Tracking FOS on-board GIMP in commanding, AEDP telemetry and header contents

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August 9, 2000

Abstract

STECF POA/FOS-003

The comprehensive review of the FOS calibration under the POA activity aims at a substantial improvement of science quality for the 24136 data sets in the FOS archive. Two important aspects are (a) the trustworthiness of the header information associated with the actual data, and (b) the confirmation that commanding at all epochs resulted in the proper execution of planned observations on-board. Both questions bear relevance to the necessity of "exception lists" and logics in the pipeline processing. In the present report we describe the steps undertaken to verify the GIMP related commanding and telemetry with reference to the code used in PASS (uplink telemetry) and with reference to the geomagnetic model and HST ephemeris used in the POA pipeline code.

Key words: Data Reduction, Calibration, Space Telescope. Faint Object Spectrograph, Dataflow, Header keywords, Data Archive

1 Introduction

In order to apply the POA corrected pipeline to a given FOS dataset it is necessary to have access to detailed information regarding the environment at the time of observation. Moreover, in order to assess the on-board correction made to account for the Geomagnetic Image Motion (GIM or GIM Problem = GIMP) it was also necessary to consider the instructions up-linked to HST for each observation.

This information can, in principle, be obtained from any of a number of potential sources (see the list below). However careful attention must be payed to the subtle differences between some of the sources. Some are more reliable than others, some don't contain the information one might have expected and some turn out to be rather elusive.

The required data that we will discuss here essentially concern the position and pointing of the spacecraft, the geomagnetic field in the vicinity of HST and the GIM correction (a voltage level applied to produce a corrective deflection) along with the models used and predictions made during the planning of the observation. The potential sources are then:

- The science and engineering databases
- The dataset headers
- The Science Mission Scheduler (SMS) files
- Byproducts from the mission scheduling process (Payload Operation Controls Centre (POCC) Application Software Support (PASS) products)
- The engineering data stream via the Astrometry and Engineering Data Processing (AEDP)

In our investigations we reached some dead ends as regards obtaining the exact information we desired. However, we were able to verify, sometimes via indirect methods, that uplinked commanding telemetry resulted in the proper execution of planned observations on-board.

One reliable source of information that we did have was those observations which included WAVECAL exposures aswell as some science exposures of HII regions and planetary nebulae. Such exposures allow the calibration of the wavelength scale regardless of the reported value. This enabled us to identify the zero-point shift for these datasets (see Kerber *et al.* 2000) which in turn enabled us to check for problems in the onboard GIMP correction applied.

This report contains a discussion of the various sources of information (sections 2 and 3) and how they were used in our analysis (section 4) followed by some comments on how future projects may learn from problems uncovered in this data flow process.

2 Finding the Input

2.1 science and engineering databases

The most convenient sources of information, in terms of quick and easy access for any automated procedure, are the science and engineering databases, this is essentially what they are for.

However these databases turn out to suffer from two deficiencies:

1. The content is limited. To record every single parameter up-linked and every sensor and detector reading that came back down would clearly have been impractical and unnecessary. Therefore the database was populated with those parameters for which the designers foresaw a need. Moreover, the resolution chosen was often also restricted. Unsurprisingly, in trying to fix an unforeseen calibration problem, we found that we needed parameters which were either not recorded at all, or not at a suitable resolution.

2. The data pipeline was put into place well before the mission became a reality. In order to test the data flow in the absence of real data, parameters to be up-linked were often used to fill the database where a real measured value (from the downlink) would be preferable. Although, of course, in the vast majority of cases, the databases were filled with the real data, in some cases the intended values (up-linked) may have seemed sufficient. For example, the pointing values that appear in the databases are in fact the intended pointing, not that which was actually achieved. For most purposes this was sufficient, however, when the possibility of automatically stacking WFPCII exposures was investigated at the ST-ECF, it became apparent that whilst exposures that were intended (by the PI) to be exactly aligned appeared to be so in the database, they were in fact shifted significantly.

Therefore we regarded the science and engineering database values as unreliable and not suitable for our purposes.

