MEMORANDUM

TO: Distribution

FROM: W. Podgorski, T.Gaetz

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FILE: WAP-FY97-007

SUBJECT: Telescope Alignment

REF: 1) ISIM to Telescope and Spacecraft ICD, TRW IF1-0016A
2) Observatory to Science Instrument ICD, TRW IF1-20B

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Kodak: C. Atkinson
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1.0 Introduction

SAO has been asked to provide coverage of the various AXAF system level alignments. This includes Kodak's telescope alignment and Ball's ISIM alignment, as well as spacecraft and aspect camera alignments. This memo is intended to document SAO's coverage of the AXAF telescope and ISIM alignment process as well as several cross-check measurements which have been made.

2.0 Telescope and ISIM Alignment Overview

The AXAF Telescope alignment process is designed to set the HRMA optical axis normal to the SI focal plane and the HRMA focus at a pre-defined point (in three linear axes) within the focal plane. The process utilizes the OBA to ISIM interface plane and three precision mounting pads on this interface as basic alignment references. Definition of this interface(Ref 1) allows Ball and Kodak to make independent alignments to it.

Three metal ISIM mounting pads are provided by Kodak on the aft end of the OBA. The three ISIM feet attach to these pads thru inline (Ball provided) spacers. The ISIM alignment process must set the SI focal planes 28.500” aft of the OBA/ISIM interface when the ISIM is at the center of its focus range(Ref 1). The SI's mount on the SIM translation table(TT) and their focal planes are defined to be 14.000” aft of the TT interface. The SIM must therefore be aligned such that the TT mounting plane is 14.500” aft of the OBA/ISIM interface plane with the ISIM in the center of the focus range. The TT mounting plane must be parallel to the OBA/ISIM interface plane, and many other positioning and alignments must be met (mounting of the SI's, positioning of their focal planes, etc.)

On the Kodak side, the HRMA must be aligned to the OBA/ISIM interface plane. The basic HRMA alignment reference is the Factory Alignment Referemce Mirror (ARM). The ARM has a flat surface, to which the HRMA optical axis was aligned, and a 10 meter spherical zone. The HRMA focus was measured (in 3 linear DOF) in the Kodak alignment tower relative to the ARM 10M focus. In Kodak's telescope alignment procedure a "surrogate" ISIM was used as a reference. This "surrogate" was the "ISIM Alignment System", or IAS. It contains the Centroid Detector Assembly(CDA) which was used to align the HRMA at Kodak, along with plano and spherical reference mirrors. The CDA was placed with its focal plane at 28.500" from the OBA/ISIM interface plane and centered relative to the mounting pads. The plano and sphere were also adjusted so as to be on-center when they are translated into viewing position. The Kodak alignment was then done by adjusting the HRMA such that the ARM flat was parallel to the plano on the IAS (measured by an auto-collimator) and the ARM focus was positioned (in 3 linear DOF) such that the HRMA focus would be centered in the CDA, which represents the "aim point" for the HRMA.

3.0 SAO Cross-Check of HRMA to ARM Alignment Targets

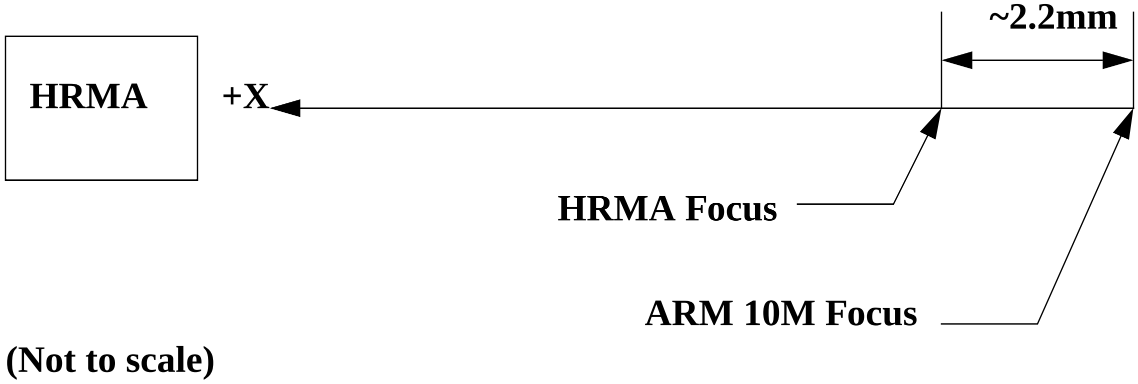
At SAO we have used our hats_plot program to analyze HATS data taken during HRMA ATP on 11/9/96 and 11/10/96. The data analysis is given in Appendix A. The resulting alignment targets are as follows:

