HERSCHEL / PLANCK

THERMAL ANALYSES REPORT

Product Code : 000000

Rédigé par/*Written by*	**Responsabilité-Service-Société** ***Responsibility-Office -Company***	**Date**	**Signature**
	H/P Thermal team	27/06/2002	
Vérifié par/*Verified by*			
M. CORNUT	Thermal Architect	28/06/2002	
Approbation/*Approved*			
P. RIDEAU	System Manager	30/06/2002	
C. MASSE	PA Manager	28/06/2002	
J-J. JUILLET	Project Manager	30/06/2002	

Data management : G. SERRA

Entité Emettrice : Alcatel Space - Cannes
(détentrice de l'original) :

Reproduction interdite © ALCATEL SPACE Company confidential

SPIRE-ALC-REP-002356

HERSCHEL / PLANCK

THERMAL ANALYSES REPORT

Product Code : 000000

Rédigé par/ *Written by*	**Responsabilité-Service-Société *Responsibility-Office -Company***	**Date**	**Signature**
	H/P Thermal team	27/06/2002	
Vérifié par/ *Verified by*			
M. CORNUT	Thermal Architect	28/06/2002	
Approbation/ *Approved*			
P. RIDEAU	System Manager	28/06/2002	
C. MASSE	PA Manager	28/06/2002	
J-J. JUILLET	Project Manager	28/06/2002	

Data management : G. SERRA

Entité Emettrice : Alcatel Space - Cannes
(détentrice de l'original) :

Reproduction interdite © **ALCATEL SPACE** Company confidential

HERSCHEL/PLANCK	DISTRIBUTION RECORD		
DOCUMENT NUMBER : H-P-1-ASPI-RP-0266	Issue 1 Date: 27/06/2002		
EXTERNAL DISTRIBUTION		**INTERNAL DISTRIBUTION**	
ESA	**X**	**HP team**	**X**
ASTRIUM	**X**		
ALENIA	**X**		
CONTRAVES			
TICRA			
TECNOLOGICA			
		Clt Documentation	**Orig.**

ENREGISTREMENT DES EVOLUTIONS / *CHANGE RECORDS*

ISSUE	DATE	§ : DESCRIPTION DES EVOLUTIONS *§ : CHANGE RECORD*	REDACTEUR *AUTHOR*
1	27/06/2002	New document	H/P thermal team

TABLE OF CONTENTS

1. SCOPE 7
1.1 OBJECTIVES 7
1.2 ORGANISATION OF THE DOCUMENT 9
2. DOCUMENTS 10
2.1 APPLICABLE DOCUMENTS 10
2.2 REFERENCE DOCUMENTS 10
2.3 ACRONYMS 10
3. HERSCHEL SYSTEM THERMAL ANALYSES 12
3.1 LAUNCH PHASE 12
3.1.1 Model Description 12
3.1.2 Hypothesis for computation 13
3.1.3 Results 14
3.2 NOMINAL OPERATION 15
3.2.1 Model Description 15
3.2.2 Interface description 21
3.2.3 Hypothesis for computation 24
3.2.4 Results 26
4. PLANCK SYSTEM THERMAL ANALYSES 29
4.1 SPACECRAFT THERMAL MODELLING 29
4.1.1 Model Description 29
4.1.2 Hypotheses for computation 36
4.2 THERMAL ANALYSES RESULTS 37
4.2.1 Thermal interfaces validation 37
4.2.2 Spacecraft temperature fluctuations assessment 39
4.2.3 BEU/DAE cpntrol box thermal interface 40

LIST OF FIGURES

FIGURE 1.1.1-1: HERSCHEL OVERALL CONFIGURATION 7
FIGURE 1.1.1-2: PLANCK OVERALL CONFIGURATION 8
FIGURE 3.1.1-1: HERSCHEL RADIATIVE VIEW (TMM ISS. 0) 12
FIGURE 3.1.1-2: MACROSCOPIC AND REFINED MODELLING 13
FIGURE 3.1.2-1: MLI SIZING CASE 14
FIGURE 3.2.1-1: OVERALL MODEL OVERVIEW 15
FIGURE 3.2.1-2: SVM GMM EXTERNAL VIEW 16
FIGURE 3.2.1-3: SVM CENTRAL CONE (+X VIEW) 16
FIGURE 3.2.1-4: SVM UNITS ACCOMMODATION 17
FIGURE 3.2.1-5: UNITS ACCOMMODATION ON LATERAL PANELS 17
FIGURE 3.2.1-6: GEOMETRIC VIEW OF THE PLM MODEL 19
FIGURE 3.2.1-7: MLI LOCAL NODAL BREAKDOWN 21
FIGURE 3.2.2-1: MLI ENCLOSURE OVERVIEW 22
FIGURE 3.2.2-2: SVM/ PLM INTERFACE DESIGN 22
FIGURE 3.2.2-3: SVM/PLM INTERFACE THERMAL MODEL 23
FIGURE 3.2.2-4: CVV I/F POINTS ONTO THE SVM 23
FIGURE 3.2.2-5: SUNSHIELD I/F POINTS ON THE SVM 24
FIGURE 3.2.3-1: GLOBAL TMM SIZING CASES 25
FIGURE 4.1.1-1: SVM GMM EXTERNAL VIEW 30
FIGURE 4.1.1-2: SVM GMM STRUCTURAL VIEW 31
FIGURE 4.1.1-3: SVM EQUIPMENT/UNITS ACCOMMODATION 31
FIGURE 4.1.1-4: TOP OF SVM SIDE +X AND -X 32
FIGURE 4.1.1-5: SUB-PLATFORM CONDUCTIVE MODELLING 33
FIGURE 4.1.1-6: HEAT PIPES NETWORK DESIGN 34
FIGURE 4.1.1-7: SPACECRAFT OVERALL VIEW 35
FIGURE 4.2.2-1: I/F STRUTS TEMPERATURE FLUCTUATIONS 39

LIST OF TABLES

TABLE 3.2.1-1: H-PLM GMM THERMAL INPUTS 20
TABLE 3.2.4-1: CONDUCTIVE HEAT LOADS AT SVM/PLM INTERFACES 26
TABLE 3.2.4-2: HERSCHEL I/F TEMPERATURES 27
TABLE 3.2.4-3: SVM SHIELD DESIGN EVOLUTION 28
TABLE 4.1.2-1: PLANCK SIZING CASE 36
TABLE 4.2.1-1: SVM/PLM I/F TEMPERATURES 37
TABLE 4.2.1-2: PLANCK I/F HEAT LOADS 39
TABLE 4.2.3-1: PLM WARM UNITS TEMPERATURE 40
TABLE 4.2.3-2: BEU/DAE INTERNAL ELEMENTS TEMPERATURE 41

1. SCOPE

1.1 Objectives

The aim of this document is to check the validity of the thermal interfaces requirement applicable on each modules, after merging of their respective thermal and mathematical model.