2.2 Header Information

The information recorded in the headers often suffers from the same two problems, though the headers do tend to be more comprehensive than the database tables. In the case of the WFPCII project already mentioned, the header information did reflect reality better than the database (essentially an alternative measure of the pointing was present which had been filled with actual downlinked values) However, the resolution was still not sufficient (for a task which, in fairness, was not envisaged when the data-flow process was implemented). This resulted in a need to extract information from the down-linked engineering data stream. STIS is also a well known candidate for header rework.

In general the headers are only *sometimes* accurate enough, often incomplete, and therefore cannot be used blindly in, for example, mass reprocessing of 24000 data FOS sets.

A further complication for the FOS is that the on-board GIMP correction was not part of the original header/software design. Keywords to carry information regarding details of the correction applied onboard were added later and restricted to indicate only whether or not the correction was applied and any error that occured. The magnitude of the GIMP correction is not present in the headers or the database.

So, the logical consequence was the investigation of more "primary" sources of information. To that end we retraced the chain of events that lead to the filling of the database and headers. We also investigated the software that predicts the GIMP corrections later to be loaded into the commanding stream.

2.3 Science Mission Specification

As a consequence of insufficient magnetic shielding on the digicon detectors the image formed on the cathode is subject to an offset caused by deflection in the Earth's magnetic field. The onboard (GIMP) correction counters this by applying a voltage, the magnitude of which depends upon the position and pointing of HST relative to the Earth, to create a counter deflection. One source of the GIMP voltages is the set of instructions up-linked to HST's on-board computer. The voltages levels that we are interested in are computed by the on-board computer according to a set of polynomial coefficients which are sent up with the mission schedule. Specifically the X and Y deflection voltages are given by:

$$X_{gimp} = A * TICK^3 * 2^{-24} + B * TICK^2 * 2^{-16} + C * TICK * 2^{-12} + D * 2^{-8} \qquad (1)$$

$$Y_{gimp} = Z * TICK^3 * 2^{-24} + Y * TICK^2 * 2^{-16} + X * TICK * 2^{-12} + W * 2^{-8}$$

where TICK is the time elapsed in integer multiples of 15 seconds. These coefficients are dependent upon the exact spacecraft position (in the Earth's geomagnetic field) at the time of the proposed observation. Therefore they are highly sensitive to the spacecraft ephemeris. HST's ephemeris model is continually updated with the latest information from the spacecraft itself. A more thorough description of the calculation of on-board GIMP correction coefficients can be found in, for example, Fitch *et al.* 1993.

The science mission specification (SMS) is submitted to the mission scheduler (or more accurately the "Payload Operation Controls Centre (POCC) Application Software Support (PASS) Mission Scheduler Subsystem") some seven days before its planned execution and a complete commanding stream ready for processing by the command loading subsystem is produced. Therefore one finds in the SMS the coefficients calculated with the ephemeris from at least seven days prior to the observations. However, these are not necessarily the final values used, further modifications are made according to the ephemeris as estimated nearer the time of the observation. In fact the times in the SMS are given in orbit relative format, e.g. *ORB,34892,EASCNCR,02H14M28.000S* meaning 2 hours 14 minutes 28 seconds since the ascending node crossing in orbit 34892. Only when the SMS is run through PASS, are these orbit relative times resolved into absolute times [1]. Fortunately at this stage some further output, so called *PASS Products* are produced.

2.4 PASS Products

One of the PASS products is the "CTReport". Here, finally, we find the actual GIMP coefficients that were up-linked. They appear in hexadecimal (all negative numbers have +4000Hex) and are accompanied by a parameter, COMPDUR, specifying the duration of the polynomial to be fit. COMPDUR has a lower limit of 900 seconds even for short exposures. Exposures longer than 1800 seconds have additional polynomials up-linked, since the fit from any one polynomial is only good for 1800 seconds. A typical "GIMP block" in a CTReport looks like this:

```
                              MMLWDSSW  0200002            96:141
04:06:37   2822439    S1520364**  N   ATP   NS TABLE FMT:YFGMPCRE, CMD:  1\
                                0001833&
                                0000001Z
 0.00359   3800700T  :FOSGIMP,COMPDUR(900),ENABLE,OPMODE(ASCALE)
  ;;S152036500Z
 0.00360             ,ORIENT(1.98073916666667E+02,3.5255725E+01
  ;;S152036500Z
 0.00361             ,4.68378589999902E+01),TIME=(ORB,33108,EASCNCR
  ;;S152036500Z
 0.00362             ,02H21M17.000S)
  ;;S152036500Z
 0.00363             ;SMSTIME=1996.141:04:06:38.000
   S152036500
```

