# Pointing accuracy (Moderator: C. A. Stephenson)

## *Introduction*

The pointing accuracy of the Herschel Observatory is characterized by a number of measures. The most important of these is the Absolute Pointing Error (APE), which is defined as being the instantaneous separation between the actual and the commanded payload attitudes (RD.1). The APE is split into two components: the angular separation of the actual and the commanded boresight directions and the angular separation about the (actual) boresight direction. For Herschel, the first of these is the most critical and,[1] for pointed observations, the requirement is that it should remain below 3.7" for 68% of the time (RD.2).[2] Henceforth, we will follow common practice and refer to the 68th percentile of this quantity as being the APE.

During the commissioning of the service module a gyro anomaly was observed and corrected, which unresolved would have led to a violation of the 0.3" (over 1 min.) requirement on the Relative Pointing Error (RPE). Following the resolution of this problem, calibration measurements indicated the APE to be about 2", a value close to the goal of 1.5" (RD.2).[3] With the In-Orbit Commissioning Review concluding that the pointing performance was "fully in line with expectations" [H127], it was then only natural that the attention of the Herschel team turned towards other more pressing matters. An exception to this was the problem of the 'speed bumps' and star tracker switchovers, which was found to be due to the presence of 'warm' pixels on the star tracker CCD. The star tracker CCD had initially been operated at the manufacturer's nominal temperature of 20C (RD.3, p.15) and, after initially flagging the warm pixels as bad, the problem was resolved definitively in OD320 by reducing the temperature set-point to -10C.[4]

A further year passed before it was realized that this reduction in the temperature had simultaneously changed the distortion of the star tracker CCD, degrading the APE. In OD762, this change in the distortion was compensated by modifying the on-board value of the star tracker focal length and with this the APE was reduced to a value below that measured during commissioning. Further work to improve the CCD distortion model continued and, following the updates to the on-board distortion

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[1] Action: Need to check with Miguel as to whether the other APE component was ever measured and if so what the result was.

[2] Since the distribution of the APE has neither zero mean nor is normal, the requirement is not readily expressed in terms of its standard deviation.

  There is a similar, slightly less restringent, requirement on this component of the APE during scans.

[3] The APE was estimated by means of a dedicated programme of pointing calibration measurements made using PACS. It is noted that the estimates do not include the contribution from the spacecraft jitter and that they assume the pointing errors about the spacecraft *y*- and *z*-axes to be normally distributed, with the means of these distributions providing the instrument misalignments.

[4] It was stressed that the term 'pointing problem' should only be applied to issues associated with a violation of the pointing constraints [H142]. Therefore on Herschel there were just two pointing problems: the gyro anomaly and the CCD temperature issue. All subsequent pointing activities were directed at 'pointing improvements'.

correction coefficients in ODs 866 and 1011 and the flagging of certain stars in the catalogue as 'bad' in OD1032, it is believed that, in general, an APE below 1" was finally achieved.[5]

## *Requirements*

The PACS team stressed from very early in the mission that the APE of 2" achieved during commissioning, although far superior to the required 3.7", was still inadequate for their instrument. This was also the situation on the Infrared Space Observatory (ISO) mission, where certain instruments would have been effectively crippled had the pointing accuracy not been improved far beyond the specifications. There is also consensus that the pointing modes were fixed too early in the mission [H4, H144], requiring the Herschel Science Centre to construct composite modes, which proved to be both cumbersome and inefficient.

- ➢ Ensure that the specifications on the spacecraft's pointing (and its ACMS modes) develop in harmony with those on the instruments [H4, H144].

- ➢ Never accept pointing specifications that are inadequate for the instruments [H127, H153].

(There was a strong division of opinion in the Meeting over the above two lessons, with some believing that expecting the requirements to be realistic is itself not realistic.)

- ➢ Involve the instrument scientists in defining the specifications and balance any additional development costs against those of dealing with an inadequate system [H4, H127].

- ➢ Base the instrument calibration plans upon realistic expectations of the pointing performance [H127].

- ➢ Remind Industry that many requirements specify only the minimum functionality (avoid imposing arbitrary restrictions and over-specify where possible) [H4, H191].

- ➢ Avoid features that complicate the concatenation of ACMS pointing modes [H4, H144].