The description of the geometric and thermal mathematical model built for HERSCHEL and PLANCK is presented, as well as the studies derived from the thermal analyses performed on both satellites.

Each satellite is composed of:

- A Service Module (SVM)
- A Payload Module (PLM)

Herschel and Planck overall configuration are depicted in Figure 3.1.1-1and Figure 3.1.1-2

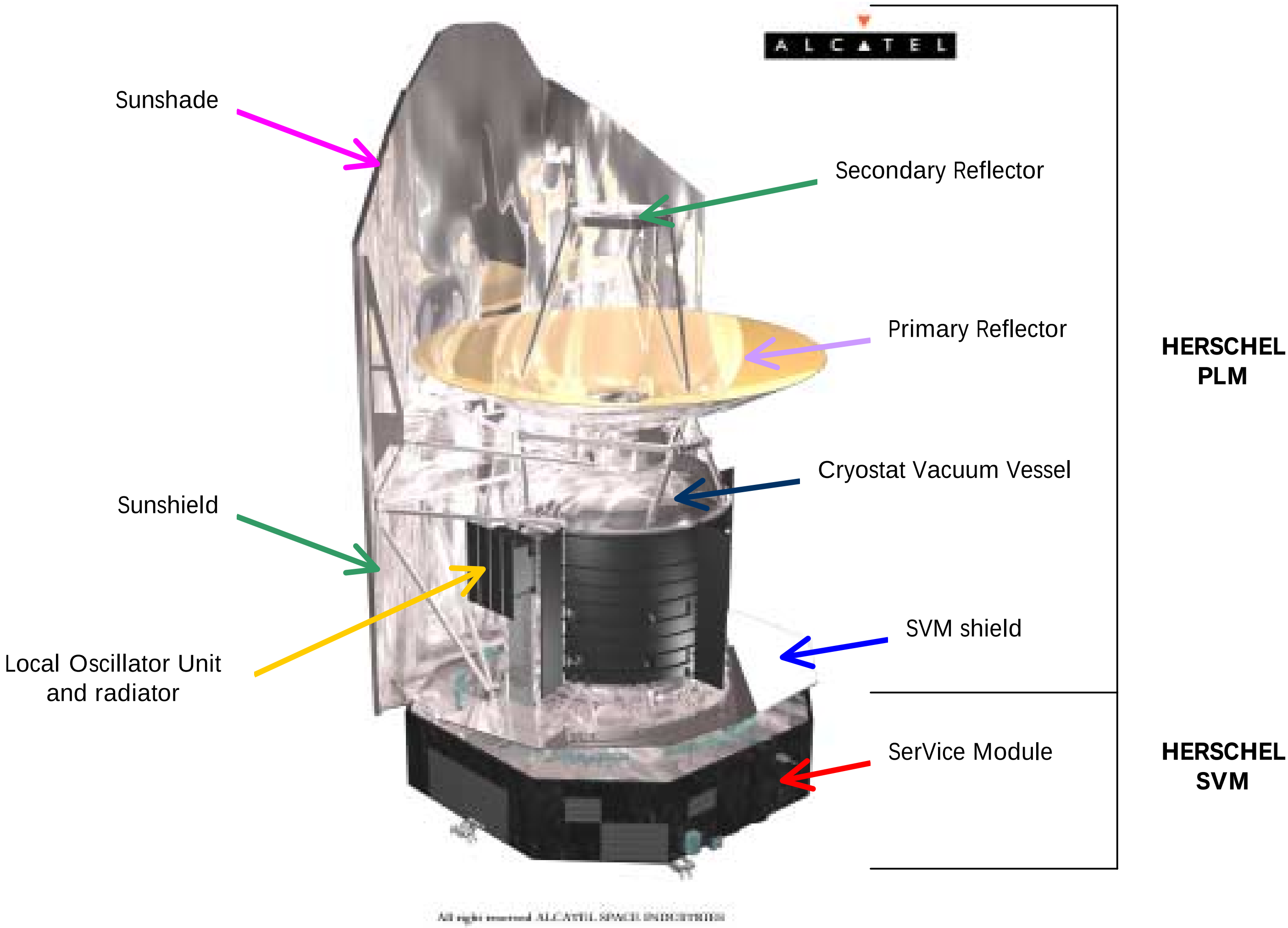


Figure 3.1.1-1: HERSCHEL overall configuration

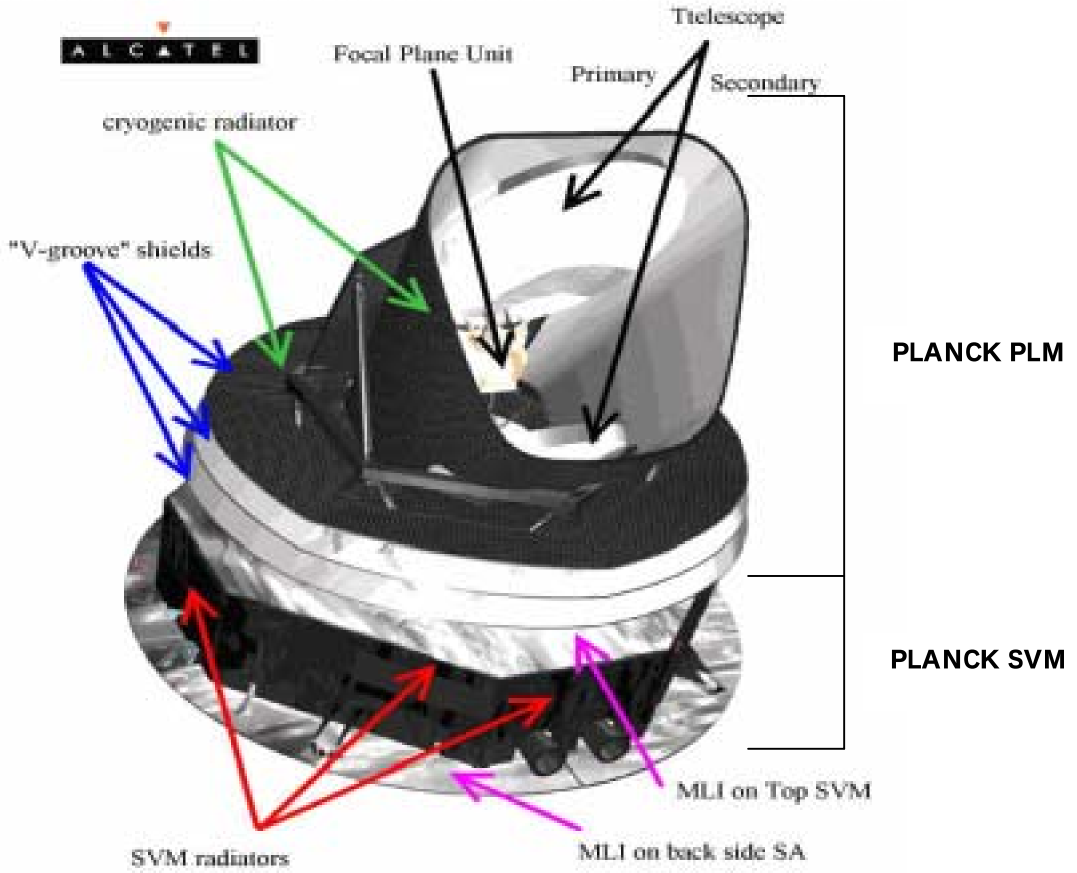


Figure 3.1.1-2: PLANCK overall configuration

ALCATEL has built an overall thermal and mathematical model (TMM) for each satellite, merging the different TMM made by the sub-contractors.

HERSCHEL global TMM used for the launch phase studies is:

- H-PLM TMM issue 0 built by ASTRIUM and delivered in November 2001 (RD-6, Issue 1).

HERSCHEL global TMM used for orbit phase results from the compilation of:

- H-SVM TMM issue 0 built by ALENIA and delivered in February 2002.
- H-PLM TMM issue 1 built by ASTRIUM and delivered in March 2002 (RD-6, Issue 2).

PLANCK global TMM results from the compilation of:

- P-SVM TMM issue 0 built by ALENIA and delivered in February 2002.
- P-PLM TMM built by Alcatel (Ref: H-P-ASPI-DD-1568).

The SVM thermal modelling is representative of the configuration as it was in February 2002. Especially, the instruments warm unit definition in term of size, mass and thermal dissipation is in accordance with their respective Interfaces document (IID-B) version 2.0. The purpose of the overall thermal analyses is however not dedicated to verification of the SVM thermal control, which is performed by ALENIA with a model representative of the working baseline configuration agreed for the PDR Data Package. The main objective of the system thermal analyses is to validate the thermal interfaces between the modules (SVM and PLM). System thermal analyses support also trade-off activities at system level and management of the instruments thermal interfaces. An up to date configuration is therefore usually not required. Anyway, potential impacts of the upgraded configuration are always identified.

