HERSCHEL / PLANCK

Herschel system alignment plan

H-P-2-ASPI-PL-0276

Product Code: 000000

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TITRE

Herschel system alignment plan

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RESUME D'AUTEUR

Ce plan est le plan d'alignement système (satellite) de Herschel.

Les besoins d'alignement systèmes sont rappelés.
La séquence d'alignement et de vérification d'alignement est présentée
Les contributeurs sont identifiées, et les allocations sont présentées et justifiées.
Finalement les besoins d'alignement et stabilité sous-systèmes sont synthétisés.

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Herschel-Planck-alignement satellite

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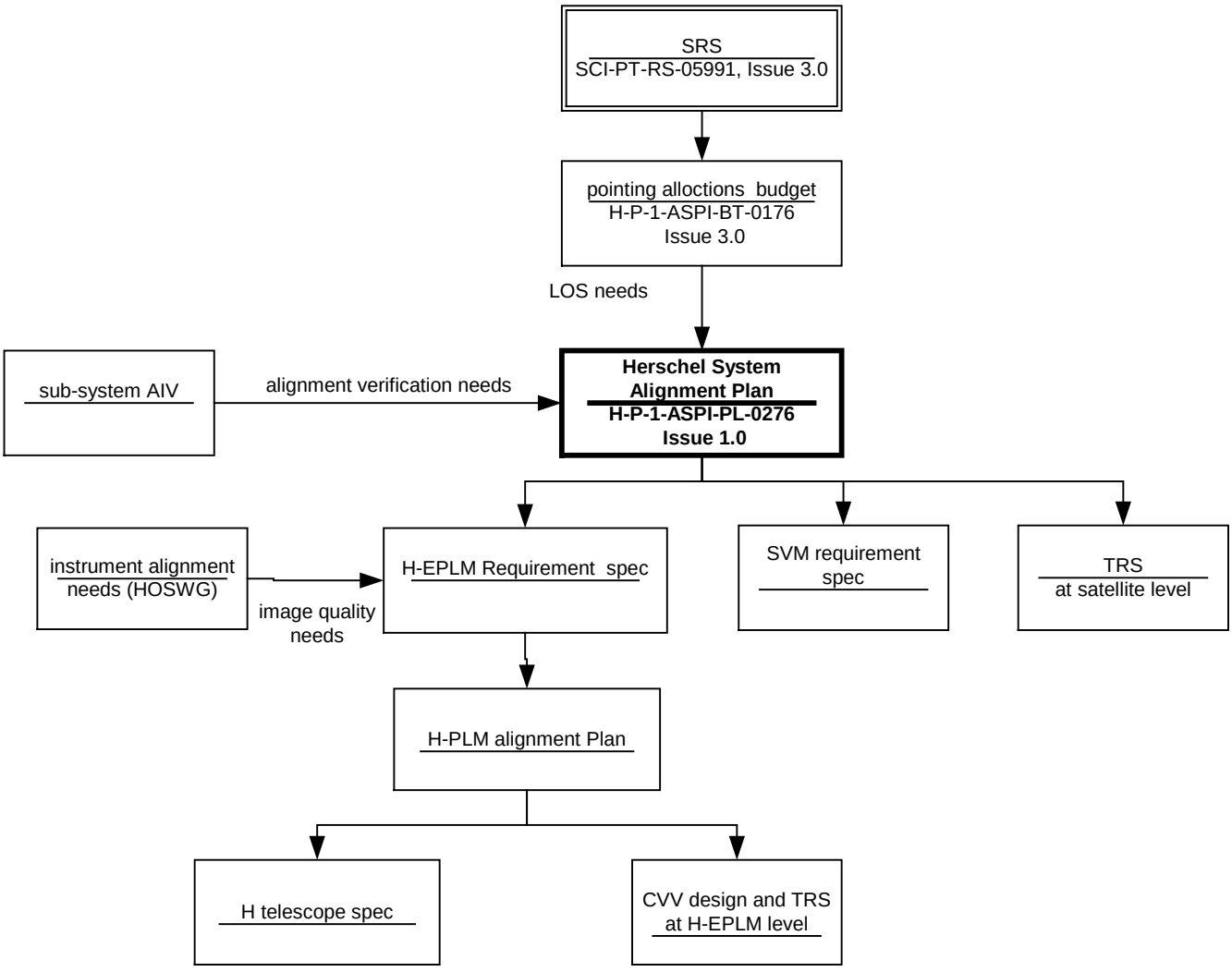
1. INTRODUCTION

1.1 Purpose of this document

This document provides the alignment plan for Herschel satellite. It describes the alignment needs, means, and verification at satellite level. The issues related to alignment of the telescope w.r.t instrument Focal Plane Units as well as LOU alignment are under ASED responsibility: they are described in document RD3.
This plan starts from the system alignment needs, as given by the Attitude and Control Monitoring system. Based on the alignment sequence, the contributors to each requirement are identified. A justified allocation is made for each one of them.
This plan also defines the optical interfaces and associated OGSE necessary to implement this alignment concept.
Finally the alignment requirements at sub-system level are synthesized.
This is illustrated by the following flowchart:



Nota: on some drawings included in this document, the spacecraft shows some minor differences with the baseline (for example the telescope still has it's tripod, whereas the current baseline is an hexapode). This is has no impact on the validity of this document, as the drawing 's only purpose is the illustration.

1.2 Reference and applicable documents

1.2.1 Applicable documents

[AD1] "System Requirement Specification"
SCI-PT-RS-059111 Is/Rev 2/1

[AD2] "STB of alignment tools Cube-tooling ball-target"
ref ASPI/01/BO/IT/MP/034

[AD3] "Inputs to Herschel System Alignment Plan"
ref: H-P-2-ASPI-TN-0217 is/rev 1.0

[AD4] "Herschel and Planck Pointing budget module allocation"
ref H-P-1-ASPI-BT-0176 is/Rev 3/0

1.2.2 Reference documents

[RD1] "SVM Requirements spec"
ref H-P-4-ASPI-SP-0019 Is/Rev 2/1 07.06.02

[RD2] "Herschel SVM: Interface with CVV struts and SSH struts"
ref F0278C HESA 180S000S A Ind D

[RD3] "Herschel alignment concept"
ref H-P-2-ASPI-TN-0002 Is 1 24.05.02

[RD4] "H-EPLM requirements specification"
REF H-P-2-ASPI-SP-250 Is/Rev 1/0 30.05.02

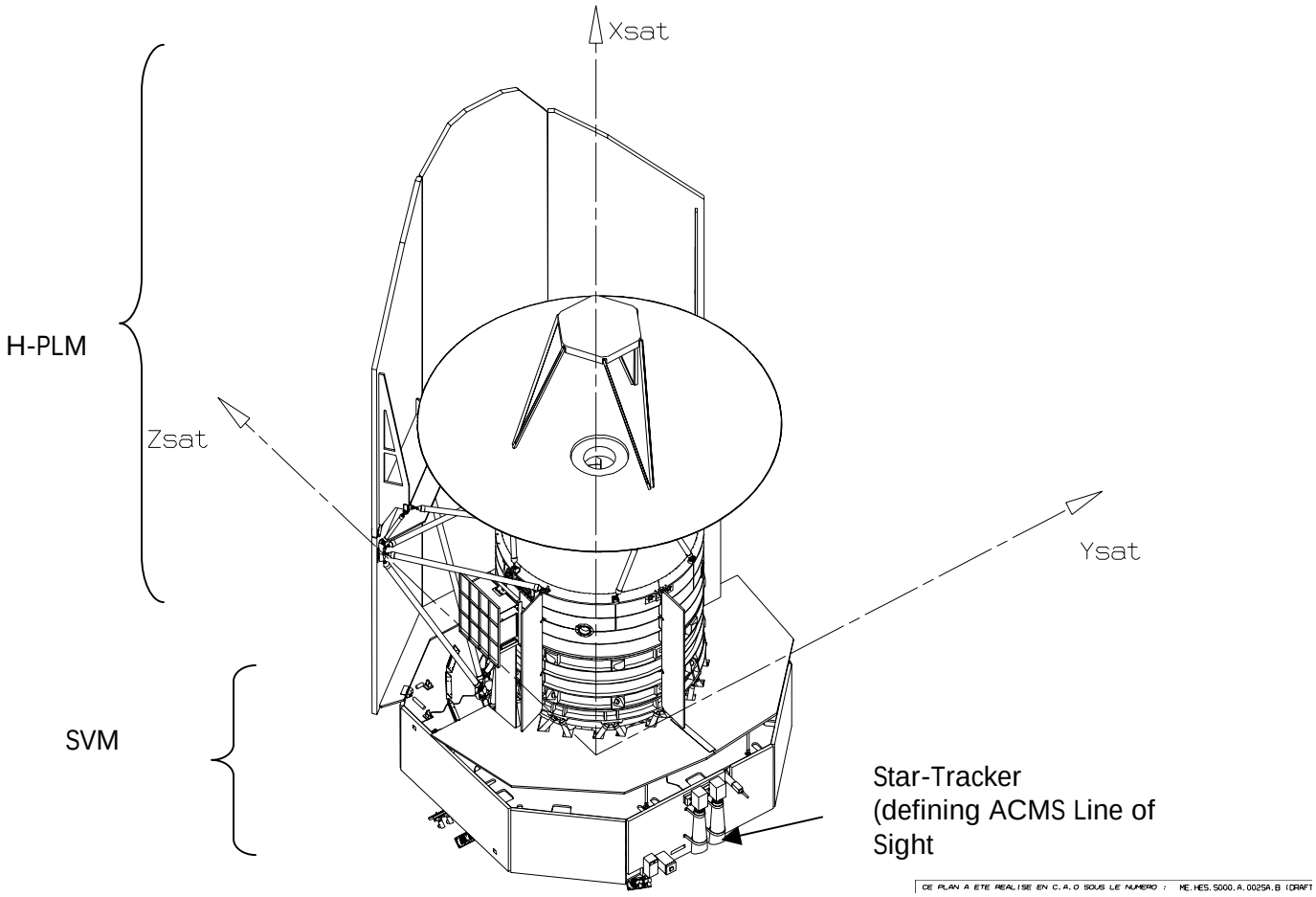
[RD5] "SVM structure specification"
ref H-P-SP-AI-0001 Is/Rev 2/0 14.11.01