SAO Calucualed Alignment Targets
(all in mm, HRMA co-ordinates)

Optic	Q0r	Q0i	xcorr	Y0	Z0
MP1	-0.0114	0.0076	0.334		
MP3	-0.0002	0.0134	0.276		
MP4	-0.0013	0.0058	0.499		
MP6	-0.0038	0.0049	-0.018		
HRMA	-0.0042	0.0079	0.272		
ARM10	0.0102	-0.0607	-1.914		
(ARM10-HRMA)	0.0144	-0.0686	-2.186	0.072	-0.034
C. Atkinson: (AXAF-97-0020)	0.01498	-0.06928	-2.2682		

Note that the the HRMA focal distance is about 2.2 mm SHORTER than the ARM 10.

HRMA vs. ARM 10M Focus



4.0 Absolute Focal Length Comparisons

Five different estimates of the position of the absolute focus of the HRMA are presented below. All four are referenced to the P side of the CAP, CAP Datum A. The first two estimates use the ARM 10M focus and the Kodak measured alignment data from the HRMA ATP. SAO and Kodak have analyzed the data separately and performed slightly different calculations and are within 0.2mm of each other. SAO's raytrace calculation is within 0.8 mm of the first two. This is important in that it is completely independent of the ARM data and HATS ATP data. The fourth and fifth estimates are Scott Texter's measurements using a laser rangefinder and the XRCF focus position found for the HRC. A summary of the data is given below:

```
HRMA focus to CAP datum A (mm)

       10,079.4   - SAO from ATP & ARM data
       10,079.2   - Kodak from ATP & ARM data
       10,079.8   - SAO Raytrace
       10,079.1   - TRW from XRCF data (meas 1)
       10,080.2   - TRW from XRCF data (meas 2)
```

The conclusion from the above data is that the HRMA focus is known relative to the ARM 10M focus to an accuracy under 1 mm. (This is for an ARM 10M at 70F. The ARM 10M focus temperature sensitivity is +0.13mm/degF)

4.1 SAO Calculation of Absolute Focal Position

Alignment of the HRMA is performed using the ARM 10M focus as the reference. However, other methods may be used to check this alignment, at least in focus. The chosen method to cross-check the focus is to use a laser rangefinder. To use this method as a cross-check we must know the HRMA focus position relative to some known mechanical reference. For convenience, we have chosen the P side of the CAP, or “DATUM A”.

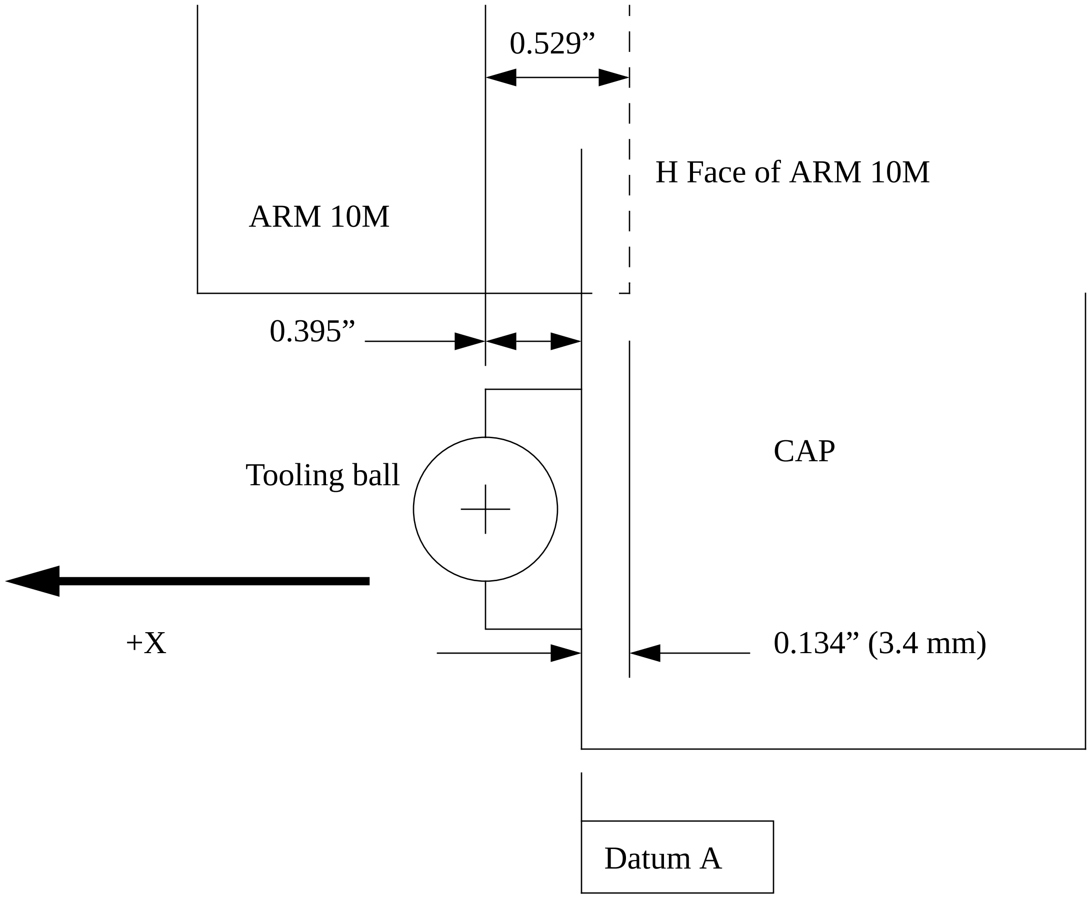
As for absolute focal length relative to datum A we get:

```
10078.2   - ARM 10M focus
   +3.4   - ARM 10M flat surface to Datum A
10081.6   - ARM 10M focus to Datum A
   -2.2   - HRMA focus to ARM 10M focus
10079.4   - HRMA focus to CAP datum A
```

