DISTRIBUTION

TIB	SPD	SESD	PASSOPS (Goddard)
Baggett, S	Blades, J.C.	Bely, P.	Kalinowski, K..
Baxter, D.	Crocker, J.	Lupie, O.	Kimmer, E.
Bohlin, R.	Hartig, G.	Toth, B.	Welter, G.
Biretta, J.	Macchetto, D.		
Bucciarelli, B.	Stanley, P.		
Burrows, C.			
Clampin, M.			
Cox, C.			
Ewald, S.			
Gilliland, R.			
Gilmozzi, R.			
Greenfield, P.			
Hack, W.			
Hasan, H.			
Holfeltz, S.			
Hulbert, S.			
Keyes, T.			
Kinney, A.			
Kinney, E.			
Koorneef, J.			
Koratkar, A.			
Krist, J.			
Lallo, M.			
Lattanzi, M.			
Mackenty, J.			
Nota, A.			
Paresce, F.			
Ritchie, C.			
Sleiman, G.			
Soderblom, D.			
Sparks, W.			
Taff, L.			
Taylor, C.			
Tullos, C.			
Vener-Saavedra, P.			
Walter, L.			

Attitude Determination and Target Location

Colin Cox & Matt Lallo, September 6, 1995

Typically, aperture location determinations, and pointing analyses are performed with the aid of an SI-FGS alignment report. An SI-FGS alignment report takes as input, a time period of interest, and a position of interest in RA and DEC. The request is sent to PASS OPS where engineering telemetry is extracted for the time interval in question. The PASS code operates on this telemetry to determine the guide stars' positions in FGS space, and V2,V3, and then, using the RA and DEC of the guide stars, produces a pointing of the V1 axis in RA and DEC, and the telescope roll angle. From this information, the V2,V3 position of the specified target is computed and returned for analysis by the instrument team, or in some cases by the ST ScI. The PASS code can be kept up-to-date as new or more accurate distortion mapping or FGS to FGS alignments become known. The reports are used to gain knowledge of aperture locations to update the PDB SIAF file, by linking a star's observed position in a camera's pixel space or in a small aperture to V2,V3, thus locating that aperture, or pixel, in telescope coordinates. Edges of larger apertures can be located in a similar way. More recently, PASS alignment reports are being used to build up a statistical base of pointings, thereby making noticeable, trends and patterns relating to telescope pointing.

This study grew from an earlier investigation, prompted by the FOC group's concerns over interpreting SI-FGS alignment reports, provided by PASS. There appeared to be some inconsistencies in the pointing calculations, leading the group to come to us to provide an independent check of PASS's code. We had been involved in similar computations, in analyzing WF/PC to FGS distortions. Another motivation arose from a GO request to locate an aperture in celestial coordinates, for a specific telescope pointing. This is the inverse of the information obtained from a PASS reports, in which celestial coordinates are provided as input, and the telescope coordinates (V2,V3) are the end result. Developing a good understanding of the attitude determination method and associated errors, and thus, a general confidence in the reports, is necessary if this procedure is to become a useful tool for field-of-view calibrations during SMOV, after the COSTAR installation.

The report, *A Comparison of HST Pointing Calculations, Cox & Lallo, 28 May 1992,* discusses an earlier attempt to provide confirmation of the PASS determinations, but we used an attitude-determination method based on spacecraft quaternions. These are a few steps removed from the pure FGS information that PASS uses. We found discrepancies in the 1 arcsecond range, between our determination, and PASS. At that time, we listed some possible sources of error, that included delays incorporating roll changes into the quaternions, as well as inconsistent use of star coordinates. In anticipation of the post-launch calibration effort, special plate catalogs were prepared for certain fields, so that more well determined celestial coordinates could be used to better locate apertures. This has, on occasion, led to inconsistencies between PASS alignment reports, as the input celestial coordinates were sometimes taken from the Guide Star Catalog and sometimes from the special plate catalog. Consistency must be maintained for the target and its associated guide stars.

This time, in an effort to create a more controlled test, we worked from the most basic information that the telescope provides us, namely, FGS lever arm positions, PMT counts (in the case of fine lock), and the telescope's velocity. Further, we made certain we and PASS used the same set of RAs and DECs for the two guide stars and target, The OMS group is creating code of their own, to produce pointing and target position information, and, as a further confirmation of our test, will run the same input coordinates and time period.

Our input was engineering information obtained from OMS. For the coarse track calculation, we used the spacecraft velocity to transform star coordinates to their positions as seen by the moving telescope. The velocities file, though reporting velocities once per second, could not be used in its raw form; the values were actually updated only once a minute, so the points reported between the freshly updated measurements, were discarded. A separate file contained guide star data, the FGS lever arm positions.

The first real step towards getting the attitude was the transformation of the lever arm positions to V2,V3. This was a two-phase process. First, the lever arm angles were converted to the individual FGS's X,Y positions, accounting for FGS distortions. Next, a rotation was performed to go from each FGS space to the telescope V2,V3 system. The polynomial coefficients for the distortion model, and the rotation matrices were taken from the SCHF.DAT file in the Project Data Base. For each line of telemetry, we calculated a V2,V3 as described, and with the corresponding time, found the spacecraft velocity by interpolating between the one minute measurements in the velocities file. We then applied the velocity aberration correction to the celestial coordinates of the target and guide stars.