1.3 Acronyms

HP	**H**erschel-**P**lanck
SRS	**S**ystem **R**equirements **S**pecification
TBC	**T**o **B**e **C**onfirmed
TBD	**T**o **B**e **D**efined
S/C	**S**pace**c**raft
SVM	**S**er**v**ice **M**odule
H-(E)PLM	**H**erschel (**E**xtended) **P**ayload **M**odule
Spec	**S**pecification
I/F	**I**nter**f**ace
ACMS	**A**ttitude and **C**ontrol **M**onitoring **S**ystem
AOCS	**A**ttitude and **O**rbit **C**ontrol **S**ystem
S/P-I/F	**S**VM/**H**-PLM **i**nter**f**ace plane
T/P	**T**hruster **p**lume
TRS	**T**est **R**equirement **S**heet
LoS	**L**ine **o**f **S**ight
AC	**A**lignment **C**ube
CoG	**C**enter **o**f **G**ravity
RSS	**R**oot **S**um **S**quared

2. HERSCHEL SPACECRAFT DESCRIPTION

2.1 Herschel Spacecraft Sketch



2.2 Coordinate systems definitions

2.2.1 Satellite LoS

As per SRS, the LoS of an instrument is defined as the direction on the observed sky of the geometric center of an FPU entry beam's far field pattern as projected by the telescope.
At satellite level, this direction is referenced with regards to the satellite interfaces

2.2.2 H-EPLM LoS

At H-EPLM level, the LOS is identical to the SRS one, but this direction is referenced with regards to the H-PLM/SVM interfaces

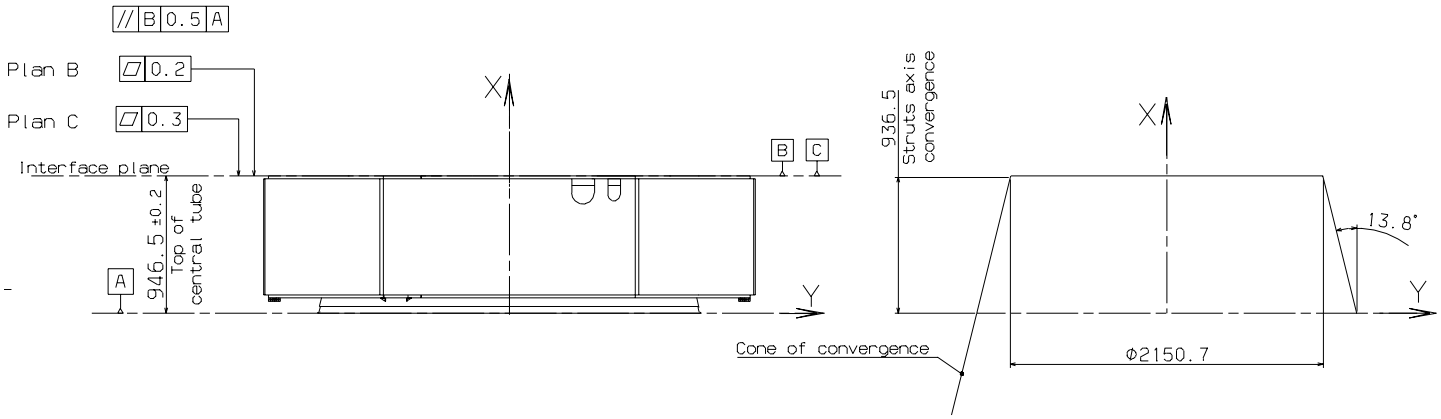
PACS Line of Sight is considered at this stage as the reference line of sight for all three instruments.

2.2.3 SVM LoS

As defined in the SVM requirement specifications, the LOS_{SVM} is defined by the vector [1, 0, 0] in SVM/PLM interface frame.

2.2.4 H-EPLM/SVM Interface

The H-EPLM/SVM interface is presented hereafter, and is called S/P I/F in the rest of this document: (cf drawing ME.HES.A180.S.000SA)



2.2.5 Thruster plume.

To each thruster plume corresponds a push direction, which is referenced with regards to the corresponding alignment cube.

3. UPPER LEVEL ALIGNMENT NEEDS

The present section reminds how system level alignment and stability requirements have been derived from system performance requirements:

3.1 Alignment needs with regards to pointing budget

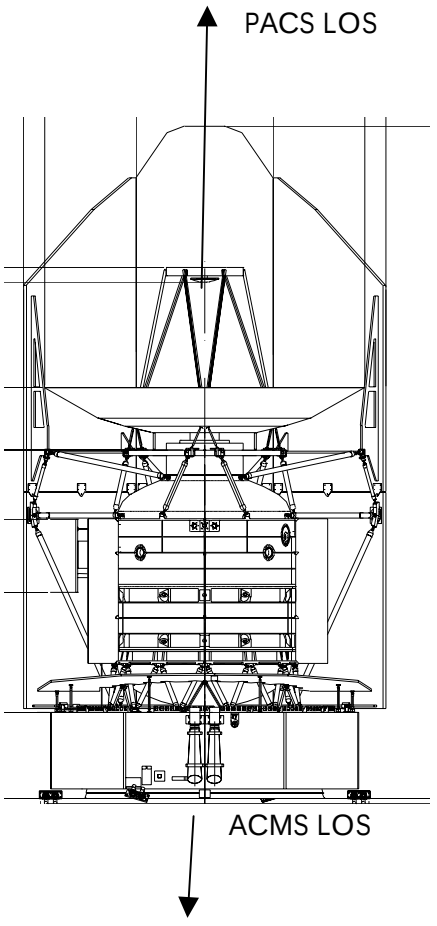
The alignment allocations with regards to pointing budget are described in [AD3], and are reported hereafter
The following hypotheses are taken:

- PACS LOS is considered as the reference for instrument.
- ACMS will be aligned with regards to PACS LOS.
- SPIRE and HIFI positions and orientations in telescope focal plane will be measured/analyzed with regards to PACS ones.
- In orbit, PACS LOS will be calibrated, and the SPIRE and HIFI LOS will be derived by analysis. Peak-up procedure data will be downloaded to ground.

3.1.1 LOS

3.1.1.1 PACS

#	Requirement
	The PACS LOS shall be aligned with the opposite ACMS sensor LOS with an accuracy of 0.30 degree maximum(requirement include ground error sources and in orbit effects [gravity release, launcher effects…]).



These two directions have to be in-orbit parallel at +/- 0.3° maximum

3.1.1.2 SPIRE

#	Requirement
	The SPIRE LOS shall be known with regards to PACS LOS with an accuracy better than 3.6 arcsec (requirement include ground error sources and in orbit effects [gravity release, launcher effects…]).