[1] in fact the SMS undergoes several revisions during the period before it is up-linked, but no copy of the final version was routinely sent back to STScI nor was it kept at GSFC, except in the raw telemetry format, see section 2.4.1

```
                    MMLWDSSW  020000A          96:141 04:06:56   2822458
S1520365**  N   ATP   NS TABLE FMT:YFGIMPCB, CMD:  1&
                                  00018AB&
                                  00001E9&
                                  003FF10&
                                  003FEEC&
                                  0001101&
                                  003F8C5&
                                  000047C&
                                  003FEF3&
                                  003F2D4&
                                  0000000
```

The time at which $t = 0$ in equation 1 is 8 seconds after the time stamp (96:141 04:06:56 in the above CTReport example). This delay arises because the FOS housekeeping processor, which calculates the offsets from the up-linked parameters, only runs twice a minute. Subsequent evaluations of the polynomial then occur every thirty seconds.

Unfortunately it seems that there was no requirement to archive these files. Some people have kept personal copies for their own use, but we were not able to locate any such files dating back to before May 1996, consequently we have this data only for the last 8 months of FOS's operational lifetime. Therefore adding header keywords of all post-onboard-correction datasets containing details of the GIMP voltages would not be possible.

The hope had been that, by using science observations with spectral features that enabled the true zero-point to be determined, we could examine the correlation between the GIMP voltage applied and the resulting zero-point shift. However we were out of luck here, by chance, we had no science cases from the period covered by CTReports, which we could use to accurately measure the zero-point offset.

2.4.1 Up-linked Telemetry

Clearly the polynomial coefficients were at some stage up-linked and one would expect that the actual up-linked telemetry would be recorded somewhere. This is indeed the case, but there was no requirement to send this back to STScI (the CTReports on the other hand were sent back to STScI but then seem to have been disposed of). During the FOS era, the telemetry was recorded on VAX VMS backup tapes which were stored in a NASA storage facility, now containing some 36000 tapes[2]. Searching such a large collection of tapes (even assuming that we could obtain the appropriate hardware and software) is simply not possible with our resources so we abandoned this possibility.

3 Finding What Happened: AEDP

Whilst looking for the details of what was up-linked, we were simultaneously searching for reliable evidence of the GIMP correction applied, in what came back down. The engineering data stream contains the keywords YFXGIMPC and YFYGIMPC which record the X and Y GIMP voltages applied respectively. They are updated twice a minute at minor frames 14 and 74 for YFXGIMPC and 15 and 75 for YFYGIMPC. Unfortunately the values recorded are not of a high enough accuracy to determine a correlation with zero-point offsets seen in the science cases and WAVECALs.

4 Analysis

So, rather frustratingly, vital information was lacking in several areas. However the information that we had managed to gather did enable some checks on the implementation and effects of the on-board correction.

Therefore we compared the AEDP values with the values that would be obtained from the flight software and from algorithms developed by the IPMG. Figures 1a & b show that the on-board algorithm is consistent with the IPMG algorithm for X and Y deflections respectively, moreover they both fit the AEDP downlinked values well. Note that the AEDP values were stored as values between zero and 256, (negative values having had 256 added) so that the flight software and IPMG values had to be scaled to achieve the fit (a factor of 6 for the X deflection and 10 for the Y deflection). Nevertheless, the shape and phase agreement are convincing evidence that the GIMP corrective was implemented as we would expect from our understanding of the flight software *and* according to our own models.

A similar analysis of AEDP magnetometer values showed good agreement between magnetic field values predicted by the flight software/POA software and the on-board magnetometers. Figures 2 a, b & c show the AEDP values G315, G316 and G317 respectively compared with the POA computed values along the appropriate axis. AEDP values G311, G312 and G313 come from a second magnetometer magnetometer with a different orientation. G311 and G312 are

[2]These tapes are scheduled to be destroyed in the near future owing to the high cost of storing them

