

The Focal Plane Monitoring Program

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ABSTRACT

The OSG runs a focal plane monitoring program, known as the "Heptathlon", routinely checking the SIs and FGSs four times a year as a way of assessing trends and stability in the HST focal plane. The test can measure relative positions of the SIs to within 50 mas and by repetition assess stability of the focal plane and FGSs. This program has served as a running supplement to SI aperture location programs to support accurate pointing, and has illustrated focal plane trends such as the FGS to FGS drift that resulted in the April 1996 re-calibration of the FGS coordinate space. Plots of such results and trends from past visits between the first and second servicing mission are presented and discussed.

1. Introduction

The focal plane monitoring program gives us focal plane positional information by acquiring targets in each of the science instruments while having a WFPC2 parallel of multiple targets in each case. The stars in the instrument apertures, the WFPC2 and the guide stars are all selected from M35, an astrometrically known field. A fixed pair of astrometric guide stars is used to place a cluster member in each of the SIs, including the non-guiding FGS. For the cycle 7 implementation and beyond, POS TARGs used after the SI's initial pointing step the target to two additional V_2, V_3 locations, providing scale and angle information. After each SI's observation, a WFPC exposure is taken at the same pointing, imaging several cluster members and providing SI-WFPC relative positions and orientations. The test is unique in that the astrometry of M35 is quite accurate (20-30 mas) and that the same guide stars are used for the entire test and for each visit. Rolls differing by 180° are required for Spring and Fall observations, and SI targets are chosen so that the same pair of guide stars are used, although they switch between FGS1 and FGS3. Figure 0 illustrates the HST field of view superimposed on the M35 star field in the Fall roll. The Heptathlon guide stars are labeled. The example depicted is FOC f96 observing target 480 (pickle #) while WFPC2 images 3 other cluster members. Table 1 gives the stars used for

Spring and Fall tests, and table 2 lists the past visits analyzed by OSG. All entries in table 2 except the last one (cycle7) were used as the basis for the data presented here.

2. Analysis & Results

Instruments

An individual visit allows us to measure pixel positions of the target stars. For the spectrographs, on-board target acquisitions were used to ensure precise positioning of the target at the reference. Remaining offsets between intended and actual placement of the reference pixel on the sky are accounted for and determined via image analysis and data reduction. PDB values for scales and angles are used. Focal plane coordinates, (V_2, V_3) for the corresponding star are calculated from the telescope's attitude determination. An accurate attitude (or mapping of V_2, V_3 onto RA and Dec.) calculated by GSFC PASSOPS, is accomplished by computing the locations of the guide stars in FGS space, and via FGS calibrations, transforming out to V_2, V_3 . Since the astrometric celestial coordinates are known, a fit is then made to the guide star V_2, V_3 and RA, Dec. After including other corrections such as differential velocity aberration, the HST attitude is determined from this basic data. (Cox and Lallo 1992). The V_2, V_3 of a target can now be calculated. From these values we map a particular position in an SI to the focal plane. Analysis gives us SI reference point positions in the V_2, V_3 frame defined by the FGSs, as well as relative to the WFPC when the parallel images are used. Comparing the relative to the absolute positions allows the discrimination between FGS motions, and movement with respect to the WFPC. Note that not every WFPC parallel field star given in table 1 is used for analysis of each visit; small ($< 2^\circ$) roll differences can result in one or more of the candidates being off the chip from visit to visit.

Figure 1 shows the WFPC2 reference point, WFALL measured over a 3-year period between servicing missions. The location is determined by using the WFPC2 distortion model to fit the measured pixel positions of several stars to their V_2, V_3 positions calculated from the telescope attitude. Within a Heptathlon visit, all the SIs' WFPC parallels are combined to determine the reference position from a single fit. The error bars indicate the scatter in the fit, which includes centroiding inaccuracies, astrometric star position uncertainties, and a small guidestar separation effect. The latter is due to FGS to FGS misalignment over the small area of the pickle covered by the guidestars during the various SIs' pointings. There is also an important systematic error of about 0.1 arcsec principally arising from inaccurate knowledge of the FGS positions. The overall motion represented is a fairly steady drift of about 150 mas a year in V_2 and 70 mas a year in V_3 . The total shift is 0.5 arcsec. This is attributed to FGS motion in the focal plane since SI to WFPC relative motions are much smaller.