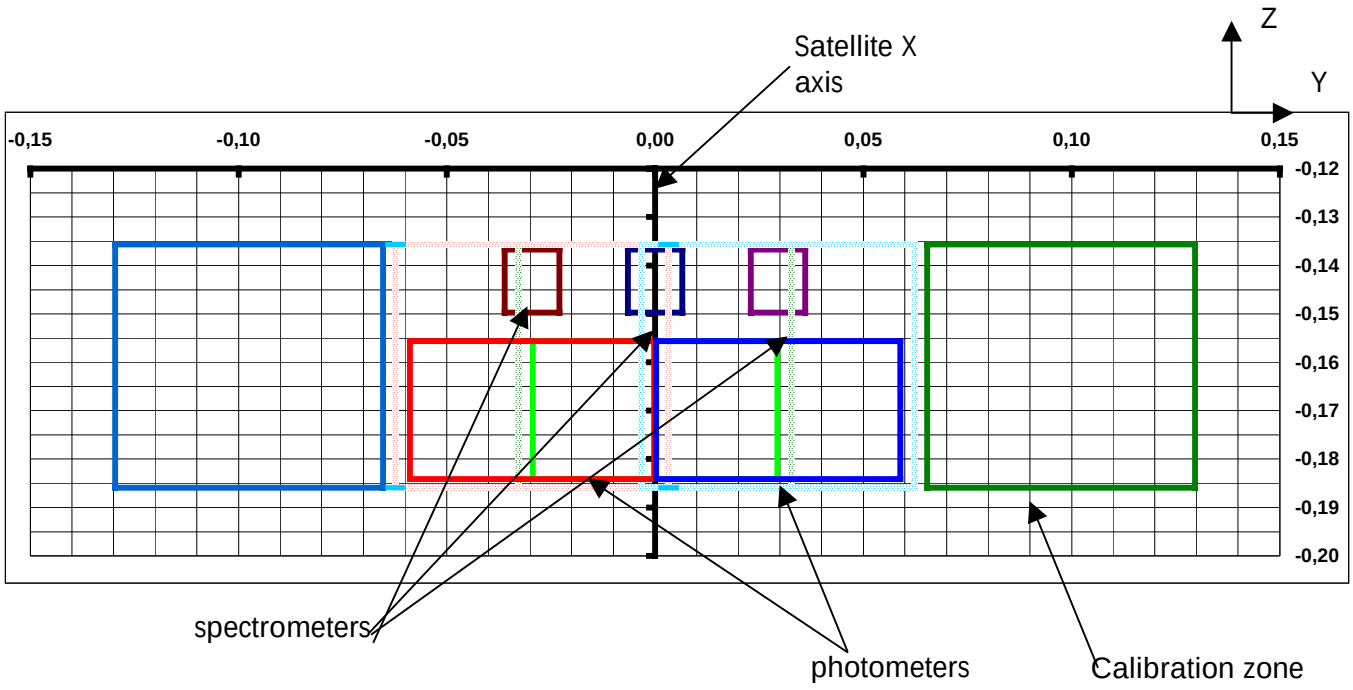
3.1.1.3 HIFI

#	Requirement
	The HIFI LOS shall be known with regards to PACS LOS with an accuracy better than 3.6 arcsec (requirement include ground error sources and in orbit effects [gravity release, launcher effects…]).

3.1.2 around LOS

#	Requirement
	For each instrument, the Around LOS misalignment knowledge with regards to the H-PLM/SVM interface shall be less than 0.3 arcmin at 68% confidence level.

Nota: the contribution of SVM to around-LoS alignment is included in the SVM pointing requirements RD1
To illustrate this requirement, the PACS instrument is taken as an example. It's nominal field of view, depending on the mode (photometer mode or spectrometric mode), as projected in the sky by the telescope, is the following (units in degrees):



The angle between this FOV orientation and Y satellite (nominally 0dg), quantifies the PACS around LOS.

3.2 Alignment needs with regards to thrusters

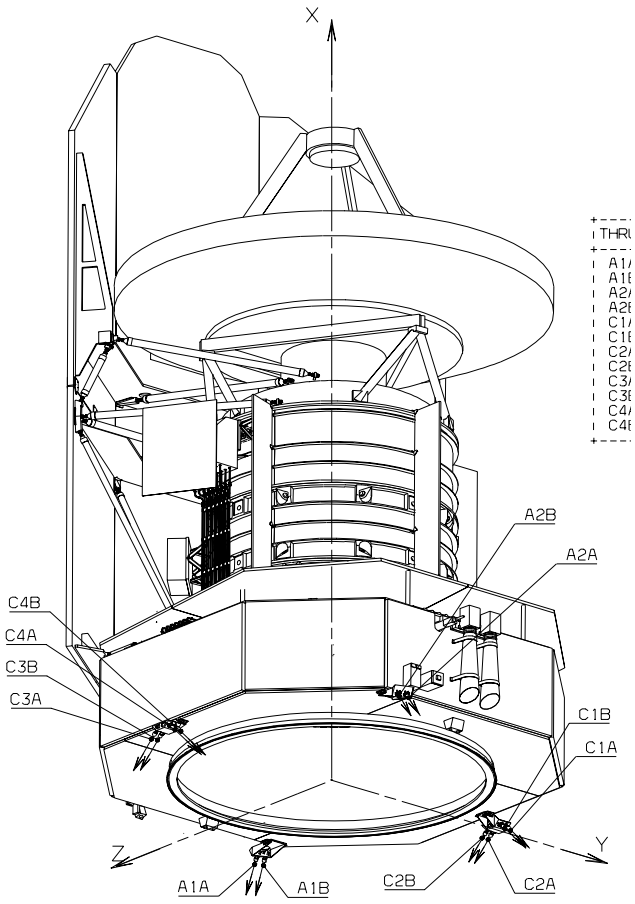
The 10 N thrusters are used for orbit correction and maintenance (see MISS 095, SPER 045).). They are ideally all aligned with the Spacecraft centre of mass. Herschel CoG may vary during lifetime of [14.9, -4.4, -2.4] cm (according to SRR inertia data).

#	Requirement
	Taking in account thruster accommodation (typically in the order of 2 meter from centre of mass), the alignment accuracy between the thruster push axis and the BOL S/C CoG shall be better than 0.5°.

#

(2*sin(0.5°)= 1.7 cm representing around 10% of center of mass variation)

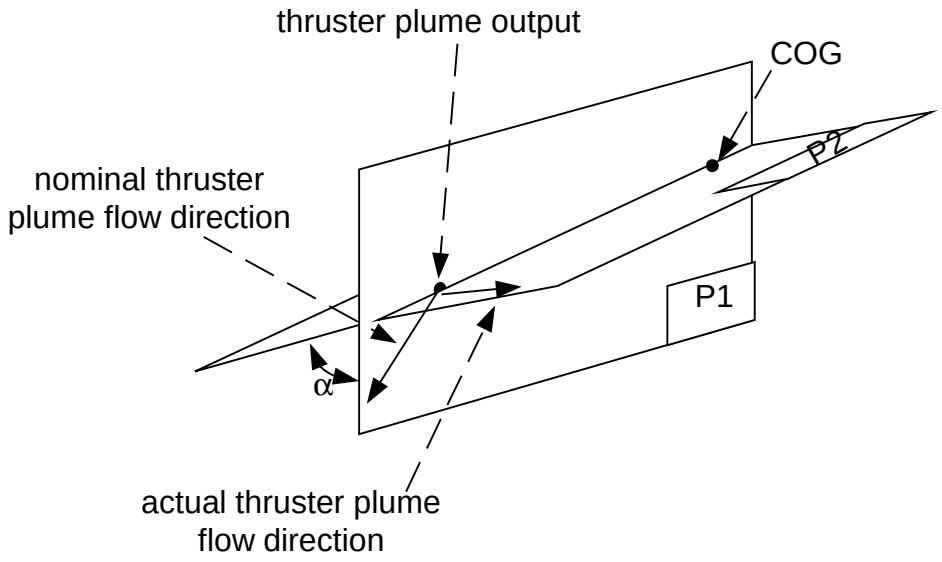
#	Requirement
	The thruster adjustment range shall be large enough to cover the difference between the theoretical CoG and the actual one at BOL. Each one of these thrusters shall be aligned with regards to the satellite CoG.