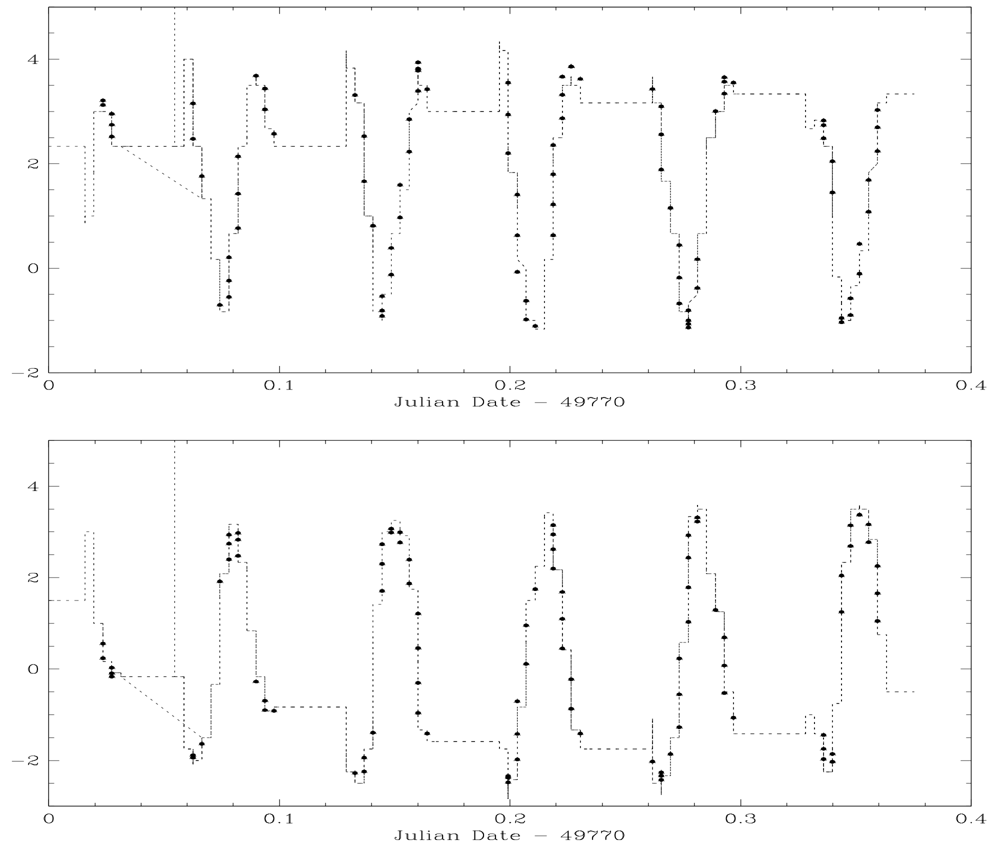

Figure 1: **Agreement between AEDP and predicted GIMP Deflections. a:** X-deflection **b:** Y-deflection **Key:**filled circles=flight software algorithm, Stars=IPMG Algorithm, dotted line=AEDP values. Note the coarse sampling of the AEDP data in the deflection dimension. Irregular spikes reflect periods of telemetry drop out.

simply the inverse of G315 and G316, suggesting of course that this magnetometer is simply pointing in the opposite direction. Curiously though, G313 does not match G317 (see figure 2c). This seems to be a disagreement between the on-board magnetometers which we have not investigated further. Instead we take the agreement with G315-7 as verification of our magnetic model.

5 Conclusions and Suggestions

We experienced many difficulties when trying to obtain accurate information regarding the operation of FOS. Such problems have been reported elsewhere (WFPCII project) and make the implementation of automated recalibration and data reduction routines for archive data very much more difficult to implement. In this instance, the implementation of an on-board fix