Corrected RAs and DECs, along with V2,V3 positions for the two guide stars, allowed us to perform subsequent calculations in the telescope frame of reference. We then determined the telescope attitude, expressed as RA, DEC of the V1 axis, and the roll about this axis. For guide stars a and b, the V2 V3 values were expressed as unit vectors $\mathbf{v_a}$ and $\mathbf{v_b}$ in the telescope's frame of reference. The RAs and DECs define unit vectors in celestial coordinates which, for any telescope attitude, transform into unit vectors $\mathbf{u_a}$ and $\mathbf{u_b}$ in the telescope's frame. For the correct telescope attitude, and in the absence of any errors, we would obtain $\mathbf{u_a} = \mathbf{v_a}$ and $\mathbf{u_b} = \mathbf{v_b}$. We defined the best fit attitude as that which minimizes the error function, $|\mathbf{u_a} - \mathbf{v_a}|^2 + |\mathbf{u_b} - \mathbf{v_b}|^2$. An initial approximate solution is obtained from a planar model of the V2V3 space. The error function was minimized with the routine FRPRMN, taken from *Numerical Recipes*. To confirm that the solution found is valid, we transformed the celestial coordinates of the guide stars into V2,V3 values and compared them with the input V2,V3s. We found that the calculated positions lay along the line joining the input positions and the displacement vectors were of equal magnitudes but opposite signs. From the solution (the spacecraft attitude), the celestial coordinates and the telescope coordinates are related and either set can be calculated from the other. In deriving celestial coordinates from V2,V3 measurements, the final step needed is to apply the velocity aberration correction with the reverse velocity to transform back to barycentric coordinates.

The data segment used for this study came from an HRS observation of HD24912 through the small (0.″25 square) science aperture. When we averaged our final result over the same time period that PASS processed we obtained a value of:

$$V2 = -227.213 \pm 0.009 \qquad V3 = -238.342 \pm 0.013$$

compared with the PASS results:

$$V2_{pass} = -227.211 \qquad V3_{pass} = -238.350$$

Our determinations of the target star's V2,V3 position during the observation agree very well. Our numbers are given with a standard deviation over the time period, attributable to jitter and noise.

We found the rms error in the described fit to be 0.″31. PASS reports a very similar uncertainty of 0.″30. This represents the angular separation between the input V2,V3s, obtained from the FGS measure-

ments, and the V2,V3s calculated by the fit. This error can be caused by the guide star's positional uncertainty in the GSC, known to vary (in the northern hemisphere) from 0".5 to 1".1 (Taff et al., 1990).

Our results, and PASS's, are effectively identical. The code which converts FGS lever arm data to X,Y (FGS detector space) is an adaptation of PASS's original code, altered by Bely, Bucciarelli, and Lattanzi, 1987, to process engineering data in OMS format. This code is used for both fine lock and coarse track data, but in the latter case the PMT counts that constitute the fine error signal are read in as nulls. The subsequent code which converts to V2,V3, applies the velocity aberration correction, and calculates the telescope attitude, was independently developed. The test described above was a coarse track example. To test the code in the fine lock case, we took an HSP observation for which a fine error signal existed, ran our code, and compared the final results to the PASS alignment report. Our positional determination, in this fine lock case was nearly identical with PASS's, with the V2 position being alike to the sub-milliarcsecond level, and V3 differing by only 3.5 mas.

Therefore, to address past concerns with SI-FGS alignment reports, we contend that the PASS attitude determination is, and always has been, an accurate *procedure*, subject to good knowledge of FGS rotation matrices, FGS scales and distortions, and true celestial coordinates of the target and guide stars.

Figures 1 and 2 depict the guide stars' calculated positions in V2,V3, for FGS 2 and 3. The top two frames of each graph are time series (in hours) of V2 and V3. The magnitude of the scatter of positions is roughly 50 mas, most of which is due to the known coarse track error. The rms scatter would be the same as that listed above for the target.

Figure 3 shows the telescope attitude as a function of time, giving the apparent pointing in RA and DEC of the V1 axis, in the top two frames. The bottom frame displays the telescope roll, measured anti-clockwise from North. The variation of the apparent pointing, due to velocity aberration, is clear.

Figure 4 shows the calculated target position, again as a time series for V2 and V3 separately and as a V2,V3 plot. The time period is considerably shorter in this case to compare with a PASS report which integrated a 60 second time period. The target was kept stationary for over 30 minutes. Figure 5 includes a zoomed version of the V2V3 plot with the results of the PASS report indicated.

Finally, Figure 6 represents the GHRS apertures in V2,V3 space, with the target star's calculated position indicated. The spectroscopy was carried out successfully, proving that the star was in the Small Science Aperture, the small square located 1".7 from the star's calculated position. The locations of the apertures are derived from a series of measurements and concomitant SI-FGS reports. Situations like this have given rise to a lack of confidence in the SI-FGS reports in the past. However, the relatively large discrepancy can be attributed to inaccurate knowledge of the target and guide star celestial coordinates. Plate measurement errors and general astrometric properties of the GSC have been discussed by Taff et al. (1990), and the effect of such errors on the measured target position at the SI are discussed by White and Gilmozzi (1989). Based on their information, our offset of 1".7 is quite large, but seen to be still within the expected uncertainty range.

The determination of target position provides an update to the RA and DEC with errors that we can

estimate quite well. For targets that are visited several times using different sets of guide stars we can regard this result as astrometric data. It may well be worth retaining target acquisition results, particularly as the years go by, and the proper motion errors, discussed by White and Gilmozzi, increase.

REFERENCES

White, R. L., Gilmozzi, R. 1989, ST ScI internal report, *The Effect of Guide Star Position Errors on HST Target Acquisition.*

Taff, L.G., Lattanzi, M.G., Bucciarelli, B., Gilmozzi, R., McLean, B.J., Jenkner, H., Laidler, V.G., Lasker, B.M., Shara, M.M., Sturch, C.R. 1990, *Some Comments on the Astrometric Properties of the Guide Star Catalog, Ap. J.* **353**, L45.

Cox, C.R., Lallo, M.D., 1992, ST ScI internal report, *A Comparison of HST Pointing Calculations.*