The alignment constraint between the thruster axis and the Satellite CoG is more clearly shown on the following drawing where:

P1 is defined by
- -the nominal CoG
- -the nominal thruster direction
- -the nominal thruster location

P2 is defined by
- -the measured CoG
- -the measured thruster plume direction
- -the measured thruster plume position



the angle alpha shall be lower than 0.5°

4. ALIGNMENT SEQUENCE

4.1 Alignment sequence at H-EPLM level

This alignment sequence is described in the Herschel alignment concept [RD3]

4.2 Alignment sequence at Herschel satellite level

4.2.1 alignment sequence - simplified

The alignment sequence is the following

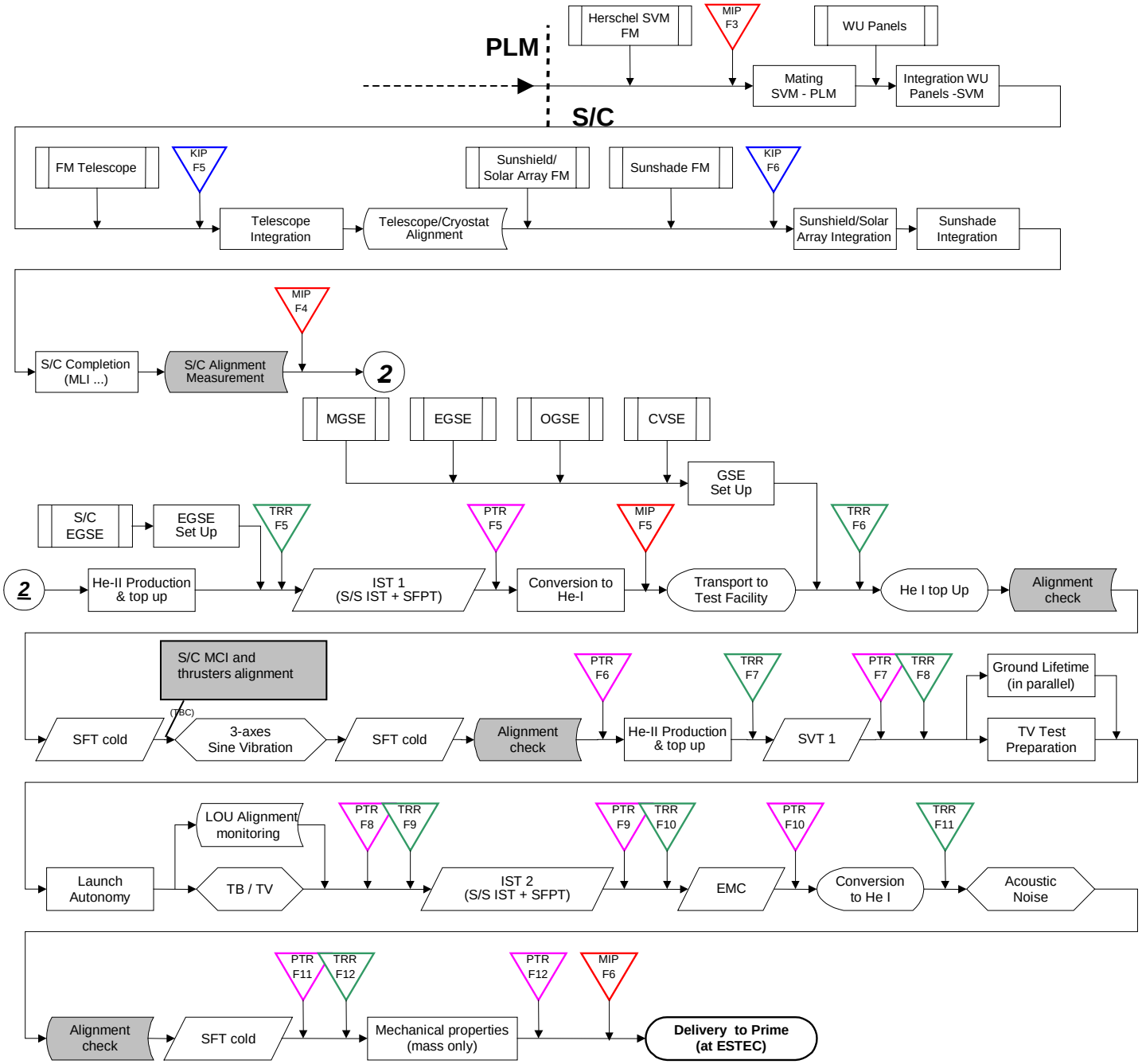
1. delivery to Alcatel of aligned SVM and aligned H-EPLM, each one with one reference cube
2. mating & mating verification (by verification of the alignment of the two cubes)
3. the optical reference for the satellite is the satellite optical cube, whose position will be referenced with regards to the launcher interface plane.
4. A reference alignment measurement is performed with theodolites: the mating is verified, and all the accessible cubes are referenced with regards to the satellite cube
5. Once the helium tanks are filled, an alignment check is performed
6. The spacecraft CoG is measured, and the thrusters are aligned with regards to this known CoG.
7. After EMC and acoustic tests, the alignment is checked for the last time.

The configuration in which Herschel centre of mass will be measured is still subject to consolidation. In particular, the following issues shall be addressed:

- representativity of Helium filling,
- representativity of fuel and pressurant filling,
- capability of measurement of CoG along X axis.

4.2.2 Alignment steps in the complete satellite AIV sequence

After the H-EPLM has been mounted on the SVM, the following AIV sequence flows:



Alignment related steps are represented in the grey boxes.

The preceding graph is based on the facts that, in the frame of the shimming, no "optical" alignment is made between the H-PLM and the SVM. A mechanical mounting is sufficient because:

- the mating has no impact on the alignment of FPU with regards to the telescope, nor on the LOU alignment.
- the alignment of the star-tracker with regards to the SVM interface has a sufficient accuracy to limit the impact of the mating (as shows the budgets in section 6.1)
- the alignment of the thrusters is performed after the spacecraft CoG measurement. Mating influence is canceled

Each one of the alignment steps is described in the following sections. The relevant Test Requirement Sheets are presented in the following table:

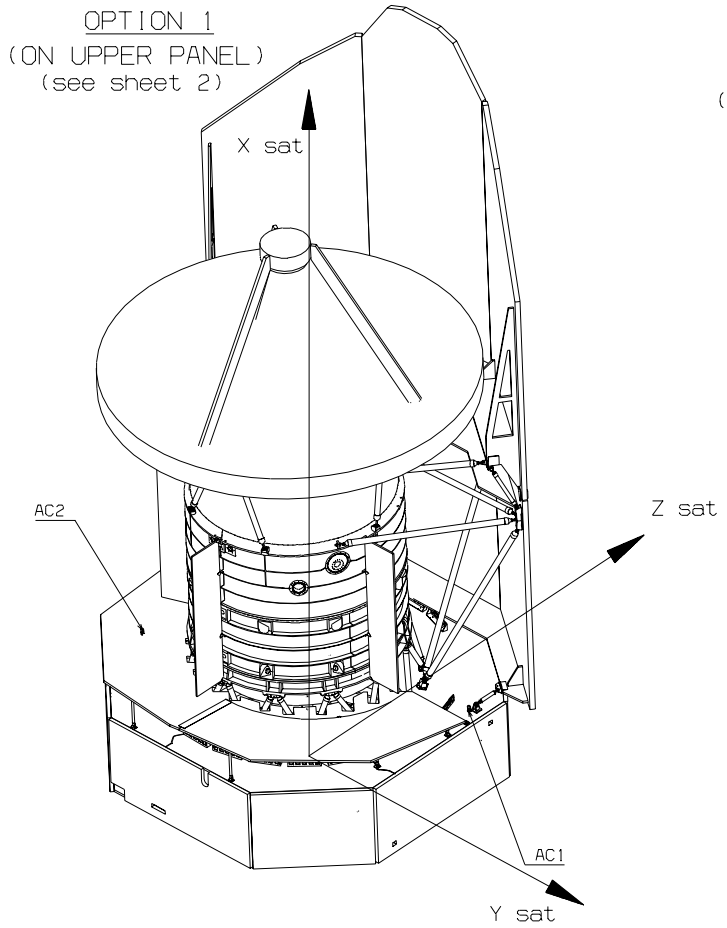
Specimen to be tested					TEST TO BE PERFORMED
Herschel	**SAT**	**STM PFM**	**ALG**	**0**	Satellite Mechanical axes determination and stability check
Herschel	**SAT**	**STM PFM**	**ALG**	**1**	Thrusters alignment, reference and stability check
Herschel	**SAT**	**STM PFM**	**ALG**	**2**	CVV Alignment Check versus SVM
Herschel	**SAT**	**PFM**	**ALG**	**3-1**	"ACMS Unit 1" Alignment, reference and stability check
Herschel	**SAT**	**PFM**	**ALG**	**3-2**	"ACMS Unit 2" Alignment, reference and stability check
Herschel	**SAT**	**PFM**	**ALG**	**3-n**	"ACMS Unit n" Alignment, reference and stability check