The calculation above makes use of the measured ARM 10M focal distance of 10,078.2 mm (from ARM 10M center of curvature to flat face on H side of ARM 10M). This is documented in Kodak Tech Note AXAF-94-0241-1 by Mark Waldman.

The H face of the ARM 10M relative to Datum A is located as follows (see diagram next page):

> The ARM 10M tooling ball center is 0.529” (in the +X direction) from the ARM 10M H face. When the ARM 10M is mounted on the CAP the tooling ball center is 0.395” from the CAP Datum A plane, which puts Datum A +0.134” (3.4mm) in the + X direction relative to the H face of the ARM 10 M. See diagram below.



4.2 Kodak Absolute Focal Length Calculation (C. Atkinson)

The HRMA Focus, compensating for the ACF focus effects, and 1g effects, was measured to be 2.268 mm in front of (towards +X) the ARM (reference Technote 97-0020), excluding the effect of the CAP sag on the ARM. This effect is expected to move the ARM focus more negative by approximately 0.039 mm (reference Technote 95-0257), making the on-orbit focus of the HRMA +2.308 mm from where the ARM focus would be, on-orbit.

The ARM10m Focus is 10078.2 mm, after adjusting for temperature, from its surface, based on the 10m lens bench testing. This puts the HRMA focus at 10075.9 mm (I dropped the microns) from the ARM surface, with an uncertainty of 1 mm. Using some drawing dimensions from Erik Shepard, this puts the back focus with respect to the H6 aft end at 9178.9 mm. From the H side CAP Datum (D), the focus is 10,0296.3 mm. As a note, Casey (in Technote 95-0137) predicted the back focus from the H6 aft end to be 9179.8 mm, so we only differ by 0.9 mm, and our uncertainty is 1mm, and HDOS’s is much bigger than that.

Using Charlie's numbers:

```
 9,178.9 mm  from the aft end of H6 mirror
  +842.2 mm  H6 length
    +8.2 mm  H6 aft end to H side of CAP (0.323 in)
   +49.9 mm  CAP thickness
10,079.2 mm  HRMA on-orbit focus, from your data,
                relative to datum A
```

4.3 SAO Raytrace Calculation of Absolute Focal Length

From HDOS mirror data and Kodak assembly data we have calculated the absolute HRMA focal length as follows:

```
10,274.7 mm  from the P side of the CAP(datum A) at XRCF
  -194.9 mm  finite conjugate effect
10,079.8 mm  Infinite conjugate HRMA focus, relative to
             Datum A calculated from HDOS data plus measured
             spacings3.1.4 XRCF Focus Cross-Check (S. Texter)
```

4.4 XRCF Cross-Check of Focal Length using HRC ARM (S. Texter)

The OPTICAL distance measured between the XARM and the HRC ARM (HARM) using our laser rangefinder when the HRC-I was known to be at the XRCF Finite Conjugate focus was 10182.0 mm. Here are the corrections:

```
10182.0     optical distance measured between XARM and HARM
  -29.7     phase delay ranging through 56mm thick
               XARM rather than air(BK-7,calibrated earlier
               at TRW)
  -47.4     distance from +X surface of XARM to
               +X(P side) surface of CAP (DATUM A)
 +169.2     distance from +X surface of HARM to
            HRC MCP surface (from Randy Moore)
_______     Total
10274.1     XRCF Finite Conjugate distance from CAP
               DATUM A to image
 -195.0     Finite to Infinite Conjugate shift
_______
10079.1     HRMA on-orbit distance from CAP DATUM A
               to image
```

