Maintaining the FGS3 OFAD Calibration with the Long-Term Stability Test

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Abstract

The Hubble Space Telescope carries three Fine Guidance Sensors (FGS) that serve as part of the Pointing Control System and can be used for millisecond of arc astrometry on stars as faint as V=17. The *HST* Ritchey-Chrétien design produces optical distortions in the field of view of the telescope, which because of residual misalignments, must be calibrated on-orbit for any instrument. The series of optical field angle distortion (OFAD) calibrations begun in December 1990 has shown evidence that some aspects of the OFAD change with time. A series of long-term stability (LTSTAB) tests was begun on 2 December 1992 to characterize and monitor these changes. Each LTSTAB test consists of a single orbit visit to the ecliptic open cluster M35 which was used for the OFAD. As of the writing of this report (November 1993) eight LTSTAB tests have been performed. The current status of our analysis of these data is summarized in this report.

I. Introduction

The *HST* is a Cassegrain telescope of the Ritchey-Chrétien design. The prescription of the Optical Telescope Assembly (OTA) contains optical field angle distortion (OFAD) and some astigmatism. This report is intended as one of a series of appendices to the final report on the Optical Field Angle Distortion (OFAD) Calibration (Jefferys et al., this volume). A familiarity with that report is assumed in the following.

For reasons that are not well understood at this time, the metrology of the FGS optical system, and hence the OFAD, has not fully stabilized. A post-launch period of change was expected since many of the structures in the FGS are made of graphite epoxy which shrinks in a non-uniform way due to water desorption. While the amount of change that is observed has decreased since the first few months after launch, there remains a time varying part of the distortions that are observed by the FGS. We have had to generalize our OFAD model and our calibration tests to account for these time dependent changes. A series of long-term stability (LTSTAB) tests was begun on 2 December 1992 to characterize and monitor these changes. Each LTSTAB test consists of a single orbit visit to the ecliptic open cluster M35 which was used for the OFAD calibration. As of the date of this report, eight LTSTAB tests have been

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performed. The current status of our analysis of these data is summarized in this report.

II. The LTSTAB Model

Our present model of the distortion changes reflects the simplest physically possible change within the FGS unit. We use the qualifier of "physically possible" to exclude changes such as the magnification of the *HST* OTA. The magnification of the telescope could not change enough to model the observed changes in the FGS distortions without this change being readily observable in the *HST* camera images. Such a change has not been observed by the cameras and so we have excluded this possibility from our modeling.

The simplest physically possible change within the FGS unit would be a change in only the relative positions of the two flat mirrors that make up star selector A. A change in the relative positions of these two mirrors would cause a change in the magnitude of the star selector encoder parameter ρ_A. The star selector encoder parameters ρ_A, ρ_B, k_A, k_B, and M are the instrumental parameters that relate the observed rotation angles θ_A and θ_B to the Cartesian coordinates x and y via the equations

$$\begin{aligned} \cos\rho &= \cos\rho_A\cos\rho_B + \sin\rho_A\sin\rho_B\cos(180° - q) \\ \sin\rho\sin p &= \sin\rho_B\sin(180° - q) \\ \sin\rho\cos p &= \cos\rho_B\sin\rho_A - \sin\rho_B\cos\rho_A\cos(180° - q) \end{aligned} \tag{1}$$

with $q = (\theta_B + k_B) - (\theta_A + k_A)$ and $p = \phi - \theta_A - k_A$ and

$$\begin{aligned} x &= \sin\frac{\rho}{M}\cos\phi \\ y &= \sin\frac{\rho}{M}\sin\phi \end{aligned} \tag{2}$$