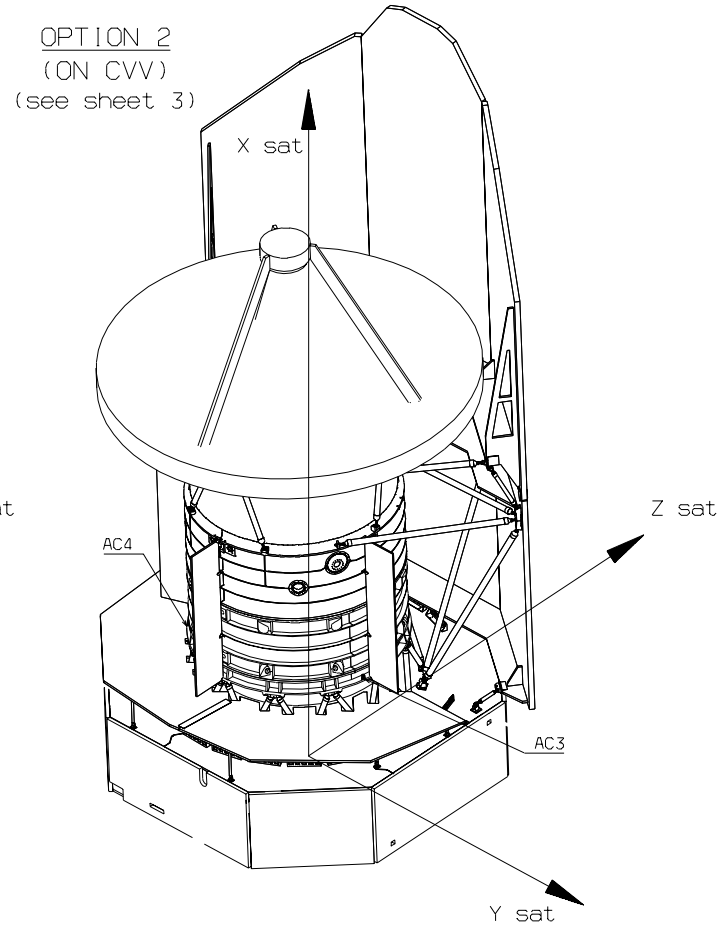
4.2.3 Mating

The mating is the mechanical mounting of the H-PLM on the SVM. Once the PLLM is fixed on the SVM, the reference plane is the launcher interface plane (Xsat, Ysat, Zsat), and is represented by the satellite optical cube.

By measuring the position of the H-PLM cube with regards to the SVM cube, the mating is checked.

The satellite cubes might either be the SVM ones, or ones dedicated to the spacecraft. In the case we would chose to have 2 dedicated balls and cubes for the spacecraft, their location could be the following (AC1 for reference, AC2 for redundancy)

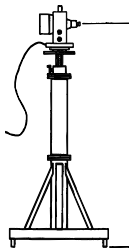


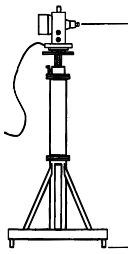


4.2.4 Spacecraft alignment measurement and alignment checks

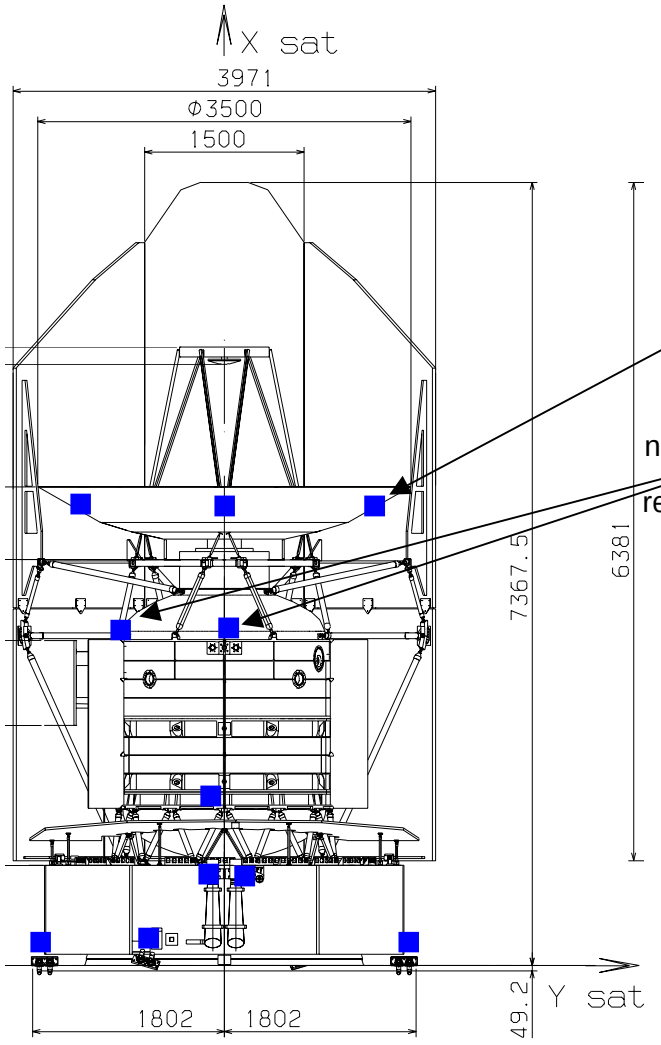
The alignment between each subsystems are firstly measured adjust after mating (this allow to have the reference), and then checked in the following way . Theodolites are used

Measurement theodolite (looking at each cube, to measure it's orientation and position with regards to the reference theodolite)





Reference theodolite (looking at the satellite reference cube)



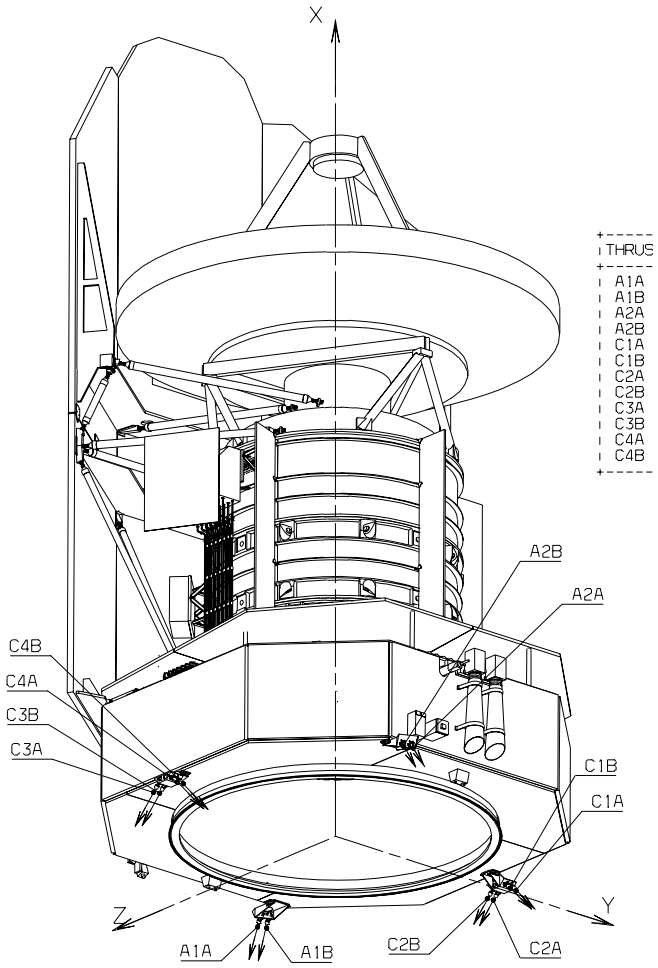
The optical cubes to be looked at are the following:

Element			Optical cubes and balls quantity
H-EPLM		telescope	3 (or 4) cubes with reticules
		H-EPLM cube	2 cubes with reticules
SVM	external	SVM reference	2 cubes
		Thrusters	12
		Star Trackers	2 cubes
Satellite			2 cubes and 2 balls

4.2.5 Thrusters alignment

At this stage, the spacecraft CoG measurement is performed. This measurement will give the position of the projection of Herschel Spacecraft CoG in the YZ plane. Due to the fact that the Spacecraft cannot be tilted to perform the CoG location measurement along X axis, this one shall be determined by analysis. The accuracy will then be lower for this X direction.

The 12 thrusters are distributed in the following way.



This alignment is based on classical theodolite measurements.