Figures 2 to 5 show the motion of the other instruments with respect to the FGS system and their motions relative to the WFPC2. For the most part the instruments move about 130 mas per year in the V2 direction and less than 50 mas per year in V3. With respect to the WFPC2 the motions are not significantly greater than the error bars. The exception is the FOC which shows very little recent V2 motion with respect to WFPC2, but a V3 trend of about 130 mas a year. FOC also shows somewhat unique behavior by the fact that there appears to be a significant oscillation in the reference position, even relative to WFPC. This is not well understood, but FOC does periodically move the COSTAR DOB in OTA desorption compensation moves to maintain focus. A positional shift of the sky on the detector of approximately 0.1 arcseconds results. This is not accounted for by a PDB update to the reference position, and thus should show in our data. The directions and frequency of these DOB moves are not inconsistent with what we see. The DOB moves would affect GHRS and FOS as well, however on-board acquisitions remove this dependency from the final data.

The error bars for the absolute positions are based on the guidestar separation errors discussed in the next section, target and reference point measurement errors discussed in the errors section, plus the known residuals of the special M35 catalog. Error bars for the WFPC relative plots are based on only the star catalog errors, errors in the WFPC reference point fit, and again the SI target measurement and reference point offset uncertainties. Since the WFPC exposure is in parallel, guidestar position errors are removed in this relative measurement, and the FGS-FGS misalignment error cancels.

Guide Stars

An estimate of the accuracy of the pointing calculations is obtained by comparing the angular separation of the guide star pair as calculated from their known sky positions with that obtained from the FGS measurements and calibrations. The difference between these separation estimates has typically been 50 to 100 mas for Heptathlon observations using accurate FGS-FGS alignment data. This difference is presumably due to inaccurate knowledge of the positions and orientations of the FGSs plus the 30 mas uncertainty in the guide stars' astrometric coordinates. An initial calibration of FGS alignments was made in February 1991 and the derived solution was used for the telescope pointing and positional analyses until April 1996, although long-term motion of the FGSs of up to two arcseconds had been measured. With this solution, guide star separation errors of up to 0.5 arcsec were common. For typical guidestar/target geometries, a value comparable to this separation error (White and Gilmozzi 1989) must be included, along with SI and target position uncertainties, in assessing the total blind pointing error budgets. A second FGS calibration was performed and uploaded in February 1994. New positions for the SIs in the redefined V_2, V_3 reference frame were calculated based on Heptathlon results using what was then the non-operational improved FGS calibrations.

On April 14th 1996 the February 1994 solution was installed in the Project Data Base. This reduced the separation errors with astrometric guidestars down to less than 100 mas and showed improved targeting accuracy. A record of the displacement between the blind pointing position and the corrected target acquisition position had been maintained by the FOS group and we used their data collected since January 1994 to illustrate the improvement in the blind pointing accuracy. Figure 6. The grey areas indicate ellipses containing 68% of the total counts, analogous to a 1 standard deviation for a one-dimensional distribution. The mean radii are given in arcseconds. The history of the guide star separation errors extracted from the Heptathlon data is shown in Figure 7. *All the calculations are based on the February 1994 solution.* It can be seen that even by April 1996, the date of the implementation, the continued FGS motion meant the solution was not as accurate as it had been. The accuracy continues to worsen but at a very slow rate and is still considerably better than in earlier epochs. However, since the 1997 servicing mission, which included the replacement of FGS1, a new alignment solution has been obtained and we are planning for its operational implementation September at the end of SMOV.

3. Errors

Fundamental to the test are accurate celestial coordinates for the M35 members. Guidestars, targets, and parallel WFPC stars are all taken from a specially determined subset of McNamara and Sekiguchi's (1986) M35 catalog. Starting with the original ground-based catalog, PASSOPS-GSFC applied FGS color/magnitude corrections using 50 reference stars from a January 1993 FGS3 Full OFAD. This re-reduction of McNamara's positions puts the relative errors at approximately 25 mas; and is known internally as the Welter W3 catalog. (Welter 1994).

Although we can calculate focal plane positions from a Heptathlon based on operational or non-operational FGS alignment matrices, such alignments cannot be known to better than 30 mas. This represents the error inherent in relating the FGSs to one another via ground-based fields.

Centroiding errors in the WF images are somewhat less than 0.1 pixel, corresponding to less than 10 mas. The metachip distortion solution which is applied to the raw centroid positions has errors smaller than 0.1 WF pixels across the metachip. The field stars' undistorted centroids are mapped via a linear fit to their corresponding calculated V_2, V_3 positions. The V_2, V_3 of the WFALL reference pixel is derived from this fit.