Figure 2 in Jefferys et al. (1993) shows the geometry of the FGS coordinates. For completeness, we give the functional form of the OFAD model used in our analysis:

$$\begin{aligned} \Delta x_{dist}(x, y; a_{ij}) = x_{true} - x = {} & a_{00} + a_{10}x + a_{01}y + a_{20}x^2 + a_{11}xy + a_{30}x(x^2+y^2) \\ & + a_{21}x(x^2-y^2) + a_{12}y(y^2-x^2) + a_{03}y(y^2+x^2) \\ & + a_{50}x(x^2+y^2)^2 + a_{41}y(y^2+x^2)^2 + a_{32}x(x^4-y^4) \\ & + a_{23}y(y^4-x^4) + a_{14}x(x^2-y^2)^2 + a_{05}y(y^2-x^2)^2 \end{aligned} \tag{3}$$

$$\begin{aligned}\Delta y_{dist}(x,y;b_{ij}) = y_{true} - y = {} & b_{00} + b_{10}x + b_{01}y + b_{20}x^2 + b_{11}xy + b_{30}x(x^2+y^2) \\ & + b_{21}x(x^2-y^2) + b_{12}y(y^2-x^2) + b_{03}y(y^2+x^2) \\ & + b_{50}x(x^2+y^2)^2 + b_{41}y(y^2+x^2)^2 + b_{32}x(x^4-y^4) \\ & + b_{23}y(y^4-x^4) + b_{14}x(x^2-y^2)^2 + b_{05}y(y^2-x^2)^2\end{aligned}$$

where the coefficients a_{ij}, b_{ij} are the constants that are estimated.

III. The HST Observations

The long-term stability test (LTSTAB for short) program consists of periodic visits (ideally once per month) to the M35 field used for the OFAD. In fact, M35 was chosen for the OFAD calibration because of the need to run the LTSTAB tests. Since M35 is in the ecliptic, the telescope does not gradually roll about this field throughout the year as it does for a target off the ecliptic. Instead, the telescope “flips” 180° when M35 gets closest to the anti-solar point (to be precise, the telescope rolls 180° between December 20 and December 28 with the bulk of the roll occurring on December 24). This means that we can observe the calibration field at two fixed orientations; one in the fall and one in the spring. This maximizes our sensitivity to real changes in the OFAD and minimizes our sensitivity to uncertainties in the OFAD that might appear as changes if the telescope gradually rolled through the calibration field. Each spring the LTSTAB test consists of a single orbit of observations that repeat the central pointing of the OFAD. The fall LTSTAB tests also consist of a single orbit of observations but are rolled approximately 180° about the central pointing of the OFAD calibration. These two pointings are highlighted by the heavy lines in Figure 1 in Jefferys et al., this volume. Two executions of the LTSTAB test were made before the OFAD calibration; on December 2 and 14, and four were run after the OFAD calibration; on April 5, 18, and 19 and on August 26. We expect to continue the LTSTAB tests, at a rate of approximately once per month, whenever M35 is observable.

IV. Results from Our Analysis of the LTSTAB Data

We have subjected the data from the eight orbits from the LTSTAB test runs to a least-squares estimation. The star positions, the OFAD coefficients, a_{ij} and b_{ij}, and the star selector parameters, ρ_B, k_A, k_B, and M were all held fixed to the values determined from the 19 uncorrupted orbits obtained during the 10 January 1993 OFAD calibration. These star positions and parameters are given in Tables 1 and 2 of Jefferys et al. (1993). A unit pointing quaternion, two linear drift parameters, and ρ_A were estimated for each LTSTAB orbit.

Since the *HST* observations are relatively insensitive to absolute scale, the variances of all scale-like quantities in an OFAD solution are inherently large. But when the other parameters are held fixed and only ρ_A is estimated, the estimated variances are approximately equal to the variance of the factional change in ρ_A,

$$\Delta\rho_{A_i} = \frac{(\rho_{A_i} - \rho_{A_{OFAD}})}{\rho_{A_{OFAD}}}. \tag{4}$$