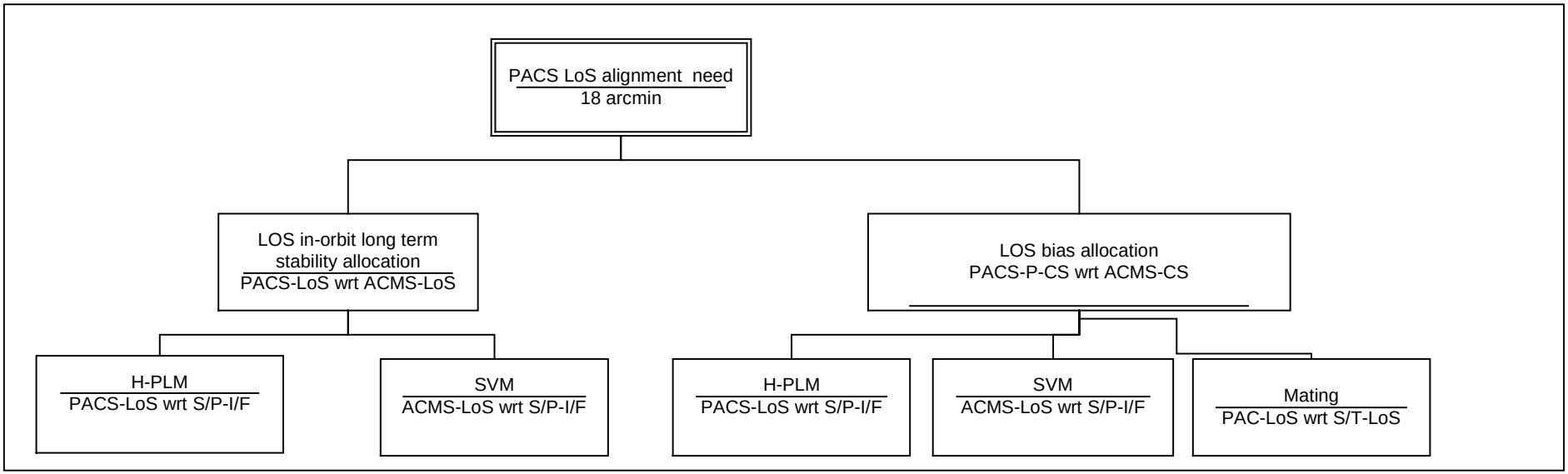
5. CONTRIBUTORS ALLOCATIONS

For each one of the contributors identified in the section 4 , the allocation is given and justified.

5.1 contributions to alignment allocations with regards to pointing budget

5.1.1 LOS - contributors

There is no alignment for line of Sight at satellite level. The contributor's tree to the line of sight is thus the following:



5.1.2 LOS - allocations

5.1.2.1 PACS

5.1.2.1.1 PACS in-orbit alignment stability

5.1.2.1.1.1 SVM internal stability:

The allocation to the in-orbit stability of the ACMS LoS with regards to the SVM-PLM interface Coordinate System is 1.15arcsec at 68% confidence level. This is in line with the long term stability requirement of ACP-050-H (cf [AD4])

5.1.2.1.1.2 HPLM internal stability:

The in-orbit PACS LOS stability with regards to the PLM-SVM Interface is required to be less than 0.2 arcsec (68% probability) to the H-EPLM (cf [RD4], requirement number HERS-0700). First analyses by ASED shows a value of +/-0.7 arcsec worst case which is in line with the requirement.

5.1.2.1.2 PACS alignment bias

5.1.2.1.2.1 SVM LOS alignments bias

The ACMS LOS alignment bias with regards to the SVM-PLM interface Coordinate System shall be lower than 0.25° i.e. 15arcmin. This is more stringent (by a factor $\sqrt{2}$) than the specification in [RD5] table 5.1.2.1-1, but considered as achievable.

5.1.2.1.2.2 H-PLM LOS alignment bias

The PACS LOS alignment bias with regards to the PLM-SVM Interface shall be lower than +/-5 arcmin (including ground and in-orbit effects). This is required to the H-EPLM via the H-EPLM specification(cf. [RD4], HERS-0640)

5.1.2.1.2.3 Mating misalignment: PACS LoS wrt ACMS-LoS

The on-ground LOS alignment bias of the mating shall be lower than 1 arcmin(TBC). This is in line with the Herschel SVM interface design: F0278C HESA 180S000S A Ind D

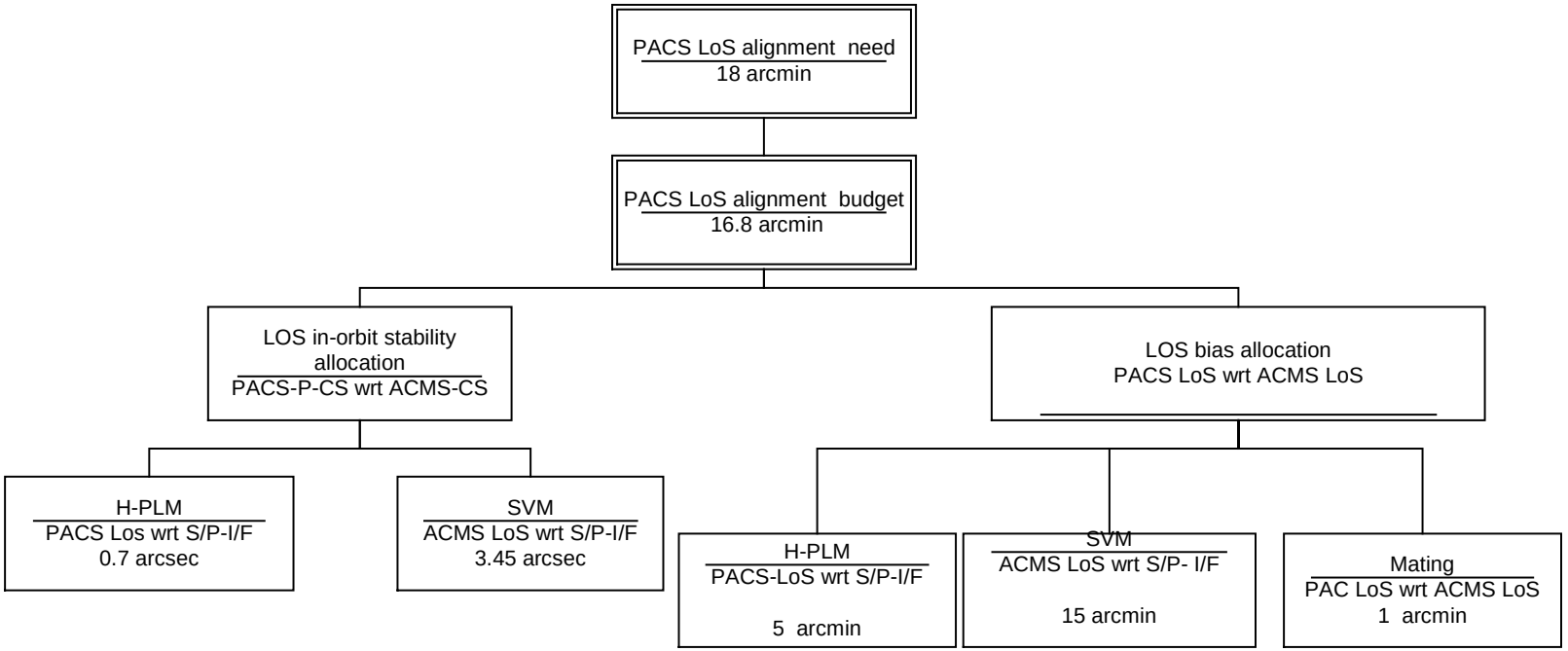
5.1.2.1.3 synthesis

The following table gives the relevant contribution, present status and the relevant references

Contributor		Contribution (worst case)	Status	reference
SVM	Bias	15arcmin	Specified	H-P-SP-AI-0001 is 2 03/11/01 table 5.1.2.1-1
	stability	1.15 *3 = 3.15arcsec	In line with ACP-055-H	AD4
HPLM	Bias	5arcmin	Specified	RD4
	stability	0.7arcsec	Covered by H-EPLM specification	RD4
Mating		1arcmin	In line with current interfaces	F0278C HESA 180S000S A Ind D

5.1.2.1.4 PACS LOS alignment - budget

The upper level AOCS needs have been derived in the following way to the modules
Misalignments having the same frequency are summed RSS. Misalignments having different frequency are summed linearly.