We also made a second measurement through a different, thinner, region of the XARM (clear center region but not including the glued on reticle):

```
10179.9   optical distance measured between XARM and HARM
  -26.5   correction for phase delay ranging through
             50mm XARM (BK-7, calibrated earlier at TRW)
  -47.4   distance from +X surface of XARM to +X(P side)
             surface of CAP (DATUM A)
 +169.2   distance from +X surface of HARM to HRC MCP
             surface (from Randy Moore)
_______
10275.2   XRCF Finite Conjugate distance from CAP DATUM A
             to image
 -195.0   Finite to Infinite Conjugate shift
_______
10080.2 HRMA  on-orbit distance from CAP DATUM A to image
```

This gives a good indication of the error, which seems to be about a millimeter.

5.0 Cross-Check of Telescope Factory Alignments

The telescope alignment was set using Kodak's ISIM Alignment System (IAS). As discussed in Section 2..0, the IAS incorporates the CDA from the HATS, as well as plano and spherical reference mirrors and a reference reticle. The IAS attaches to the OBA on the OBA/ISIM interface pads. The lateral and axial focus positions of the ARM 10M focus are measured using the CDA. The tilt of the HRMA (thetaY and thetaZ) is measured using an auto-collimator (AC) which measures the angles between the flat portion of the ARM 10M and the plano on the IAS.

The alignment was performed by manipulating the entire optical bench (with the IAS installed) in 6 DOF with the HRMA being independently supported. After the alignment was measured to be within tolerance in this condition (denoted as "unhung" since the HRMA was NOT hung from the HRMA struts) the HRMA to OBA struts were set to lengths calculated so as to preserve the "unhung" alignment condition. The struts were then attached to the HRMA and the support for the HRMA was removed, transferring all of the HRMA's weight onto the HRMA struts. This condition is denoted as the "hung" condition since the HRMA is hanging on the HRMA struts. Many sets of alignment data were taken in this "hung" condition to verify that the strut setting and hanging operation resulted in alignment which was acceptable.

After the HRMA was "hung", Scott Texter of TRW performed a cross-check of the focus using the laser rangefinder. This cross-check adds confidence to the process and will be performed again at the observatory level.

5.1 SAO Analysis Method

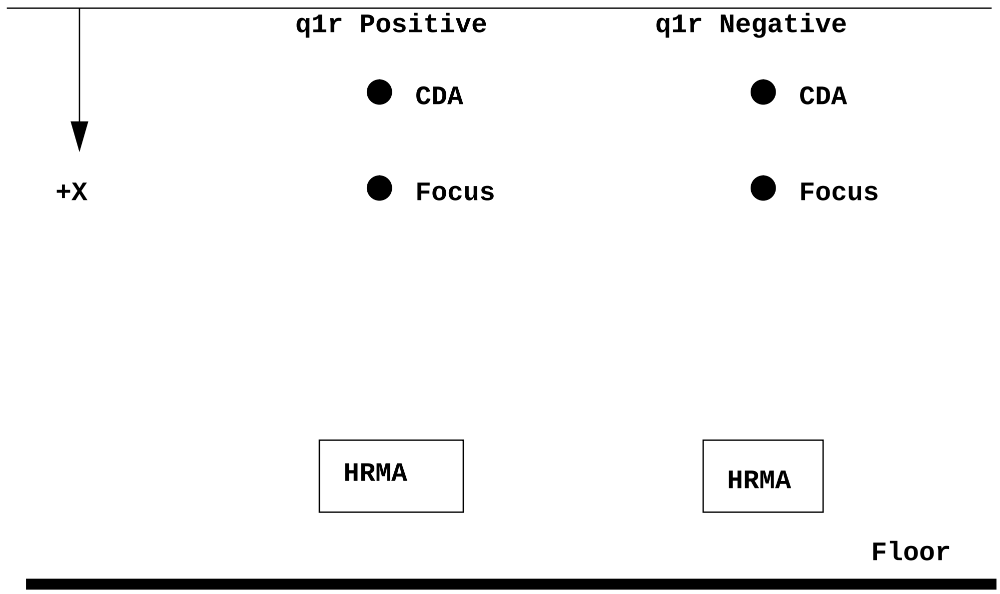
The telescope targets (using all of ARM) were taken from From AXAF-97-0020-Atkinson "ISIM to ARM Alignment Targets":

```
 q0_r        0.01498
 q0_i       -0.06928
 Axial X    -2.26818
```