1.2 Organisation of the document

In the present document, the different descriptions and studies concerning each satellite have been described in a dedicate chapter. HERSCHEL model description and thermal analyses are presented in chapter 3. Chapter 4 is dedicated to Planck.

2. DOCUMENTS

2.1 Applicable documents

The applicable documents reported below are applicable in their last issue.

The rules and requirements that they contain shall be applied for the HERSCHEL/PLANCK thermal control development and design.

[AD-1]: "General design & interface requirements"	Ref: H-P-1-ASPI-SP-0027
[AD-2]: "PPLM Thermal analyses"	Ref: H-P-3-ASPI-AN-0330
[AD-3]: "SVM interface specification"	Ref: H-P-4-ASPI-IS-0042
[AD-4]: "SVM Requirement Specification"	Ref: H-P-4-ASPI-SP-0019
[AD-5]: "H/P Environment and Tests Requirements"	Ref: H-P-1-ASPI-SP-0030
[AD-6]: "System Design Report for PDR"	Ref: H-P-1-ASPI-RP-0312
[AD-7]: "Self Spacecraft emission analysis"	Ref: H-P-3-ASPI-TN-0188
[AD-8]: "H/P system requirements specification"	Ref: SCI-PT-RS-05991

2.2 Reference documents

[RD-1]: "PLANCK heat pipes network definition and interfaces"	Ref: H-P-TN-AI-0020.
[RD-2]: "Instrument Interface Document, Part B: "High Frequency Instrument"	Ref: SCI-PT-IIDB/HFI-04141.
[RD-3]: "Instrument Interface Document, Part B: "Low Frequency Instrument"	Ref: SCI-PT-IIDB/LFI-04142.
[RD-4]: "Instrument Interface Document, Part B: "Photoconductor Instrument"	Ref:SCI-PT-IIDB/PACS-2126.
[RD-5]: "Instrument Interface Document, Part B: "Instrument HIFI"	Ref: SCI-PT-IIDB/HIFI-2125.
[RD-6]: "H-EPLM Thermal Model and Analysis"	Ref: HP-2-ASED-RP-0011.
[RD-7]: "SVM Thermal Analysis Report"	Ref: H-P-TN-AI-0005.