For FOC f/96 there is approximately a 1 pixel (14 mas) error going from a well centered target to the reference pixel, mainly due to distortion variations and somewhat to centroiding. Measurements of the GHRs target's location in the 16X16 pixel 1"75 map image have an error of approximately 0.1 pixel or 11 mas, and the offset to the nearby reference pixel can be assumed to be this value. FOS target centering was done by successive peakups, the final peakup having 50 mas spacing. The target's miscentering versus the

return to brightest was found by determining the flux peak by a fit to the grid of fluxes at each dwell. This was taken as the target's location. This method has uncertainty less than 15 mas. In all cases then, the targets' relative locations within the SIs is good to between 10 and 20 mas. These errors discussed here affect how accurately we can calculate the offset from the target's computed V_2, V_3 position to the reference point's V_2, V_3 position. The computed target V_2, V_3 , and thus the reference point's V_2, V_3 contain the celestial coordinate inaccuracies, and the FGS misalignment discussed above. For FOC, GHRS, and FOS, the PDB values for scale and angles are used to transform from target to reference point V_2, V_3 . Any errors in these values will of course propagate, however since the targets are usually very well centered, the errors in calculating the small displacement from target to reference are much less than those associated with the calculation of the target's V_2, V_3 position.

4. Conclusions & Future Visits

The Heptathlon has been successful in monitoring changes in the instruments and FGS positions, and pointed out the value of updating the FGS-FGS alignment matrices. Overall, the SI motions with respect to the FGSs have been of order 0.1 arcsec per year since Spring of 1994, with relative motions between instruments significantly smaller.

For the cycle 7 implementation of the Heptathlon, the addition of POS TARGs enhance the test and provide independent checks of certain SI alignment program results, such as scale and orientation. In cycle 7, the Heptathlon will replace the FOC aperture location program. For the other SIs it will monitor NIC1, 2, and 3, WFPC, and STIS CCD positions, orientations, and scales, and to a more limited degree FGS1's position.

Currently the Heptathlon takes less than two orbits to perform, and when run a minimum of twice a year provides adequate monitoring. Four times a year is preferable for establishing statistically significant trends. This fall we will be uploading current FGS to FGS alignment matrices once again, and a cycle 7 Heptathlon run immediately following will provide an assessment of our recalculated focal plane positions and of the reduced errors in the guidestar fit.

5. References

- Cox, C., Lallo, M., 1992, Instrument Science Report OSG/SOB-92-01-01
- McNamara, B., Sekiguchi, K., 1986, *Astron. J.* **91**, 557
- Welter, G., 1994, McNamara Catalog, corrected for color/mag effects. (private circulation)
- White, R.L., Gilmozzi, R., 1989, Instrument Science Report OSG/TA-002

Table 1: Heptathlon stars

Instrument	GSC ID# Spring	GSC ID# Fall
FGS1 (guider)	1887.00348	1881.00570
FGS3 (guider)	1881.00570	1887.00348
FGS2 (astrometer)	1881.00030 1877.01022	1881.00156 1881.00153 1881.00476 1877.01412
FGS2 WFPC PAR	1877.00928 1877.00294 1877.00626	1881.00183 1881.00496 1877.00814 1877.00182
GHR5	1881.00222	1877.01412
GHR5 WFPC PAR	1881.00512 1881.00012	1877.00928 1877.01142 1877.01156
FOS rd	1881.00542	1877.00148
FOS rd WFPC PAR	1877.00626 1881.00546 1881.00512 1881.00462	1877.00626 1881.00546 1881.00512 1881.00462
FOS bl	1877.00222	1877.00148
FOS bl WFPC PAR	1881.00276 1881.00060 1881.00117 1881.00402	1877.01178 1877.01142 1877.01156 1877.00928 1877.00294 1877.00300
FOC F96	1881.00554	1877.00216
FOC F96 WFPC PAR	1877.01156 1877.00928 1877.00294	1881.00562 1881.00183 1881.00496

Table 2: Heptathlon Visits

Date	Comments
1994:115	Roll +90 First measurement after SM1
1994:321	Roll -90
1995:353	Roll -90
1995:086	Roll +90
1995:116	Roll +90
1995:279	Roll -90
1995:316	Roll -90
1996:050	Roll +90
1996:105	Roll +90 Run immediately after FGS-FGS re-alignment
1997:026	Roll +90 Run as baseline before SM2
1997:118	Roll +90 First measurement after SM2 (FGS2/3 guiding)