Analysis of Alignment data:

Converting q1_r_ave to axial focus:

```
x0_arm10 = -0.5*(F/r)*q1_r

focus factor = 0.5*(F/r)

where F is the ARM-10 radius of curvature,
      r is the radius of the ARM-10 zone.


from [AXAF-95-0209-WALDMAN]:
    F   = ARM-10 radius of curvature = 10079.48 mm
    2*r = ARM-10 zone diameter       =   377.19 mm
 -->r   = ARM-10 zone radius         =   188.60 mm
    focus factor                     =    26.723


from hats_plot:

    F              = 10078.2
    r              =   188.6
    focus factor   =    26.718

[Note 1.28 mm difference in radius of curvature!]

[From WAP email]:
 Since +X is down towards the HRMA from the focus, a
 NEGATIVE q1r would give a POSITIVE x, making the focus
 more towards the HRMA than the detector. A POSITIVE q1r
 would make x NEGATIVE, making the focus furthur away from
 the HRMA then HATS. Diagrammatically:
```



5.2 SAO Analysis of "Unhung" Case

According to the test log, the last complete rcd file for the "unhung" case was is101600.rcd on Jul 27-28 1997; this contained 84 alignment measurements.

The alignment coefficients are assessed by taking an 8-point Fourier transform of aperture 0, 3, 6, 9, 12, 15, 18, and 21; this is the largest Fourier transform which avoids the obstructed apertures (13 and 14). The mean and standard deviations for the 84 tests are taken using rdbstats:

	avg (mm)	stdev (mm)
q0_r	0.07898	0.00318
q0_i	0.00045	0.00185
q1_r	0.07938	0.00044
q1_i	0.00094	0.00031
q2_r	-0.00068	0.00043
q2_i	-0.01384	0.00036

from which we get:

		avg (mm)	stdev (mm)
q1_r		0.07938	0.00022
Axial	X	-2.121	0.006

As a cross check, the Y and Z decenters are estimated by taking a straight mean of the Y, Z values for 20 spots. This is a symmetric sum in which a spot is included only if the spot 180 degrees away in azimuth is also included; that is, the obstructed apertures and the apertures 180 degrees away in away in azimuth are excluded from the mean.

The radius of the defocus circle is estimated based on a mean of half the magnitude of the vectors between pairs of spots differing by 180 degrees in azimuth. This gives an estimate of the radius of the focus circle but not the for the sign; I use the same sign as found for the 8-point fourier transform.

	avg (mm)	stdev (mm)
"q0_r"	0.08003	0.00335
"q0_i"	-0.00567	0.00191
foc_radius	0.07427	0.00039

from which we get:

"q1_r"	0.07631	0.00011
Axial X	-2.0392	0.0104

Summarizing the estimates for the "unhung" case:

		units	Lateral Y	Lateral Z	Axial X
[a]	Target	(mm)	0.01498	-0.06928	-2.26818
[b]	8_pt_fourier	(mm)	0.07898	0.00045	-2.121
[c]	cross_check(*)	(mm)	0.08003	-0.00567	-2.0392
[d]	[b] - [a]	(mm)	0.06400	0.06973	0.147
[e]	[c] - [a]	(mm)	0.06505	0.06361	0.229
[f]	[b] - [a]	(mil)	2.52	2.745	5.787
[g]	[c] - [a]	(mil)	2.561	2.504	9.016
[h]	EKC 8/4 telecon	(mil)	1.3	1.3	4.

(*) "q1_r" and Axial X sign for [c] assumed to be the same as for [b]

5.3 SAO Analysis of the "hung" case:

According to the test log, the last complete rcd file for the "hung" case up to 8/2/97 was is120402.rcd; this contains 57 alignment tests.

The alignment coefficients are assessed by taking an 8-point Fourier transform of aperture 0, 3, 6, 9, 12, 15, 18, and 21; this is the largest Fourier transform which avoids the obstructed apertures (13 and 14). The mean and standard deviations for the 57 tests are taken using rdbstats:

	avg (mm)	stdev (mm)
q0_r	-0.88112	0.00071
q0_i	0.18639	0.00047
q1_r	0.06748	0.00050
q1_i	0.00337	0.00047
q2_r	0.02611	0.00049
q2_i	-0.02864	0.00042

The axial alignment parameter is calculated to be:

		avg (mm)	stdev (mm)
q1_r		0.06748	0.03374
Axial	X	-1.803	0.013

As a cross check, the Y and Z decenters are estimated by taking a straight mean of the Y, Z values for 20 spots. This is a symmetric sum in which a spot is included only if the spot 180 degrees away in azimuth is also included; that is, the obstructed apertures and the apertures 180 degrees away in away in azimuth are excluded from the mean.