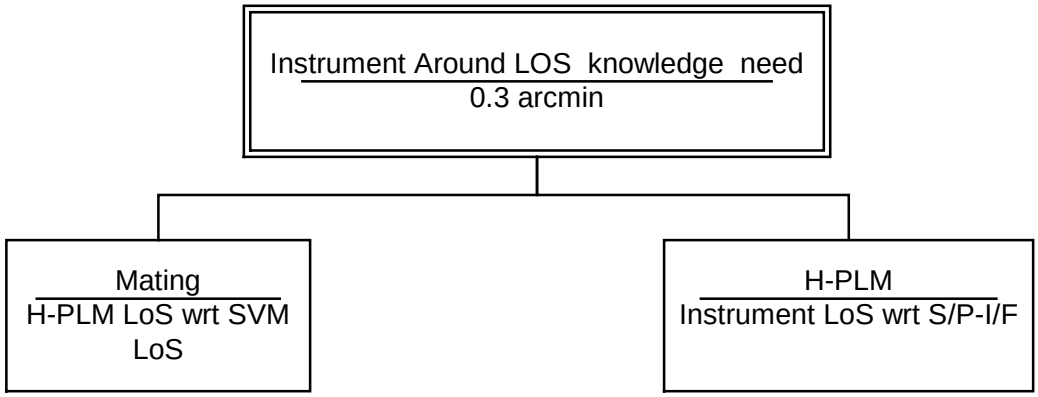
5.1.2.2 SPIRE/HIFI LOS knowledge

SPIRE and HIFI in-orbit LOS shall be known with regards to PACS LOS with an accuracy better than +/-3.6 arcsec (including on-ground alignment knowledge, in-orbit stability knowledge..)

Contributor	Contribution	Status	reference
HPLM	3.6arcesc	Specified	[RD4]

5.1.3 AROUND LOS-contributors

The knowledge of around-LoS angle will thus be the sum of the knowledge of the following contributors



5.1.4 AROUND LOS-Allocations

5.1.4.1 Around -LOS misalignment bias knowledge

5.1.4.1.1 HPLM around-LOS knowledge:

The around-LOS alignment of each instrument with regards to the PLM-SVM Interface frame shall be known with an accuracy better than +/-0.3 arcmin at 68% confidence level (including on-ground alignment knowledge, in-orbit stability knowledge...). This is in line with [AD4]

5.1.4.1.2 Mating misalignment: instrument around LoS wrt ACMS around LoS

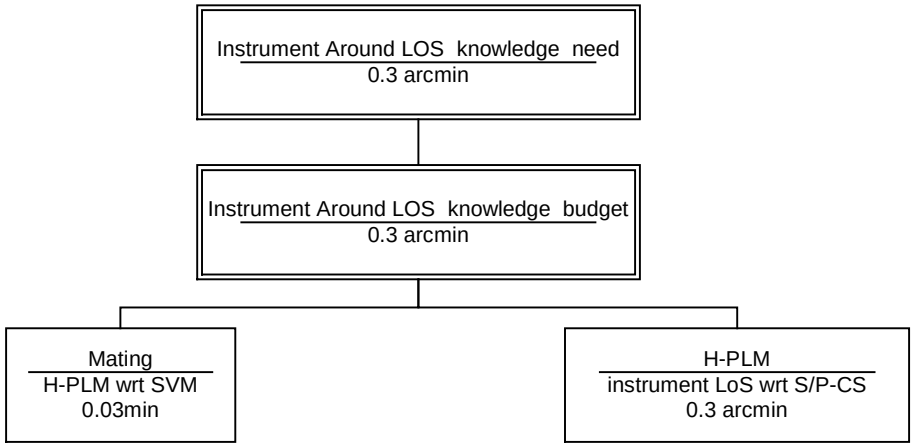
Based on the current I/F (SVM side), the tolerance on the holes diameter induces a maximum bias of 7arcsec. The around-Los contribution will then be 0+/-2 arcec at 68% confidence level

5.1.4.1.3 synthesis

The following table gives the relevant contribution, present status and the relevant references

	Contribution @68% confidence	Status	Reference
HPLM bias	0.3	Required to H-EPLM	[RD4]
Mating	0.03 arcmin	SVM interface	

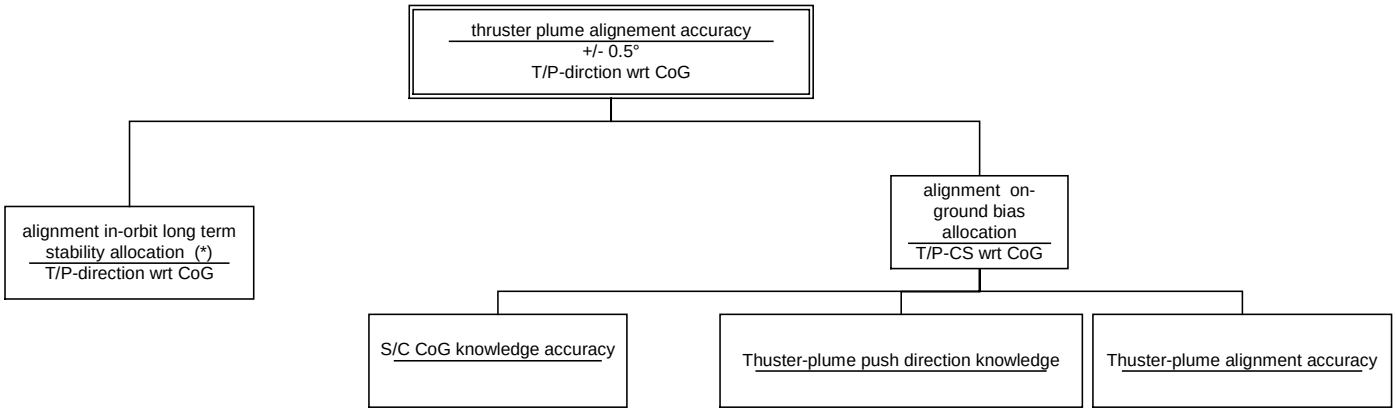
5.1.4.1.4 AROUND LOS-Allocations -budget



5.2 allocations to thruster plumes alignment

5.2.1 alignment accuracy – contributors

The alignment of the thrusters is performed at satellite level, after the satellite CoG is measured.
The contributors are thus the following



(*) in-orbit CoG variation is not included in this contributor. It is included in the upper-level ACMS budget.

5.2.2 alignment accuracy-allocations

5.2.2.1 allocations

The in-orbit alignment stability of the thruster together with it's on-ground "push direction" knowledge wrt SVM I/F reference frame shall be less than +/-0.25°. This is a requirement on the SVM structure.

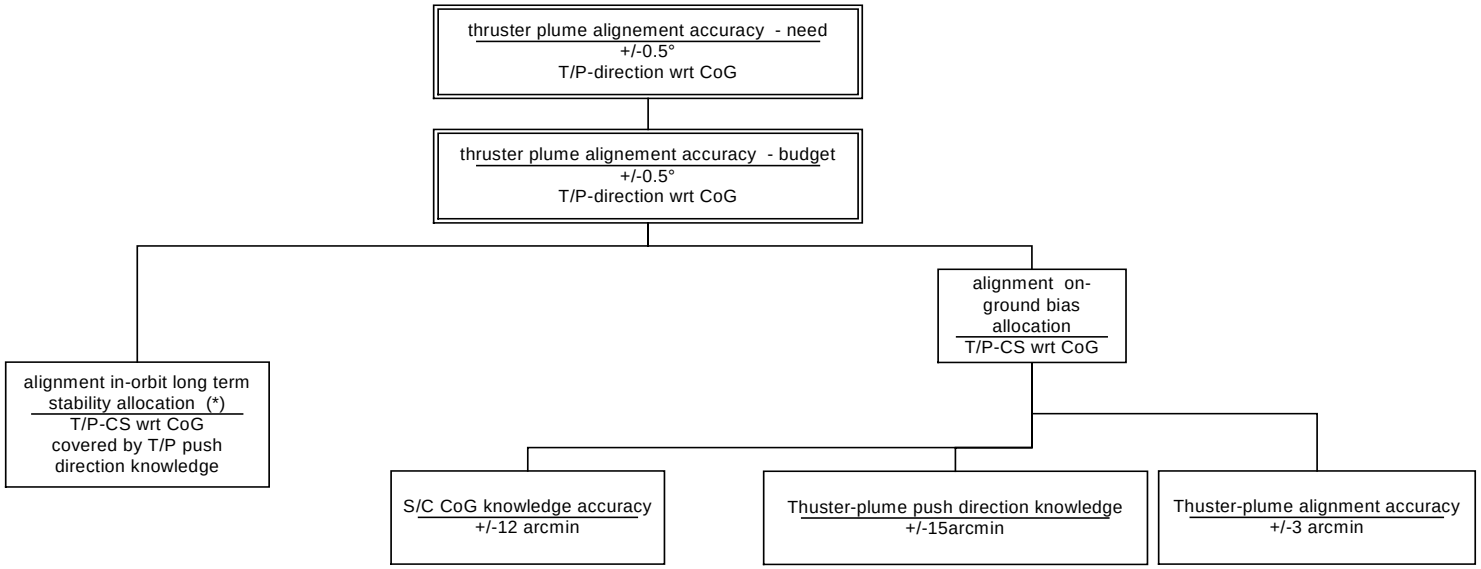
The alignment accuracy of the thruster plume with regards to the S/C-CS - at system level-shall be better than 3 arcmin.

