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FIRST/Planck Project

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subject **FIRST - AOCS pointing performance (Action AI-FI-06892-02)**

Following the FIRST AOCS Instrument Meeting held at ESTEC on 11 June 1998, please find attached, for your information, the relevant paragraphs of the updated FIRST/Planck Satellite System Requirements Specification "Carrier" concerned with the FIRST Pointing performance.

Attached are the following paragraphs:

4.2 Operation Modes
4.2.1.1 FIRST Science Observations
4.2.1.3 Payload Operational Mode
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4.3.3.2 FIRST Tracking Solar System Objects
4.3.3.3 FIRST Nodding

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The document RD-17 FIRST Scientific Pointing Mode (PT-SP-04673) is currently under review and could be transmitted to you by end August.

If you have any comments on the subject, do not hesitate to contact us.

Regards,

F.C. Vandenbussche

H. Schaap

4 MISSION OPERATIONS

4.1 GENERAL REQUIREMENTS (valid for both spacecraft)

MOGE-005 F/P *The satellite design shall enable the operational control by the ground segment during all mission phases and modes in both nominal and contingency situations.*

MOGE-010 F/P *The spacecraft shall be able to support continuous communications with the ground during station visibility periods.*

MOGE-015 F/P *During all mission phases and operational modes the spacecraft shall be able to receive telecommands and transmit housekeeping data in any attitude of the spacecraft.*

MOGE-020 F/P *The spacecraft design shall support the following telemetry modes:*

- *Real time housekeeping data (spacecraft and payload)*
- *Real time science + real time housekeeping data*
- *Real time housekeeping data + dump of on-board mass memory*
- *Real time housekeeping +real time science + dump of the on-board mass memory*

4.2 OPERATIONAL MODES

The satellite operational modes and related requirements are defined in this section. They are managed either by the spacecraft, or from the ground.

MOOM-005 F/P *Each spacecraft shall support all the modes of operation defined for the corresponding mission.*

4.2.1 Science Observation Modes

4.2.1.1 FIRST Science Observations

As an example, during FIRST Science Observations, the spacecraft will be capable to support the pointing modes defined in RD-17.

MOOM-010 F *No attitude constraints, other than the attitude constraints listed in Section 3.2.7 apply during science observations.*

The FIRST FOR is defined as the collection of all possible instantaneous directions of the optical axis of the telescope such that none of the constraints on spacecraft attitude are violated. The FOR is thus equivalent to the instantaneous sky coverage.

The Line of Sight (LOS) of an instrument is defined as the direction in the sky of the chief ray of the instrument. Because the instruments share the focal plane, the LOS of each instrument is in general slightly different from the optical axis of the telescope; but it is of course within the telescope Field of View (FOV). For each instrument the FOR will be slightly different. This difference will be neglected in the following.

Because of these different LOS's the three FIRST instruments cannot observe the same (non-extended) target simultaneously. In general each observation will be executed with a single instrument **(the prime instrument)**. Nevertheless it might be useful to execute observations simultaneously with a second instrument. Because of the secondary importance of these observations, full operational configuration capability of the second instrument is not required but a so-called **parallel mode** would be selected for these secondary observations. In this mode the "parallel" FIRST instrument is operated in a fixed configuration, i.e. no change in power dissipation in the Focal Place Unit is allowed. In this case the two instruments share the available TM bandwidth.

MOOM-015 F — *During the Observation Period it shall be possible to point the LOS of the prime instrument to any target within the FOR according to any of the operational observing modes as described in RD-17.*

MOOM-020 F — *During the Telecommunication Period it should be possible to point the LOS of the prime instrument to any selected target within the FOR whose coordinates are compatible with telecommunication phase Earth-pointing requirements.*

FIRST Fine Pointing Mode

The fine pointing mode consists of observation pointings, followed/preceded by slew(s).