## *Resources*

Early in the mission the ESA project office lost their pointing expert and the responsibility for the commissioning was passed to the instrument teams. In response, the Herschel Science Centre set-up a Pointing Working Group (PWG), with members from Industry, all instrument teams, Flight Dynamics and the project office. There is general agreement that during commissioning the PWG worked very well; the main problem was in maintaining its momentum into routine operations. For this, the resources proved wholly inadequate. In addition to a lack of available staff, difficulties were encountered in gaining access to information essential for pointing improvement activities [H127, H142]. Access to the documentation on the star catalogue was initially restricted and the provision of in-flight test data from identical gyros

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[5] An exception to this is the degradation of the APE noticed when operating within a certain range of the solar aspect angle, the so-called 'warm attitude' problem.

(flown on a number of military satellites) was denied due to the data's sensitive nature. However, it was precisely the failure of the gyros to meet the specifications that forced the 'CP raster' mode to be abandoned [H192]. The telemetry data required for a ground-based pointing reconstruction (see below) did also not become available until late in the mission.

> Plan the PWG several years before operations start and include representatives from Industry, the instrument teams, Flight Dynamics, the project office and the Science Centre [H127].

> The PWG must have access to all relevant information (documentation, star catalogues, in-flight test data,...) [H127, H142, H192].

> Ensure availability of sufficient resources to plan and implement pointing improvements [H127, H142].

> To facilitate efficient communication, at least one member of each instrument team should have a good understanding of the pointing system [H127].

The PACS ICC has published various reports criticizing the design of the Herschel ACMS and believes that the latter was not properly tuned.

> When allocating the resources for pointing improvement work, take into account the limitations of the ACMS [H127].

## *Pointing improvements: planning and implementation*

With attention early in the mission focused first on the gyro anomaly and then on the problems caused by the warm pixels, general improvements to the pointing performance were not considered until very late in the mission. This delay could have been avoided had a plan for improving the pointing been in place. Therefore, a key recommendation, for which there was universal agreement at the Lessons Learned Meeting, is:

> Ensure that a plan for improving the pointing accuracy is in place following commissioning [H142].

Learning from problems experienced on the ISO mission, the Herschel star tracker included improvements to its CCD distortion model. However, no plan was produced for estimating the model's various on-board parameters, which remained set at their pre-flight values for much of the mission.

> Plan in advance how to estimate and use the various on-board parameters associated with the attitude sensors (and actuators) [H153].

Assurances were received from Industry that reducing the operating temperature of the star tracker's CCD would have little effect other than the one desired (i.e. the elimination of the warm pixels). It was found, unfortunately much later in the mission, that this was entirely untrue.

> Ensure that key parameters of key devices are understood [H181].

- ➢ Be critical of information and assurances received from Industry [*private communication*].

- ➢ On-board changes affecting the attitude sensors (or actuators) demand a re-assessment of the pointing performance and fast feedback [H142].

Another measure of importance for characterizing the pointing accuracy is the Absolute Measurement Error (AME), which is defined as being the instantaneous separation between the actual and the measured (estimated) payload attitudes (RD.1). Whilst the system requirements apparently apply to the real-time, on-board AME, what is really of importance for instruments such as PACS is the value of the AME corresponding to the best estimate of the pointing direction, which may be the output from a more-accurate ground-based reconstruction.[6]

Throughout the Herschel mission progressively better estimates of the distortion of the star tracker CCD have been obtained and subsequently reflected in the values of the on-board parameters used by the ACMS. Concomitantly, software has been developed on-ground to correct the attitude from the on-board filter for the known residual distortions. This software is now evolving into an independent ground-based pointing reconstruction. A serious hindrance for this work has been the absence on-ground, for much of the mission, of important data from the attitude sensors.

- ➢ Perform—and importantly plan in advance—a ground-based pointing reconstruction in order to reduce the AME below that which may be achieved on-board [H127].

- ➢ Downlink all required data (at full bandwidth) for a ground-based pointing reconstruction [H127].

## *References*

RD.1: D. G. Dungate, ESA Pointing Error Handbook. ESA-NCR-502, Vol. 1, VEGA, 19 Feb 1993.

RD.2: ESA Herschel / Planck Project Team. System Requirements Specification [SRS]. SCI-PT-RS-05991, Issue 3/3, 27 Jul 2004.

RD.3: S. Gigli and G. Berrighi. ASTR for HERSCHEL/PLANCK User Manual. Technical Report H-P-4-GAF-MA-0001, Issue 3, Galileo Avionica, Oct 2004.[7]

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[6] The availability on-ground of measurements both before and after the time of the observation allows a ground-based attitude estimator to achieve greater accuracy than may be achieved on-board.

[7] Note: I have contacted Gottlob Gienger in an attempt to obtain Issue 7 of this document.