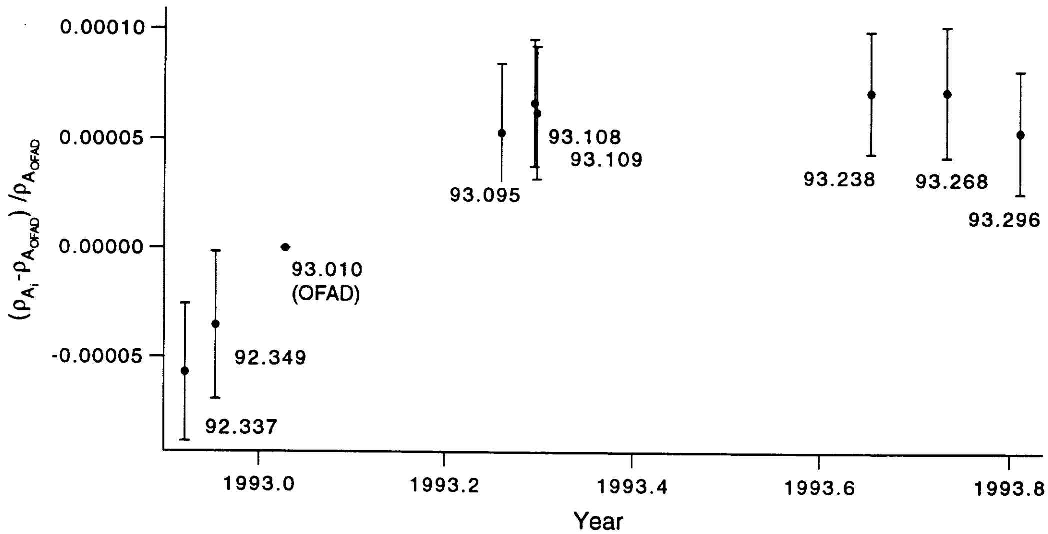

Fig. 1. The change in the star selector servo assembly angle ρ_A as deduced from the eight LTSTAB tests. The increase in ρ_A is equivalent to an apparent contraction of a star field.

The time evolution of the SSE parameter ρ_A, with the calculated variances, is shown in Figure 1. It is obvious that statistically significant changes in ρ_A are occurring that will require continued monitoring. The effect of this change is analogous to what would happen if one were to stretch a ruler. The spacing between the marks would get larger and measured distances would get smaller. In a similar fashion, as ρ_A increases, the measured separations between stars decreases. In terms of plate constants, this means that $a^2 + b^2 > 1$ in the equations

$$a\xi + b\eta + c = x \tag{5}$$

$$-b\xi + a\eta + d = y$$

when a plate from time t is overlaid on a plate from time t_0 where $t > t_0$. This is consistent with the changes observed in long- and short-term astrometric stability tests as summarized in Benedict et al. (this volume). The LTSTAB data have not revealed that higher order changes in the OFAD are occurring. The statistics of the residuals from the fits to the eight LTSTAB orbits are summarized in Table 1. For comparison, the RMS of the residuals from the 548 individual observations from the 19 OFAD orbits were 2.3 mas along both the x and y axes.

TABLE 1. Statistics of the residuals from the first eight executions of the FGS 3 LTSTAB test.

Date	Orientation	# obs	RMS (mas) x	RMS (mas) y	# GS	Dejittered
1992.337	fall	24	4.2	3.1	2	yes
1992.349	fall	22	3.1	3.2	2	yes
1993.095	spring	29	2.5	2.9	1	no
1993.108	spring	29	3.3	3.1	1	no
1993.109	spring	29	2.5	3.5	1	no
1993.238	fall	27	2.9	5.0	1	no
1993.268	fall	26	3.1	4.5	1	no
1993.296	fall	26	3.4	4.6	1	no
Total			3.2	3.8		

V. Remaining Work and Conclusions

The LTSTAB orbits contain much information about constant quantities as well as time-dependent parameters. In particular, the positions of the stars change very slowly, if at all, and it is hoped that the coefficients of the OFAD polynomial do not change. Moreover, the fall orientation LTSTAB tests have the potential to make a significant contribution to the determination of the OFAD coefficients because of their 180° roll relative to the spring pointing. Consequently, we are working on a "grand-OFAD" solution that will simultaneously use all of the OFAD plus LTSTAB orbits to determine the constant and time-dependent parts of the FGS distortion model.

As more LTSTAB tests are run, especially at approximately one month intervals, we will be able to finally determine whether or not changes are occurring in higher order terms of the distortion model. We will also be able to determine an appropriate functional form for the time-dependent parameters and estimate the relevant coefficients. This will permit optimal interpolation of the distortion model to any epoch. Looking forward, the continued execution of the LTSTAB tests is mandatory to maintain the OFAD calibration which, in turn, is essential for all future astrometry science with *HST*.