The Spacecraft CoG location on-ground knowledge accuracy shall be better than [+/-7;+/-0.5;+/-0.5]mm (TBC) in Spacecraft Coordinate system. This corresponds to 12 arcmin

5.2.2.2 synthesis

	Contribution (arcmin)	Status
Thruster-plume knowledge & stability	+/-15	specified by Alenia
System level thruster-plume alignment accuracy	+/-3	Direct specification to AIT
S/C CoG on-ground knowledge accuracy	+/-12	Direct specification to AIT

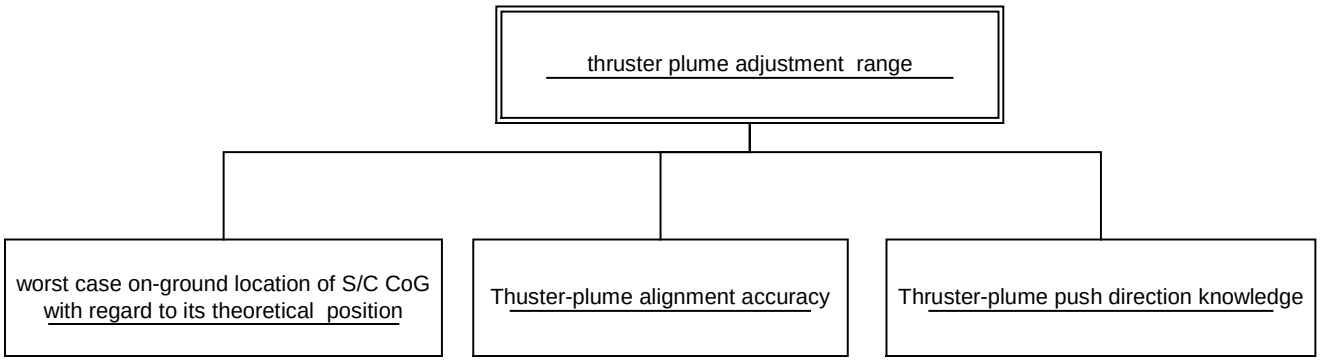
5.2.2.3 thruster-plume alignment accuracy - budget



(*) this shall not take into account the in-orbit CoG displacement.

5.2.3 thruster plume adjustment range – contributors

the following tree represents the contributors to the maximum needed adjustment range for the thrusters at satellite level.



5.2.4 thruster plume adjustment range – allocations

5.2.4.1 allocations

The distance between the actual on-ground location of Spacecraft CoG and its theoretical position shall be less than +/-30mm. This corresponds to a +/-0.86° angular adjustment range.

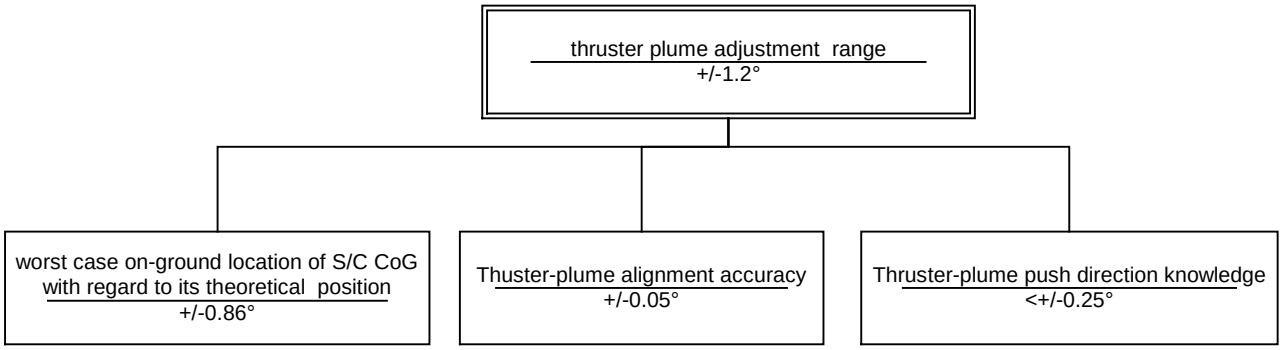
The on-ground push direction knowledge accuracy shall be better than +/-0.25°. This corresponds to +/-8.5mm distance between thruster-plume push direction and CoG. This is covered by the alignment accuracy allocation.

The alignment accuracy of the thruster plume with regards to the S/C-CS - at system level-shall be better than 3 arcmin. This corresponds to 1.7mm distance between thruster-plume push direction and CoG. This is covered by the alignment accuracy allocation.

5.2.4.2 synthesis

	Contribution	Status
Thruster-plume knowledge	< +/-0.25°	Specified by ALENIA
System level thruster-plume alignment accuracy	+/-0.05°	State of the art with margin
S/C CoG on-ground worst case bias	+/-0.86°	

5.2.4.3 angular adjustment range for system alignment needs - budget



The agreed value for thruster adjustment with the RCS contractor is 2° half cone which is in line with the requirement.

6. REQUIREMENTS

6.1 At H-PLM level

#	Requirement
	The in-orbit thermo-elastic stability of the PACS Line of Sight with regards to the PLM-SVM Interface frame shall not exceed +/-0.7 arcsec.

#

#	Requirement
	The PACS Line of Sight alignment bias with regards to the PLM-SVM Interface frame shall be lower than +/-5 arcmin (including ground and in-orbit effects).

#

#	Requirement
	SPIRE and HIFI in-orbit LOS shall be known with regards to PACS Line of Sight with an accuracy better than +/-3.6 arcsec (including on-ground alignment knowledge, in-orbit stability knowledge..)

#

#	Requirement
	The around-LOS alignment of each instrument with regards to the PLM-SVM Interface frame shall be known with an accuracy better than +/-0.3 arcmin at 68% confidence level(including on-ground alignment knowledge, in-orbit stability knowledge...).

#

#	Requirement
	H-EPLM will be equipped with at least 2 optical cubes (1 nominal, 1 for redundancy). They shall represent the H-EPLM optical reference frame.

#

#	Requirement
	H-EPLM cubes shall allow an orientation knowledge than 10arcsec in the three directions, and shall be accessible at system level, especially before and after the mating between H-EPLM and SVM.

#

6.2 At-SVM level

#	Requirement
	Between two calibrations, the in-orbit stability of the ACMS sensor LoS with regards to the SVM-PLM interface coordinate su system shall be less than 1.15arcsec (half-cone) at 68% confidence level.

#

#	Requirement
	The ACMS sensor LOS alignment bias with regards to the SVM-PLM interface Coordinate System shall be lower than 0.25 deg.

#	Requirement
	The ACMS sensor LOS shall be aligned with regards to PACS nominal Line of Sight

#

#	Requirement
	The in-orbit alignment stability of the thruster together with it's on-ground push direction knowledge with regards to SVM I/F reference frame shall be less than +/-0.25°

#	Requirement
	The thruster plume adjustment range shall be at least +/-1.2°- for thruster plume system level alignment.

#	Requirement
	SVM will be equipped with at least 2 optical cubes (1 nominal, 1 for redundancy). They shall represent the SVM interface frame.

#

#	Requirement
	SVM cubes shall allow an orientation knowledge than 10arcsec in the three directions, and shall be accessible at system level, especially before and after the mating between H-EPLM and SVM.

#

6.3 At system level

#	Requirement
	The on-ground LOS alignment bias of the mating shall be lower than 1 arcmin.

#

#	Requirement

The on-ground around-LOS misalignment due to the mating shall be known with an accuracy better than 0.5 arcmin at 68% confidence level.

#

Requirement

The alignment accuracy of the thruster plume with regards to the S/C Coordinate system - at system level- shall be better than 3 arcmin

#

Requirement

The S/C CoG on-ground knowledge accuracy shall be better than [+/-7;+/-0.5;+/-0.5]mm (TBC)

#

Requirement

The distance between the actual on-ground location of S/C CoG and its theoretical position shall be less than +/-30mm.

#

END OF DOCUMENT