MOOM-*025 F* — *During science observations, the pointing requirements corresponding to the selected observation mode shall be met.*

MOOM-030 F — *It shall be possible to maintain the fine pointing for periods of up to 22 hours, during which momentum unloading and wheel speed reversal shall not occur.*

4.2.1.2 Planck Survey Mode

Being the mission in principle an all sky coverage, all effort will be made to maximise it. The optical axis of the Planck telescope (Line Of Sight = LOS) will be 5° from the -X axis in -Z direction (see Figure 5.1.1. and AD-2.2)

MOOM-035 P — *The spin axis of the Planck spacecraft shall be nominally parallel to the +Z-axis and pointing to the Sun.*

MOOM-040 P — *The direction of the spin shall be unique throughout the mission.*

MOOM-045 P — *The spacecraft shall be capable of re-pointing the spin axis to ± 10° away from the Sun.*

MOOM-050 P — *The orientation of the spacecraft spin axis out of Sun direction shall remain within the envelope defined by the amplitude of the Lissajous orbit seen from the Earth.*

4.2.1.3 Payload Operational Modes

MOOM-061 F *The FIRST spacecraft must as a minimum support the modes of instrument operation as specified in Table 4.2.1.3.*

MOOM-062 P *The Planck spacecraft must as a minimum support the modes of instrument operation as specified in Table 4.2.1.4.*

MODE	HIFI	PACS	SPIRE
#1	Prime	Off	Off
#2	Off	Prime	Off
#3	Off	Off	Prime
#4	Off	Prime	Parallel
#5	Off	Parallel	Prime

Table 4.2.1.3. - FIRST Payload Operational Modes

MODE	HFI	LFI
#1	Prime	Prime
#2	Prime	Off
#3	Off	Prime

Table 4.2.1.4. - Planck Payload Operational Modes

- **FIRST Mission**

During slews from one target to another it might be desirable to operate either SPIRE or PACS in a fixed default configuration the so-called **serendipity mode**. In this mode no change of power dissipation in the Focal Plane is allowed and no guarantee is given w.r.t. slew performance but the instrument can use the full amount of TM allocated to it. No parallel observations are allowed in this mode.

MOOM-065 F *During satellite slews, the FIRST satellite shall provide all the resources necessary for operation of at least one science instrument in serendipity mode. Such science observations shall not put any demands on the spacecraft attitude profile.*

MOOM-070 F *During the Telecommunication Period, the satellite shall provide all the resources required to operate one instrument in any of its fully operational mode. Such observations shall be executed at an attitude compliant with the attitude constraints during the Telecommunication Period.*

- **Planck Mission**

MOOM-080 P *The mission and spacecraft design shall allow for complete (2) sky coverage in any period of 6 to a maximum of 7.5 months during the routine operations phase.*

MOOM-085 P *During the Telecommunication Period the Planck satellite shall provide all resources required to operate both instruments in their nominal operational modes.*

4.2.2 Calibration Mode

This mode will be used to measure the relative angles between the lines of sight of the instruments and the axes of the primary attitude.

4.2.2.1 FIRST Calibration

Extensive initial calibrations shall take place during the Performance Verification phase.

In addition the validity of these initial calibrations will be checked periodically by a single calibration.

MOOM-095 F *A calibration mode shall support execution of multiple calibrations in order to establish the angles between stellar reference and the instruments lines of sight such that the pointing requirements of the fine pointing mode can be met at all possible spacecraft attitudes satisfying the attitude constraints of Section 3.2.7. and for all possible spacecraft operational conditions.*

MOOM-100 F *During the routine operations phase, the spacecraft shall be able to support a check of the validity of the initial calibrations by a single calibration not exceeding 10 minutes every 24 hours (at the start of the Observation Period (OP). A ground facility shall be provided to update, if necessary, the calibration values such that the pointing requirements of the fine pointing mode can be met during the next 24 hours.*

4.2.2.2 Planck Calibration

MOOM-105 P *It shall be possible to derive the absolute angle between the LOS of each Planck detector and the actual attitude of the spacecraft with accuracy compatible with the Planck pointing requirements (AME).*

4.2.3 Survival Mode (valid for both spacecraft)

The purpose of the survival mode is to maintain safe spacecraft and instruments after a major on-board failure or a violation of the attitude constraints. While in Survival Mode, the on-board schedule is discontinued.

MOOM-110 F/P *The survival mode shall be activated automatically by the S/C after a major on-board failure or a violation of the attitude constraints of Section 3.2.7. It shall maintain a safe attitude within the constraints allowing a continuous supply of power and maintaining a stable*

thermal environment compatible with the spacecraft and instrument requirements. It shall ensure a two way communication link with the ground station when coverage is available for at least housekeeping telemetry data and commanding (i.e. providing suitable link margins with omni-directional coverage). It shall maintain spacecraft and instruments in safe conditions.