2.3 Acronyms

AD	Applicable Document
BEU	Back End Unit
BOL	Beginning of Life
CFRP	Carbon Fiber Reinforced Plastic
CTE	Coefficient of thermal expansion
CVV	Cryostat Vacuum Vessel
DAE	Data Acquisition Electronics
EOL	End of Life

EP	Entrance Pupil
FPA	Focal Plane Assembly
FOV	Field-of-view
GMM	Geometric Mathematical Model
HFI	High Frequency Instrument
LFI	Low Frequency Instrument
LOS	Line Of Sight
LVA	Launcher Vehicle Adapter
MLI	Multi Layers Insulation
MOS	Margin of Safety
N/A	Not applicable
OSR	Optical Solar Reflector
PA	Product Assurance
PAU	Pre Amplifier Unit
PDR	Preliminary Design Review
PLM	Payload Module
PPLM	Planck Payload Module
PR	Primary Reflector
PtV	Pic to valley
RD	Reference Document
RCS	Reaction Control Subsystem
RH	Relative Humidity
RMS	Root Mean Square
S/C	Spacecraft
SCC	Sorption Cooler Compressor
SCE	Sorption Cooler Electronics
SR	Secondary Reflector
SRS	System Requirements Specification
SVM	SerVice Module
TA	Telescope Assembly
TCS	Thermal Control Subsystem
TBC	To be confirmed
TBD	To be determined
TMM	Thermal Mathematical Model
WFE	Wave Front Error
wrt	With Regards To

3. HERSCHEL SYSTEM THERMAL ANALYSES

3.1 launch phase

The baseline scenario for the launcher attitude during coast-arc is a three axes control. Due to the large specified Solar Aspect Angle (± 23° roll and between 60° and 140° from Xs satellite axis), some elements usually shadowed by the sunshield/sunshade from launcher separation to the end of the mission may be illuminated. This could be critical for light structures such as MLI blankets, especially for those located onto the SVM shield and onto the SVM top. Sun impingement and solar trapping could damage the MLI and reduce its efficiency. The aim of this study is to estimate the maximum temperature level reached on some MLI of the spacecraft, and to compare the results to the conventional maximum design temperatures of such components.

3.1.1 Model Description

The TMM used for this analysis is based on the H-PLM model delivered by ASTRIUM in early phase B (issue 0). In this model, the SVM shield is extended towards the +Z side of the spacecraft. The up to date of the SVM shield design in the TMM is however not useful for this specific study. A geometric view of the model is reported in Figure 3.1.1-1. All the main H-PLM external elements are modelled.

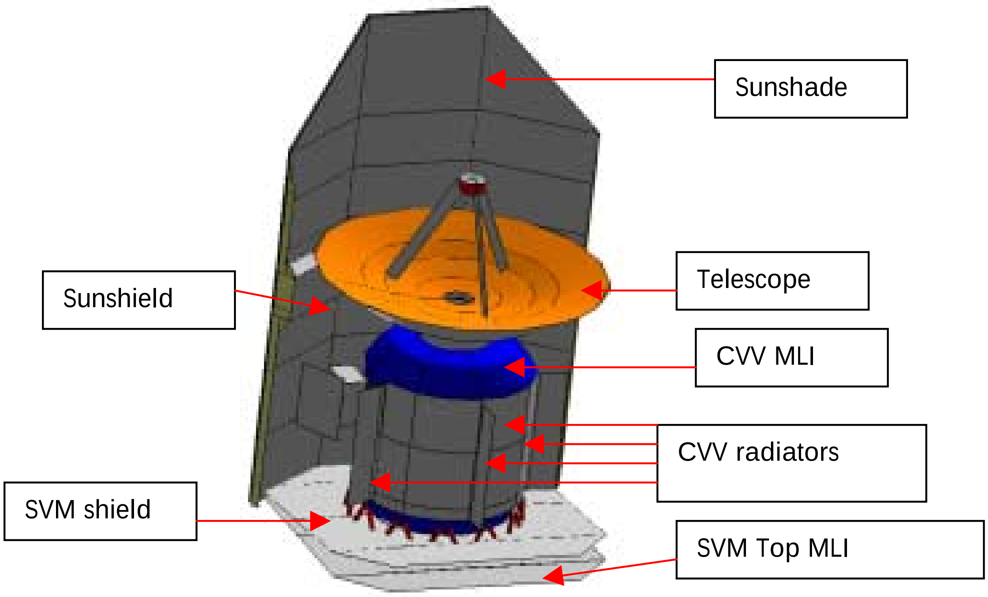


Figure 3.1.1-1: Herschel radiative view (TMM iss. 0)

Model Modifications:

The effect of sun impingement cannot be assessed with a macroscopic modelling of the sensitive elements such as the MLI on the SVM shield and on the SVM top. Due to the large size of the thermal nodes in the original ASTRIUM TMM, the temperature levels obtained are only average ones. The thermal gradients within a node cannot be estimated. The nodal breakdown of the SVM TOP and SVM shield MLI has been therefore refined, as depicted in Figure 3.1.1-2.