The radius of the defocus circle is estimated based on a mean of half the magnitude of the vectors between pairs of spots differing by 180 degrees in azimuth. This gives an estimate of the radius of the focus circle but not the for the sign; I use the same sign as found for the 8-point fourier transform.

	avg (mm)	stdev (mm)
“q0_r”	-0.89565	0.00058
“q0_i”	0.18430	0.00033
foc_radius	0.05779	0.00032

from which we get:

q1_r		0.05779
Axial	X	-1.46787

Summarizing the estimates for the “hung” case:

		units	q0_r	q0_i	Axial X
[a]	Target	(mm)	0.01498	-0.06928	-2.26818
[b]	8_pt_fourier	(mm)	-0.88112	0.18639	-1.803
[c]	cross_check(*)	(mm)	-0.89565	0.18430	-1.468
[d]	[b] - [a]	(mm)	-0.89610	0.25567	0.465
[e]	[c] - [a]	(mm)	-0.91063	0.25358	0.800
[f]	[b] - [a]	(mil)	-35.28	10.07	11.8
[g]	[c] - [a]	(mil)	-35.85	9.98	20.3
[h]	EKC 8/4 telecon	(mil)	-33.2	9.4	17.6

(*) Axial X sign for [c] assumed to be the same as for [b]

3.4 TRW Focus Cross-Check I (S. Texter)

3.2 IAS Errors

The ISIM Alignment System(IAS) is a “surrogate” ISIM which interfaces to the ISIM mounting pads on the OBA and is used to align the HRMA to the OBA/ISIM interface plane. The IAS incorporates the CDA, with the CDA focal plane at the 28.500”

3.3 HRMA to IAS Alignments

Appendix A - Alignment Targets

```
Selected Tests:
11/09/1996  21:49:36.000
11/09/1996  22:39:14.000
11/09/1996  23:44:28.000
11/10/1996  00:28:20.000
11/10/1996  01:12:16.000
11/10/1996  01:56:05.000
11/10/1996  03:10:53.000
11/10/1996  03:54:49.000
11/10/1996  04:38:47.000
11/10/1996  05:22:45.000
11/10/1996  06:06:47.000
11/10/1996  06:50:54.000
11/10/1996  07:35:05.000
11/10/1996  08:19:18.000
11/10/1996  09:03:20.000
11/10/1996  09:48:05.000
11/10/1996  10:32:04.000
11/10/1996  11:16:26.000
11/10/1996  12:00:32.000
11/10/1996  12:44:35.000
11/10/1996  13:28:30.000
11/10/1996  14:12:29.000
11/10/1996  14:56:24.000
11/10/1996  15:40:26.000
```

Zone: MP1
Plotted Variable: MP1 x_corr   Average: 0.333665

Qn	Avg Real	Sigma Real	Avg Imag	Sigma Imag
0	-0.0114872	0.00942843	0.00761617	0.00889255
1	-0.0246540	0.00108556	-0.000178940	0.000140740
2	-0.00866485	0.000348862	0.00260144	0.000299101
3	-0.00994667	0.000286006	0.00329514	0.000315259
4	0.00386654	0.000307854	0.000557469	0.000380961
5	-0.000989933	0.000367353	0.000223190	0.000267886
6	-0.000719210	0.000419767	0.000472683	0.000298438
7	0.00226001	0.000219367	-0.000360051	0.000473224
8	0.000120954	0.000300721	0.000977460	0.000475525
9	-0.000760055	0.000269372	0.000791287	0.000298926
10	0.000920816	0.000328871	0.000432460	0.000331940
11	0.000525921	0.000364910	-0.000983385	0.000308503
12	0.000376296	0.000269644	0.000142998	0.000327174
13	-0.000961545	0.000179324	-0.000246875	0.000413589
14	0.000442627	0.000248854	0.000163028	0.000391700
15	0.00135707	0.000376793	-0.000627567	0.000276163
16	0.000404869	0.000258355	-4.16370e-05	0.000352903
17	0.000358259	0.000298924	0.000840761	0.000390073
18	0.000695228	0.000207053	-0.000639097	0.000399813
19	0.00164385	0.000258243	-0.000455186	0.000384870
20	-0.000218364	0.000409475	-0.000981599	0.000262629
21	0.00187578	0.000366599	-5.97394e-05	0.000321279
22	0.0133460	0.000317961	3.04995e-05	0.000312338
23	0.0104600	0.000289332	0.00586592	0.000242296