MOOM-120 F/P *It shall be possible to enter the survival mode by ground command. Exit from the survival mode shall only be possibly by ground command.*

MOOM-125 F/P *The spacecraft shall be able to maintain the survival mode without any ground contact for at least seven days.*

MOOM-130 F/P *The survival mode shall not rely on any Random Access Memory stored data.*

MOOM-135 F/P *The exact attitude during the survival mode may not be known, but the attitude constraints of Section 3.2.7. shall be satisfied.*

4.2.4 Autonomy Mode (valid for both spacecraft)

During all mission phases, the spacecraft will be capable of operating nominally without ground contact for a period of at least 4 days without interrupting the planned operations. Beyond this pre-programmed period it shall go automatically in survival mode.

The Autonomy Mode is the normal mode of operation during the routine phase. The general autonomy, and fault management requirements are given in Section 4.4 of this document and the FIRST/Planck Operation Interface Requirements Document [AD 3-3].

MOOM-136 F/P *The spacecraft design shall comply with the AD 3-3 requirements.*

The mission will be executed according to a mission timeline, which will be uploaded at regular intervals and consists of procedures, lower level actions and/or single commands, to be executed at specified times.

MOOM-140 F/P *The spacecraft shall support on-board storage of the mission timeline for a 4 days mission time.*

MOOM-145 F/P *The spacecraft shall support autonomous (i.e. without ground contact) execution of the mission timeline.*

MOOM-150 F/P *The spacecraft shall support rescheduling of planned events in the mission timeline.*

MOOM-155 F/P *The time resolution of the mission timeline shall be 1 s (TBC).*

MOOM-160 F/P *If no ground command has been received since more than a ground programmable time, the survival mode shall be initiated.*

MOOM-165 F/P *In case the survival mode is entered because no ground command has been received, the spacecraft shall begin an automatic search phase in order to re-establish command reception capability.*

MOOM-166 F/P *It shall be possible to exit from the Autonomy Mode by Ground Command.*

MOOM-180 F/P *An On-Board Monitoring Function (OBMF) shall be provided, capable of monitoring any housekeeping parameter and any non-science telemetry packet generated by the subsystems and/or the payload, including internal Command and Data Management Subsystem parameters.*

4.3 OPERATIONAL FUNCTIONS

In addition to the operational modes described in Section 4.2, the following operational functions must be provided.

4.3.1 Angular Momentum Management

If the Planck S/C design includes wheels the following requirements are applicable to both FIRST and Planck. If not, to FIRST only.

MOOF-005 F/P *The spacecraft shall be capable of autonomous wheel off-loading.*

MOOF-010 F/P *Under nominal conditions during the scientific operations phase, wheel off-loading shall take place outside the Observation Phase (OP).*

MOOF-015 F/P *Initiation of wheel off-loading shall also be possible by ground command.*

MOOF-020 F/P *Off-loading, as well as up-loading, of each reaction wheel shall be possible to a ground-commanded value.*

4.3.2 Pointing Requirements

The following terminology shall be used:

- **Absolute Pointing Error (APE):** is the angular separation between the desired direction and the instantaneous actual direction
- **Pointing Drift Error (PDE):** is the angular separation between the short time average (barycentre of the actual pointing during some time interval) and a similar average pointing at a later time. The drift is given over 24 hours during the same observation period.
- **Relative Pointing Error (RPE):** is the angular separation between the instantaneous orientation of the satellite fixed axis at some time t and a reference axis (average, barycentre) over a defined period. This is also known as the pointing stability.
- **Attitude Measurement Error (AME):** is the angular separation between the actual and the measured orientation of the satellite fixed axis defined instantaneously. This performance requirement is referred to as "a posteriori knowledge".
- **Absolute Rate Error (ARE)** : is the angular separation between the actual and the controlled angular rate about the satellite spin axis.

In addition, for the FIRST Mission, the following "unconventional" term is defined which is specifically applicable to modes where a number of pointings are commanded relatively close to each other (e.g. for raster pointing).

