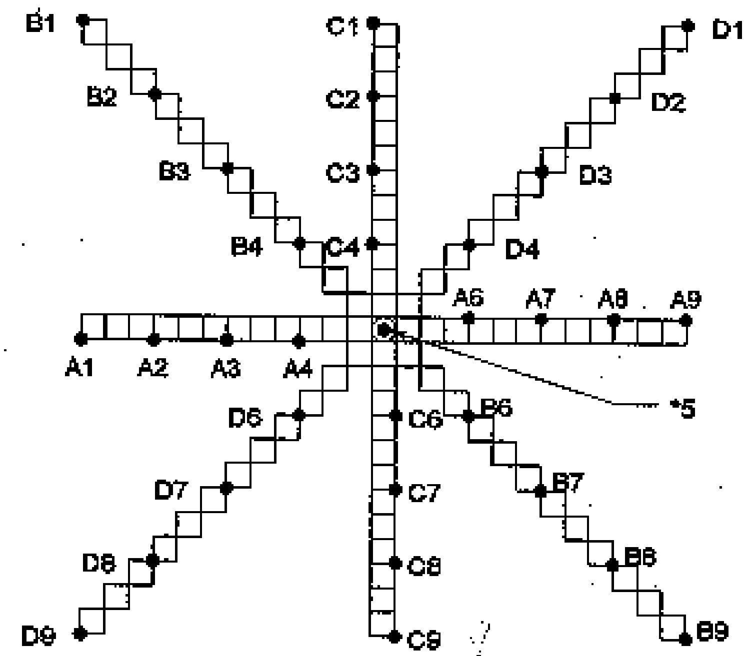


Figure 4.1.3.1-1 - Instrument Layout



GRID TARGET
WITH INTERSECTION POINTS



IDENTIFICATION OF
GRID INTERSECTION POINTS

Figure 4.1.3.1-2 - Grid Target Intersection Points and Identification

A1	90.75290	90.05154
A2	90.79586	90.05150
A3	90.83893	90.05153
A4	90.88187	90.05150
A5	90.93211	90.04437
A6	90.98250	90.03696
A7	91.02545	90.03692
A8	91.06850	90.03695
A9	91.11143	90.03692
B1	90.75363	89.86427
B2	90.79647	89.90720
B3	90.83932	89.95028
B4	90.88227	89.99336
B5	90393235	90.04351
B6	90.98243	90.09365
B7	91.02538	90.13667
B8	91.06820	90.17963
B9	91.11107	90.22251
C1	90.95269	89.86401
C2	90.92547	89.90695
C3	90.92544	89.94999
C4	90.92553	89.99294
C5	90.93256	90.04309
C6	90.93958	90.09305
C7	90.93949	90.13598
C8	90.93938	90.17898
C9	90.93927	90.22192
D1	91.11178	89.86408
D2	91.06878	89.90689
D3	91.05271	89.94896
D4	90.98271	89.99281
D5	90.93253	90.04284
D6	90.88226	90.09275
D7	90.83919	90.13568
D8	90.79620	90.17853
D9	90.75310	90.22127
PORROB1	1.00008	106.73701
PORROC1	0.99569	91.19378
CUBEX1	191.5627	89.98797
CUBEZ1	90.99742	90.00739

Table 4.1.3.1-1 - Raw Data : NAC Flight Model Focal Length and Distortion Measurements

GRID INTERSECTION POINT	phi (radians)	h′ (mm)	EFL (mm)
A1	0.00313	6.254988	1998.2
A2	0.002381	4.75674	1997.5
A3	0.001631	3.259601	1998.5
A4	0.000886	1.767767	1996.0
A5			
A6	0.000889	1.767767	1988.6
A7	0.001634	3.259601	1994.6
A8	0.002384	4.756574	1995.3
A9	0.003132	6.254998	1996.9
B1	0.004418	8.838834	2000.8
B2	0.003359	6.717514	1999.8
B3	0.002299	4.596194	1999.5
B4	0.001237	2.474873	2000.7
B5			
B6	0.001237	2.474873	2000.8
B7	0.002298	4.596194	2000.1
B8	0.0.003356	6.717514	2001.3
B9	0.004415	8.838834	2002.1
C1	0.003128	6.254998	1999.8
C2	0.002379	4.756574	1999.1
C3	0.00163	3.259601	2000.0
C4	0.000884	1.767767	1999.7
C5			
C6	0.00088	1.767767	2007.8
C7	0.001626	3.259601	2005.2
C8	0.002375	4.756574	2003.1
C9	0.003123	6.254998	2002.7
D1	0.004418	8.838834	2000.5
D2	0.003359	6.717514	1999.7
D3	0.002298	4.596194	2000.5
D4	0.001237	2.474873	2001.2
D5			
D6	0.001236	2.474873	2001.9
D7	0.002298	4.596194	2000.4
D8	0.003357	6.717514	2001.0
D9	0.004417	8.838834	2001.3