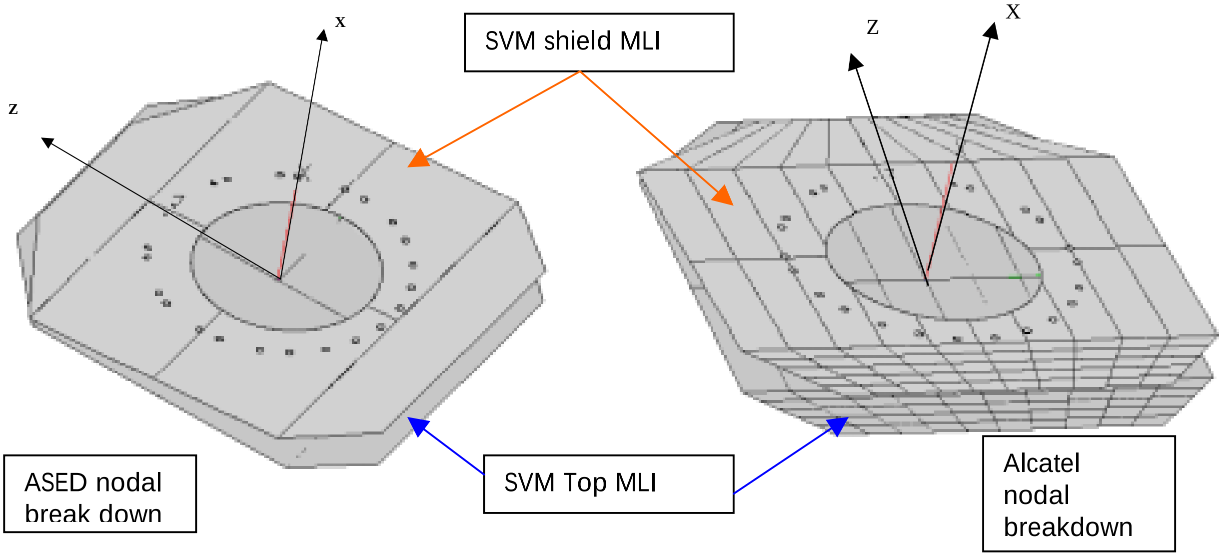


Figure 3.1.1-2: Macroscopic and refined modelling

The SVM Top MLI and the SVM shield MLI have been divided in 80 nodes, with a special care for the sun illuminated side (i.e. the –Z side), which thermal nodes size is larger than on the +Z side. The SVM top and the SVM shield are covered with aluminised external layer MLI. The thermo-optical properties are the following:

- ε=0.05 (infrared emissivity)
- α= 0.13 (solar absorptance)
- I/R specularity ratio = 70%

3.1.2 Hypothesis for computation

Herschel shall be compatible in launch phase with a Sun direction between ± 23° from the (Xs, Zs) plane (Roll angle) and between +60° to +140° from the Xs axis (Pitch angle). The sizing cases had been estimated with solar aspect angle between ± 30° from the (Xs, Zs) plane (as defined in early phase B) instead of ± 23°. The conclusions are therefore still applicable.
The solar impact on the SVM shield MLI and on the SVM top MLI is a function of respectively sin(β+5) and sin(β), where β is the pitch angle .
The solar absorbed flux is therefore defined as followed (with C_{solar} is the solar constant):

SVM Shield $Q_S = \alpha \times C_{solar} \times \sin(\beta + 5)$

SVM top $Q_S = \alpha \times C_{solar} \times \sin(\beta)$

The maximum absorbed solar flux is reached for 60° angle from the Xs axis. Therefore the solar impact on the SVM shield and SVM top MLI has been studied in this sizing case, with a Roll angle of +30° from the (Xs, Zs) plane (see Figure 3.1.2-1).

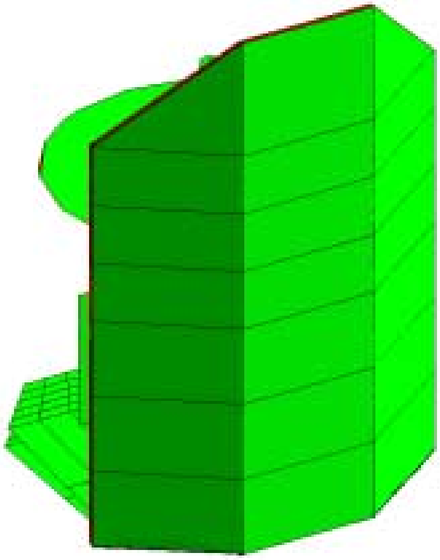


Figure 3.1.2-1: MLI sizing case

3.1.3 Results

The maximum temperatures reached on the SVM Top and SVM shield MLI blankets are presented hereafter.

Maximum temperature	Sizing case
SVM TOP	409 K
SVM shield	407 K

The previous temperatures are calculated ones, i. e. without margins and uncertainties. They are anyway well below preliminary evaluation performed by ASTRIUM (respectively 753 K and 523 K for SVM Top and SVM shield MLI). The discrepancy is due to the refined modelling of the concerned area. Anyway, the modelling is still a “macroscopic” one w.r.t. local effects induced by solar trapping. These effects may occur because of multi-reflection of the solar flux on these highly reflecting surfaces. The impact, which cannot be modelled, could be local drastic increase of the temperatures beyond the usual design range for MLI (620 K). The risk is a degradation of the concerned MLI efficiency, which in turn impacts the CVV lifetime.

Design solutions to be set are to use diffusive surface such as Kapton or white painted MLI external layers on areas potentially sun-illuminated. These solutions shall be restricted as much as possible in order not to impact significantly the CVV lifetime. For instance, using Kapton foil external layer (ε=0.63, α= 0.4) on the whole SVM shield MLI as well as on the SVM top MLI would lead to a reduction of around a month of the CVV lifetime. Before this "recovery" activity, all the involved surfaces shall be identified. We have indeed only investigated impacts at the SVM and SVM shield area, but other components can be submitted to solar flux during launch phase.

3.2 Nominal operation

3.2.1 Model Description

The two TMM modules have been merged for the HERSCHEL overall thermal model:

- The Service Module (SVM), delivered by ALENIA in February 2002 (model issue 0)
- The Payload Module (PLM) delivered by ASTRIUM in March 2002 (model issue 2)

The HERSCHEL overall model is made of a GMM and a TMM. The GMM describes the geometry, the material properties and the orbit, whereas the TMM describes the conductive links between the different elements as well as the thermal dissipations.
This coupled model will be used as working baseline for the present analyses. The overall GMM is presented in Figure 3.2.1-1.