- **Spatial Relative Pointing Error (SRPE) :** is the angular separation between the instantaneous orientation of the satellite fixed axis at some time and a pointing reference axis which is defined relative to an initial reference direction.

The pointing requirements specified below refer to the instruments Line of Sight (LOS) as defined by external references on the Focal Plane Units. Contributions to the pointing error which are instrument- and catalogue related shall not be taken into account in establishing the pointing budget.

Unless otherwise specified, the pointing error specifications are expressed as half-cone angles of the optical axis and half-angles around the optical axis. They are specified at a temporal probability level of 68% (1σ), which implies that error will be less than the requirements for 68% of the time.

MOOF-025 F/P *The pointing budget shall demonstrate compliance of the design with these requirements; it shall be established according to the rules defined in the ESA Pointing Error Handbook (RD-9).*

Two different requirements for the scientific observing modes are to be taken into account : The FIRST mission and the Planck mission.

4.3.2.1 FIRST Pointing Requirements

MOOF-030 F *During all scientific observation modes requiring periods of stable pointing, the pointing requirements with the goals as specified in the table below shall be met with a single calibration once per 24 hours.*

ERROR	*Optical Axis (arcsec)*	*Around Optical Axis (arcmin)*	*Goals (arcsec)*	*Goals around Optical Axis (arcmin)*
APE	*≤3.7*	*3.0*	*≤1.5*	*3.0*
PDE(24 hours)	*≤1.2*	*3.0*	*n.a.*	*n.a.*
RPE (1 min)	*≤0.3*	*1.5*	*≤0.3*	*1.5*
AME	*≤3.1*	*3.0*	*≤1,2*	*3.0*

MOOF-035 F/P *The Contractor shall specify under which conditions the goals will be achieved.*

MOOF-040 F *In consecutive pointings within 4 deg. x 4 deg. spherical area, the **SRPE** of all pointings following the initial pointing, as referred to the average (barycentre) pointing direction of the first pointing shall be less than 1 arcsec.*

Thus with the terminology used in the definition of SRPE, the initial reference direction is the average direction of the first pointing. The actual direction of the first pointing will lie within a cone of half angle RPE around this reference direction. The

pointing reference axes for all consecutive pointings are specified as angular co-ordinates with respect to the initial reference direction and pointing errors of consecutive pointings are specified with respect to these reference axes, respectively.

4.3.2.2 Planck Pointing Requirements

MOOF-045 P *During the sky survey mode, the pointing requirements are specified in the table below:*

ERROR	*Optical Axis (arcmin)*	*Around Optical Axis*	Goals (arcmin)
APE	*≤ 37.0*	*TBD*	
PDE (24 hours)	*≤ 6.2*	*TBD*	
RPE (30 min)	*≤ 1.5*	*TBD*	
AME	*≤ 1.0*	*TBD*	*≤ 0.5*
ARE		*5.4 arcmin/sec*	

MOOF-046 P *The spin axis motion about the spacecraft Z-axis pointing to the Sun shall be at constant rate of 1 rpm (6 °/sec).*

MOOF-050 P *The spin rate drift or fluctuation over one hour shall be less than 10^{-4}rpm.*

MOOF-051 P *The Absolute Rate Error about the satellite spin axis shall be better than 5.4 arcmin/sec*

4.3.3 FIRST Slewing Requirements

The observatory nature of FIRST implies that it will carry out a large number of observing projects with a wide range of observing times varying from minutes to hours. An indication of the possible modes of operation is given in the FIRST Pointing Mode Document [RD-17.

4.3.3.1 FIRST Slews

A slew is used to change the satellite pointing direction from the current set-point to the next set-point. The scanning mode is the mode when the telescope axis moves along the short parallel lines.

MOOF-060 F *It shall be possible to execute slews during all operational modes.*

MOOF-065 F *Slews shall nominally not use the Reaction Control Subsystem (RCS).*

MOOF-070 F *The maximum slew speed shall be at least 7 °/min when the slew angle is large enough to permit full angular velocity.*

MOOF-075 F *It shall be possible to change by command, scan rate between 0.1 arcsec/s and 1 arcmin/s with a resolution of 0.1 arcsec/s.*

MOOF-080 F *After a slew larger than 6 degrees, the satellite shall be able to acquire a new guide star in less than 30 seconds.*

MOOF-085 F *For slews smaller than 10 arcmin, during observational modes, the total time between initiation of the slew and the moment when the telescope axis is on the new target shall be less than 30 s to achieve the pointing requirements as defined in paragraph 4.3.2.1.*

MOOF-090 F *The system shall be dimensioned for operational slews of at least 90 degrees, executed twice per day. Such slews shall be completed within 15 min, including settling.*

No constraints, other than the attitude constraints listed in Section 3.2.7. apply to the slewing method.