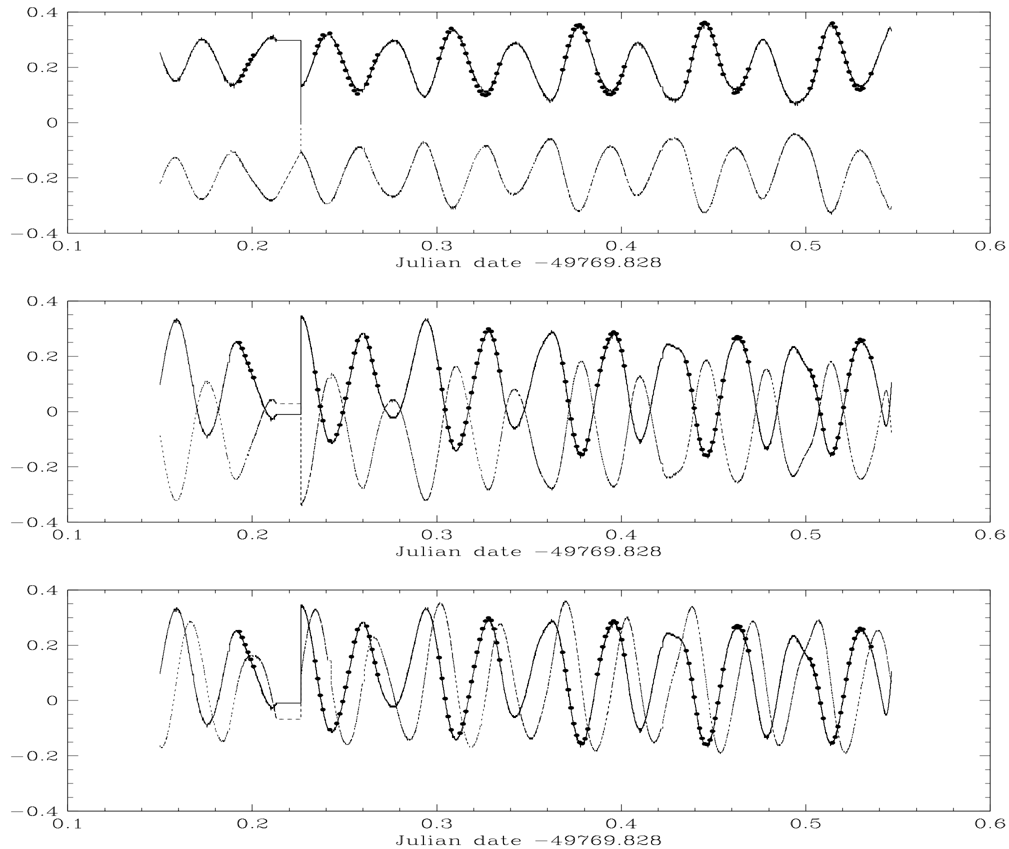

Figure 2: **Agreement between magnetic model and onboard magnetometer readings. a:** N/G315/G311 component **b:** E/G316/G312 component**c:** D/G317/G313 component. **key:**filled circles=N component from model, solid line=G315/G316/G317, dotted line=G311/G312/G313. Irregular spikes reflect periods of telemetry drop out.

which required modifications to the original data flow process lead to a situation in which many physical diagnostics of the observing process have not been recorded in headers or databases.

We did find useful diagnostics which enabled us to answer some questions. The AEDP downlinked GIMP corrective deflection values reflected the flight software algorithm and both matched the IPMG algorithms. Furthermore we verified that our magnetic model reproduces the on-board magnetometer readings as seen in the AEDP data. Nevertheless, the data we used was obtained via a circuitous route rather than directly from headers or databases and further data which would have been more useful proved to be unobtainable and probably no longer exists.

All this leads to some reflections on the current data flow process. At present it involves an exchange of information between a number of packages (say RSDP, PRESTO, SPIKE, PASS, SMS, observation, OPUS) via the project database. Some of these packages interpret the data and even have hardwired "corrections" to compensate for misunderstandings (which were tweaked later on). Most of this happens before the actual observation, so that many items have to be predicted, in particular everything to do with attitude and orbital position.

Therefore it may be necessary to tap firstly the commanding at the latest possible stage before upload and secondly the engineering telemetry in order to provide input for an improved calibration process. This could then be supplied to an "on-the-fly pre-processor", which prepares the data for improved calibration.

This could even be envisaged as a super-pipeline concept for future instrument/telescope operation scenarios as well. Rather than relying on the proper propagation of data through a long chain of processes between proposal submission and down-link we peek always at the PRIMARY source of data (e.g. PI name from RSDP; HST roll not from planning but from flight ops; temperatures from engineering; filter wheel location from engineering, not from the many stage process of converting "F578M" into FW-5780-MED" into turn wheel 31327 steps). In this way many of the potential pitfalls are sidestepped and the exception table scenario of instruments such as STIS is avoided.

References