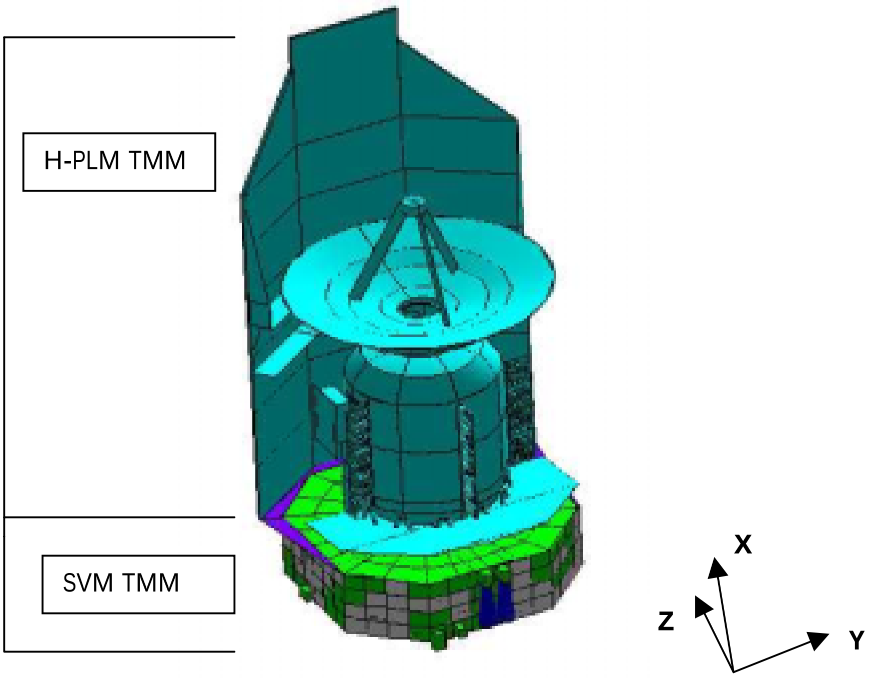


Figure 3.2.1-1: Overall Model Overview

3.2.1.1 SVM Geometrical and Mathematical Model Description

The main components of the SVM GMM are the central cone, the octagon-shaped SVM box, the payload sub-platform and the RCS panel. The central cone provides on one hand the main interface to the launcher, and on the other hand the main load path to the cryostat. The attachment with launcher adapter is provided by means of an Aluminium interface ring. The interface with the cryostat is provided by 24 struts attached on 12 adapter brackets. The octagon-shaped box accommodates the spacecraft equipment and the payload warm units on the internal side, whereas the various sensors and antennae are located on the outside of the structural panels.
The SVM box is made of 8 lateral panels, 8 shear webs, and an upper and lower closure panels.

The Payload sub-platform is used to close and to stiffen the central cone. The RCS panel is used to accommodate the piping.

The location and the size of the instruments warn units are compliant with the instruments IID-B version 2.0. The HIFI warm units are located on two dedicated panels (the –Y and the –Y-Z panels). This position allows to guarantee a stable environment for these instruments, independently of the SAA variations. The PACS warm units are grouped on a dedicated panel, located in +Y-Z. The SPIRE warm units are installed on the –Z panel. The SVM GMM views are reported from Figure 3.2.1-2 to Figure 3.2.1-5.

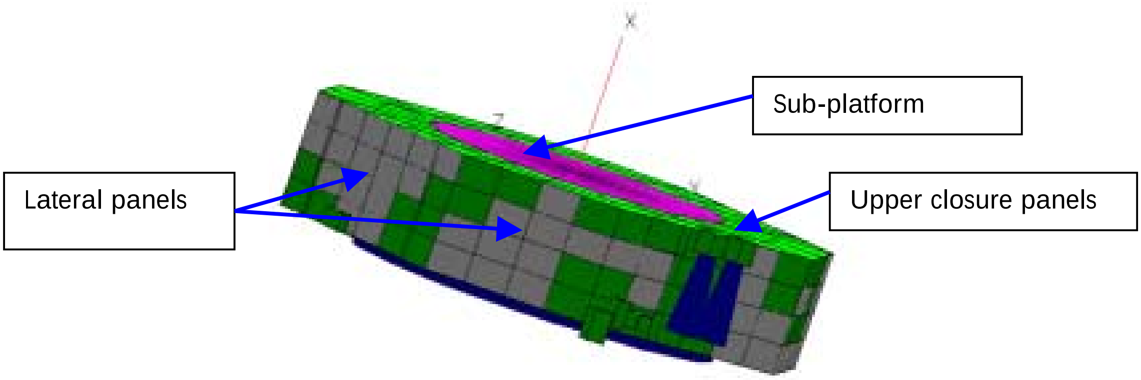


Figure 3.2.1-2: SVM GMM external view

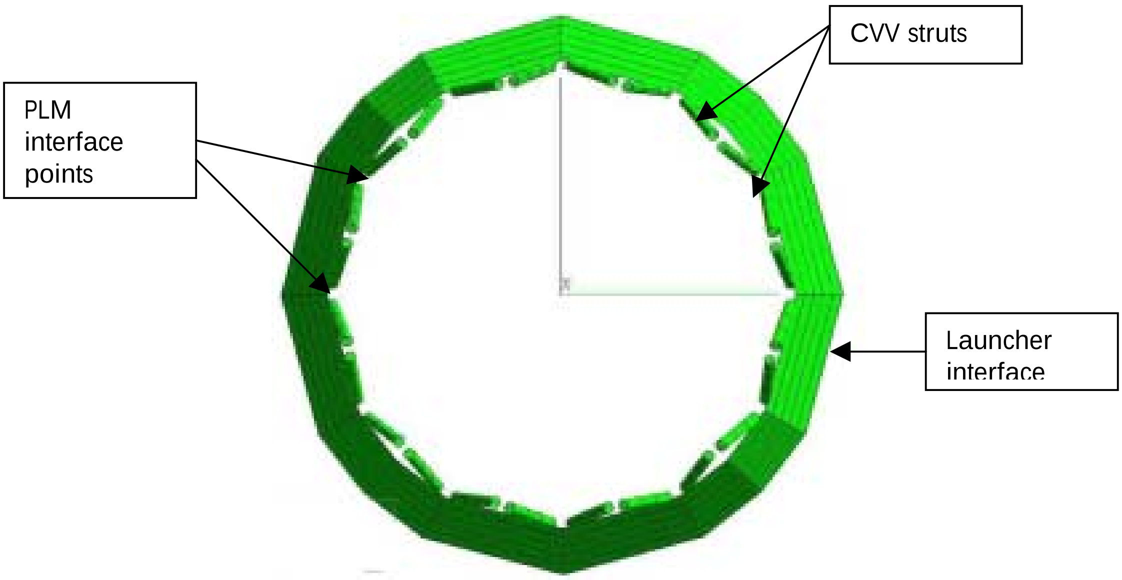


Figure 3.2.1-3: SVM central cone (+X view)