Q0_real: -0.0114872
Q0_imag: 0.00761617
Q2_real: -0.00866485
Q2_imag: 0.00260144
Second Order residuals: 0.0159253
Third Order residuals: 0.0139061

Zone: MP3
Plotted Variable: MP3 x_corr   Average: 0.275784

Qn	Avg Real	Sigma Real	Avg Imag	Sigma Imag
0	-0.000181613	0.00939612	0.0134257	0.00877083
1	-0.0119845	0.00242303	0.000177772	0.000190775
2	0.00625982	0.000584797	-0.00192694	0.000592822
3	-0.000704978	0.000344462	0.00885721	0.000454969
4	0.00467061	0.000755208	-0.00464739	0.000735165
5	0.000716076	0.000693786	-0.000990764	0.000606262
6	-2.36851e-05	0.000825359	0.000346814	0.000482180
7	0.000552802	0.000415683	-0.000231747	0.000858275
8	0.000316087	0.000348162	0.000494545	0.000818749
9	-0.000329153	0.000508082	-0.000838570	0.000487231
10	0.000758305	0.000486372	0.000138816	0.000627603
11	0.00126233	0.000863311	0.000280566	0.000497608
12	-0.000565161	0.000518206	0.00105171	0.000574070
13	0.000524265	0.000183440	-0.000128753	0.000875289
14	-4.26724e-05	0.000528505	0.000634610	0.000608741
15	0.000493736	0.000887885	-0.000758921	0.000412026
16	0.00118658	0.000439661	-0.000284250	0.000622767
17	0.000514146	0.000549599	0.00237101	0.000541848
18	-0.00120164	0.000314198	-0.000566160	0.000801804
19	0.00268860	0.000440865	-0.000180873	0.000768726
20	-0.000900636	0.000760401	0.000315513	0.000361102
21	0.000327218	0.000704608	-0.000360679	0.000682178
22	0.0145742	0.000666400	-0.00429125	0.000737911
23	-0.000875443	0.000325492	0.0131838	0.000491268

Q0_real: -0.000181613
Q0_imag: 0.0134257
Q2_real: 0.00625982
Q2_imag: -0.00192694
Second Order residuals: 0.0159225
Third Order residuals: 0.0165600

Zone: MP4
Plotted Variable: MP4 x_corr   Average: 0.499048

Qn	Avg Real	Sigma Real	Avg Imag	Sigma Imag
0	-0.00130651	0.00966201	0.00989126	0.00899813
1	-0.0306741	0.00135311	0.00109657	0.000131571
2	0.00576380	0.000266543	-0.000760843	0.000378861
3	-0.00526353	0.000298486	0.000704325	0.000330867
4	0.00568685	0.000331074	0.00286261	0.000384775
5	0.000518560	0.000352493	-0.000934154	0.000431859
6	0.00100296	0.000624920	0.00117869	0.000219262
7	0.00194468	0.000196846	-0.000475873	0.000459186
8	0.00142275	0.000228977	-0.000855522	0.000457185
9	0.000336167	0.000338754	0.00102294	0.000220293
10	-0.00106935	0.000344341	0.00105477	0.000407484
11	0.000331246	0.000482251	-0.000421276	0.000282964
12	-0.000850909	0.000296475	-0.000559852	0.000283277
13	-0.000207253	0.000144102	0.00141200	0.000556172
14	-0.000698054	0.000282343	0.00112154	0.000410668
15	-5.42325e-05	0.000445142	-0.000412129	0.000231220
16	0.000543398	0.000321287	0.00213249	0.000447965
17	0.000340040	0.000374963	-0.00118664	0.000238692
18	0.000990103	0.000240623	-0.00100679	0.000461198
19	0.000646802	0.000257122	0.000248304	0.000385696
20	-0.000729487	0.000557941	-7.96307e-05	0.000179216
21	0.000361303	0.000336374	-0.000215299	0.000385543
22	0.0115636	0.000335143	0.00177570	0.000346546
23	0.00628813	0.000286987	0.00164322	0.000251666

Q0_real: -0.00130651
Q0_imag: 0.00989126
Q2_real: 0.00576380
Q2_imag: -0.000760843
Second Order residuals: 0.00839295
Third Order residuals: 0.0133193