4.3.3.2 FIRST Tracking of Solar System Objects

MOOF-095 F *The satellite shall be able to follow, by ground command of a slew polynomial objects such as planets, comets, etc. having a maximum speed relative to the tracking star of 10 arcsec/min.*

MOOF-100 F *The pointing requirements whilst tracking solar system objects shall be as defined in paragraph 4.3.2.1.*

4.3.3.3 FIRST Nodding

The FIRST Nodding Mode is an observing mode in which the target source is moved from one instrument chop position to the other chop position. In this case the pointing direction will change in the direction of the instrument chopper throw.

MOOF-105 F *The satellite shall be able to periodically change the telescope pointing direction such that the source is moved from one instrument chop position to the other position.*

MOOF-110 F *The angular distance between the two positions shall be commendable from ground and shall correspond to the instrument chopper throw (between 0 and 16 arcmin with a resolution of 0.5 arcsec).*

MOOF-115 F *The integration times in both positions are equal and shall be changeable by ground command within the range of 10 s to 20 min (depending on the throw).*

Although the above requirement specifies the minimum duration of stable pointing as 10 s, in many cases it is desirable to have a much smaller duration of stable pointing in order to execute the nodding more efficiently. The possibility of decreasing the minimum duration of stable pointing, down to 1 s as a goal, must be investigated and possibly traded-off against Relative Pointing Error.

MOOF-125 F *Specifically, for a throw of 5 arcmin, the total cycle time shall not exceed 3 min; i.e. 72 s integration in either position and two 5 arcmin slews lasting 18 s each (including settling time).*

MOOF-130 F *In both pointing attitudes the pointing requirements as specified in paragraph 4.3.2.1 shall be met.*

MOOF-135 F *Once the set of parameters defined above are specified and loaded on board, the nodding shall be done autonomously to allow the satellite to follow the required pattern, without further ground commands.*

4.3.3.4 FIRST Peaking Up

During the observation of bright sources, a way of correcting the blind pointing error when the source is bright enough is envisaged. The spacecraft perform a five-point cross scan (left, right, centre, up, down) and a double gaussian is fitted to the two three point linear scans by the instruments.

The pointing offsets in the two orthogonal directions are computed by the instrument and the spacecraft pointing is adjusted accordingly before a much longer integration on the now correct position is carried out.

Bi-directional exchange of position pointing between spacecraft and instrument is required.

MOOF-140 F *On acquiring a source the spacecraft shall carry out the five point routine as a standard sequence (with an integration time per point pre-selected to match the expected source brightness).*

MOOF-145 F *After reception of the pointing correction from the instrument, the spacecraft shall readjust its position. The correction shall only be allowed within predefined boundaries. The boundaries shall be updateable by telecommand.*

4.3.4 Planck Slewing Requirements

MOOF-150 P *The spacecraft shall be capable of reorienting the Spin-axis regularly with the following manoeuvre performance requirement :*

- *amplitude = 3 arcmin; any direction*
- *accuracy = 1 arcmin (amplitude and direction; 3 sigma probability)*
- *duration including the settling time ≤ 5 minutes (elapsed time during which pointing requirements cannot be met)*
- *frequency : one manoeuvre every hour (in average)*

MOOF-155 P *During a series of 24 such manoeuvres (24 hours elapsed time), the cumulated manoeuvres inaccuracies, plus the accumulated uncertainties in the drift shall be kept smaller than 10 arcmin (amplitude and direction; 95% probability).*

4.4 FAULT MANAGEMENT

An on-board monitor will continuously monitor the health of the spacecraft and the proper execution of the timeline. The active processor will be monitored by a dedicated hardware watchdog. If a failure is detected in the active processor (e.g. if it enters an endless loop, or self-detects a fault) the watchdog will shut down the faulty processor and wake-up the alternative processor which will continue the