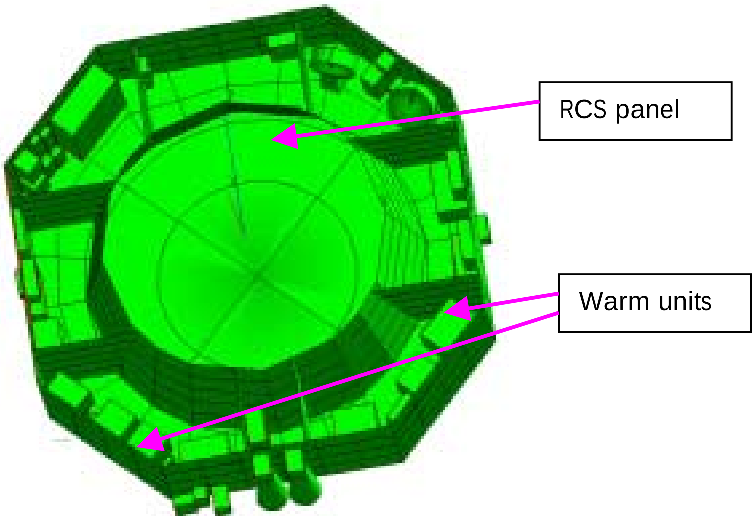


Figure 3.2.1-4: SVM units accommodation

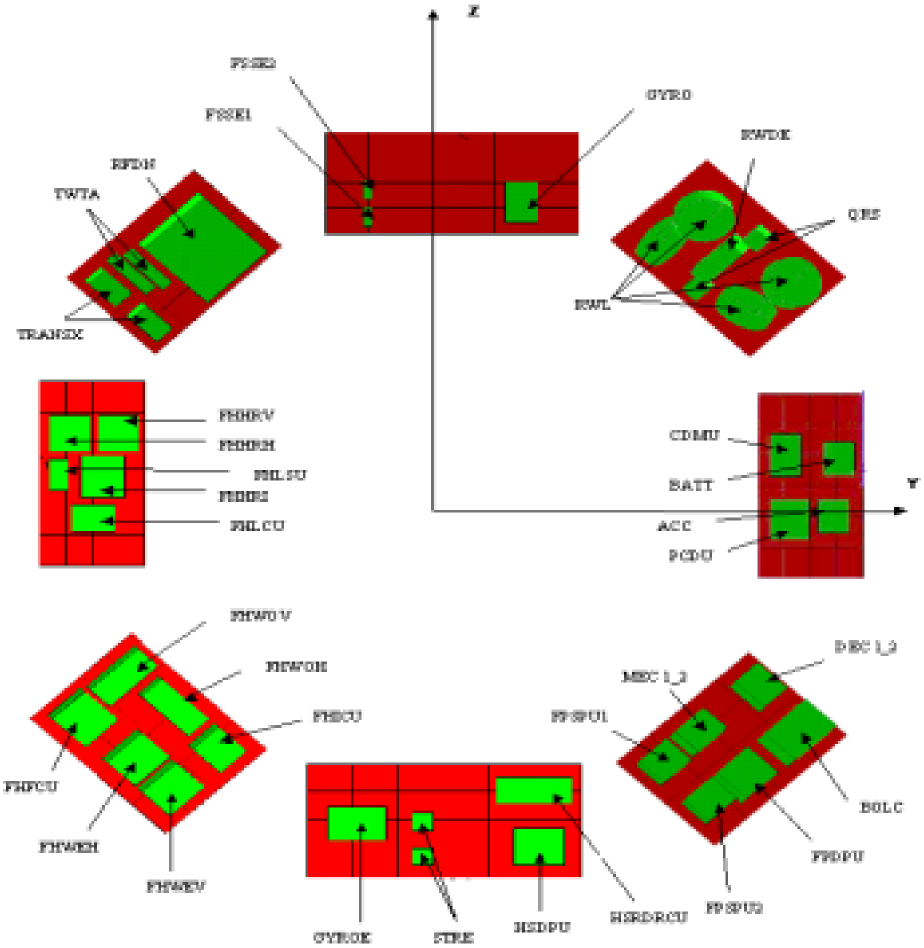


Figure 3.2.1-5: Units accommodation on lateral panels

3.2.1.1.1 External and internal coating

The SVM lateral panels are used as radiators for the overall SVM. The radiative areas are covered with Optical Solar Reflectors on the required size, in order to maintain all the units within their temperature range in hot thermal conditions. MLI blankets cover the remaining surface of the lateral panels not used as radiator, to minimise the heater power need in cold cases.
The SVM upper closure panels and the sub-platform are covered by MLI blankets (low emissivity external coating) to insulate the cryogenic PLM from the SVM.
MLI blankets are installed on the SVM lower floor and RCS panel in order to minimise the solar input in hot cases as well as the heater power need in cold cases. Minimisation of the solar flux variation is a critical issue w.r.t. thermo-elastic aspects.
The internal side of the SVM is usually black painted to minimise the temperature gradients within the structure. Equipment's that require temperature stability are Aluminium coated to limit the heat exchange with the other part of the spacecraft.

The MLI efficiency used for computation are the following (Alenia data):

MLI 20 layers		**MLI 10 layers**	
Temperature (K)	**Efficiency**	**Temperature (K)**	**Efficiency**
173	0.03	173	0.025
223	0.03	223	0.0325
283	0.0417	273	0.0485
323	0.0552	333	0.075
333	0.059	373	0.0975
343	0.064	403	0.12
376	0.079	423	0.1375

20 layers MLI are used on components to be insulated from the H-PLM, i.e. on the upper closure panels as well as on the sub-platform. In the less critical areas, 10 layers are considered.