Zone: MP6
Plotted Variable: MP6 x_corr   Average: -0.0178803

Qn	Avg Real	Sigma Real	Avg Imag	Sigma Imag
0	-0.00378496	0.00924250	0.00489395	0.00907942
1	0.00681256	0.00194262	0.00314190	0.000183253
2	0.0296826	0.000617901	-0.00306641	0.000438281
3	-0.000540723	0.000716635	0.00178889	0.000663449
4	-0.00159365	0.000662105	0.00618259	0.000771818
5	0.00228542	0.000596505	0.000874230	0.000763695
6	-0.00227198	0.000811975	0.000945180	0.000599089
7	0.00241925	0.000640479	-0.000130110	0.000958634
8	-0.00163820	0.000582282	0.000647499	0.00100150
9	0.000652445	0.000555318	-0.000354051	0.000755739
10	-0.00147656	0.000673079	0.000314182	0.000912327
11	0.00227369	0.000754415	0.000224256	0.000622488
12	-0.000956880	0.000545076	-0.000333555	0.000566971
13	0.000732373	0.000182261	-6.03745e-05	0.00104285
14	-5.51014e-06	0.000577832	-0.000987472	0.000654132
15	0.000959627	0.000785066	0.000799393	0.000546284
16	-0.00130867	0.000646494	-0.00138308	0.000942053
17	0.00144908	0.000651068	0.000893156	0.000714723
18	-0.000961374	0.000492818	-0.000791871	0.000925705
19	0.000200426	0.000796547	0.00187566	0.000733538
20	0.00139307	0.000792954	-0.00161128	0.000688718
21	-0.00260075	0.000581361	0.00356670	0.000693909
22	0.0187067	0.000659068	0.00248249	0.000750512
23	-0.00479443	0.000726189	0.00414982	0.000592946

Q0_real: -0.00378496
Q0_imag: 0.00489395
Q2_real: 0.0296826
Q2_imag: -0.00306641
Second Order residuals: 0.00661060
Third Order residuals: 0.0199215

Zone: ARM 10 M
Plotted Variable: ARM 10 M x_corr   Average: -1.91475

Qn	Avg Real	Sigma Real	Avg Imag	Sigma Imag
0	0.0101878	0.0110848	-0.0607075	0.00896789
1	0.0716639	0.000202030	-0.00231042	0.000118166
2	-0.00744350	0.000189624	-0.00554738	0.000166412
3	0.0280904	0.000174616	-0.00487209	0.000204700
4	-0.00790296	0.000178103	-0.00514141	0.000180090
5	0.0183493	0.000199991	-0.00552641	0.000142658
6	-0.0116187	0.000170969	-0.00179432	0.000175108
7	0.000543842	0.000196818	-0.00202682	0.000195846
8	0.00120014	0.000166415	-0.00714232	0.000183302
9	0.0108044	0.000192051	-0.00579374	0.000163582
10	-0.00123068	0.000168198	0.00674762	0.000163895
11	0.00390143	0.000162327	-0.00543637	0.000187034
12	-0.00350395	0.000157674	0.00160657	0.000168067
13	-0.00920053	0.000160879	-0.0102761	0.000183375
14	-0.00700336	0.000193821	0.00298443	0.000181332
15	-0.00708688	0.000165543	-0.00811152	0.000141254
16	0.00450150	0.000194237	-0.000749463	0.000190682
17	-0.00562772	0.000162031	-0.00165057	0.000156333
18	0.00926291	0.000163268	-0.00567713	0.000187013
19	0.0103832	0.000163872	-0.00458677	0.000154457
20	0.00909583	0.000176476	-0.00687724	0.000187378
21	-0.0121778	0.000173219	-0.00499105	0.000169374
22	0.0215645	0.000187611	0.00998387	0.000248751
23	-0.0279696	0.000223715	-0.00881646	0.000203005

Q0_real: 0.0101878
Q0_imag: -0.0607075
Q2_real: -0.00744350
Q2_imag: -0.00554738
Second Order residuals: 0.0409004
Third Order residuals: 0.0255655

Alignment Targets(all in mm)

Optic	Q0r	Q0i	xcorr	Y0	Z0
MP1	-0.0114	0.0076	0.334		
MP3	-0.0002	0.0134	0.276		
MP4	-0.0013	0.0058	0.499		
MP6	-0.0038	0.0049	-0.018		
HRMA	-0.0042	0.0079	0.272		
ARM10	0.0102	-0.0607	-1.914		
(ARM10-HRMA)	0.0144	-0.0686	-2.186	0.072	-0.034
C. Atkinson: (AXAF-97-0020)	0.01498	-0.06928	-2.2682		