Table 4.1.3.1-2 - NAC FM : Calculation of EFL

UNCERTAINTY (Effect on Effective Focal Length)			
ANGLES (0.000003 radians)	**DISTANCE (0.00025 mm)**	**RSS**	**THREE SIGMA**
2.1	-0.1	2.1	6.2
2.7	-0.1	2.7	8.1
4.0	-1.2	4.0	11.9
7.3	-0.3	7.3	21.8
7.2	-0.3	7.2	21.6
3.9	-0.2	3.9	11.8
2.7	-0.1	2.7	8.1
2.1	-0.1	2.1	6.2
1.5	-0.1	1.5	4.4
1.9	-0.1	1.9	5.8
2.8	-0.1	2.8	8.4
5.2	-0.2	5.2	15.7
5.2	-0.2	5.2	15.7
2.8	-0.1	2.8	8.4
1.9	-0.1	1.9	5.8
1.5	-0.1	1.5	4.4
2.1	-0.1	2.1	6.2
2.7	-0.1	2.7	8.1
4.0	-0.2	4.0	11.9
7.3	-0.3	7.3	21.9
7.3	-0.3	7.4	22.1
4.0	-0.2	4.0	12.0
2.7	-0.1	2.7	8.2
2.1	-0.1	2.1	6.2
1.5	-0.1	1.5	4.4
1.9	-0.1	1.9	5.8
2.8	-0.1	2.8	8.4
5.2	-0.2	5.2	15.7
5.2	-0.2	5.2	15.7
2.8	-0.1	2.8	8.4
1.9	-0.1	1.9	5.8
1.5	-0.1	1.5	4.4

Table 4.1.3.1-3 - NAC FM : Estimate of Uncertainty of EFL Measurement

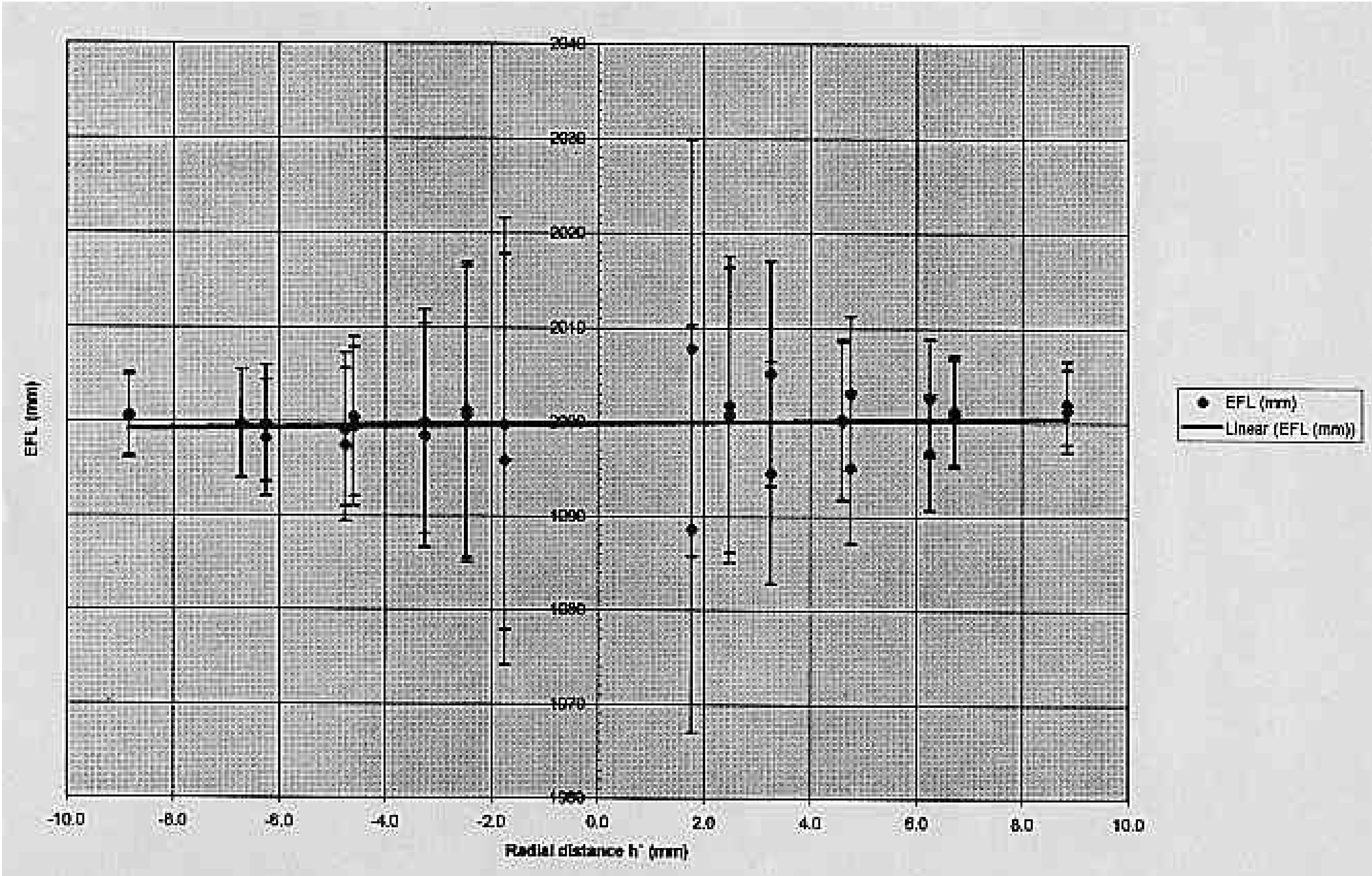


Figure 4.1.3.1-3 - NAC FM Effective Focal Length Measurements