3.2.1.2 H-PLM TMM description

3.2.1.2.1 H-PLM Geometrical and Mathematical Model

The main components of the Payload Module are the telescope, the cryostat, the Sunshield/Sunshade assembly and the SVM shield. The geometrical view is depicted on Figure 3.2.1-6.

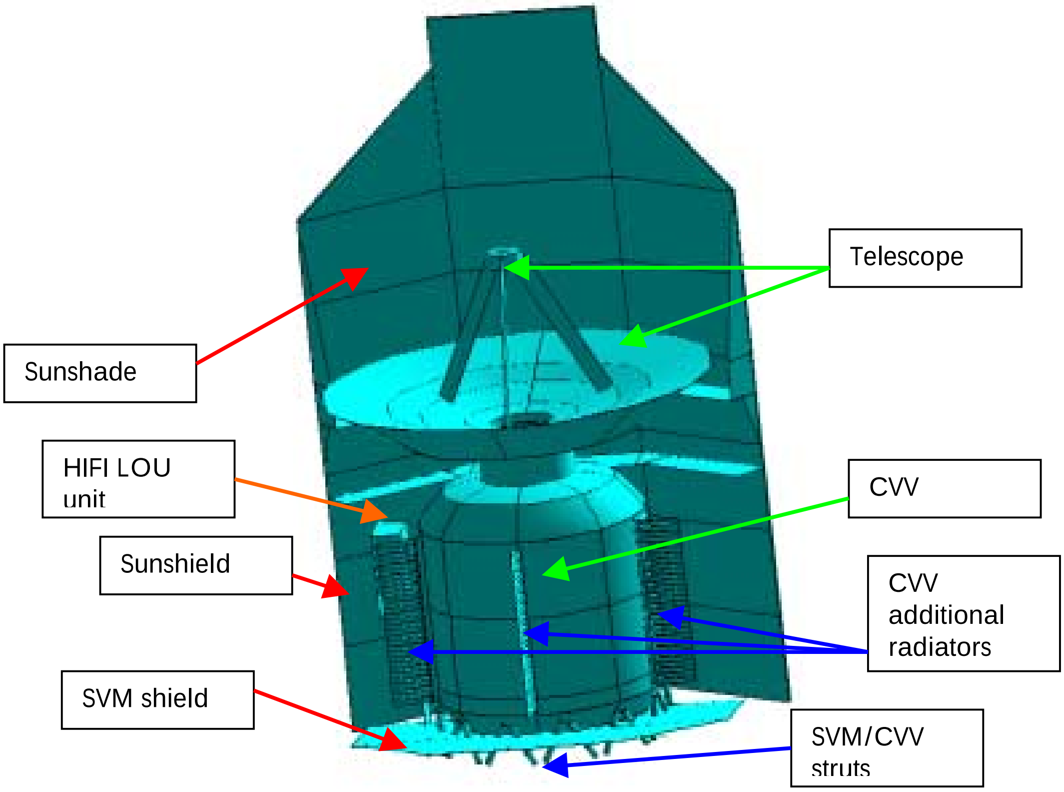


Figure 3.2.1-6: Geometric view of the PLM model

The CVV accommodates the Superfluid helium tank, the radiative screen and the instruments Focal Plane Units. Only the CVV exterior items will be described.

The Sunshield and the Sunshade are used to shadow the CVV and the telescope from sun impingement. The Sunshield serves also as solar generator on its "sunny" side.

The SVM shield is mounted on the SVM, and shadow the CVV radiators and the telescope rear side from the warm SVM top MLI.

3.2.1.2.2 External coating

A part of the CVV serves as a cryogenic radiator, whereas the remaining surface is covered with MLI. Three additional radiators have been implemented on the CVV to increase the heat capacity rejection: two located on the ±Y side and one on the –Z side.

The radiative area of the ± Y additional radiators are black painted, whereas the rear side are covered with MLI for insulation from the sunshield MLI. The sides of the LOU box are covered with MLI except the +X and the –Z side which are used as radiator.

The Sunshield and Sunshade shadow the CVV and the telescope. They are covered with high efficiency MLI on their rear sides to limit the heat loads onto the cold parts. The sunshield provides the electrical power to the spacecraft. The sun-oriented side is covered with AsGa solar cells. The sunshade sun oriented side is covered with OSR's to minimise its temperature, therefore the heat loads towards the cold H-PLM.

In the present configuration, the CVV struts are covered with a SLI (single layer insulation). The SVM shield is covered with MLI.

Main thermal assumptions included in the H-PLM GMM are gathered in the table hereafter. Not all the thermo-optical properties are in line with the PDR baseline definition. There is however no impact on the results of the present study.

ITEMS	NODES	ALPHA BOL	ALPHA EOL	EMISSIVITY	ASSUMPTIONS
CVV	12		0.95	0.8	CVV radiator
	20		0.13	0.05	CVV MLI
	3		0.95	0.9	–Z & ±Y radiators
	2		0.13	0.05	MLI on –Z & ±Y MLI radiators rear side
LOU	3		0.95	0.8	Radiator
			0.13	0.05	MLI
TELESCOPE	1			0.02	Reflector
				0.02	MLI under primary
SUNSHIELD	9	Operating 0.72	Non operating 0.9	0.82	Solar cells on +Z side
	9		0.13	0.05	MLI on rear side
SUNSHADE	9	0.1	0.2	0.84	OSR on +Z side
	9		0.13	0.05	MLI on rear side
SVM SHIELD	3		0.13	0.05	-X side Al coating
			0.13	0.05	MLI on +X side
CVV STRUTS	3*24			0.03	Aluminised Kapton Single Foil

Table 3.2.1-1: H-PLM GMM thermal inputs

The MLI performance data used for the different external items are the following:

MLI location	Layers	Efficiency
CVV	32	Emissivity: 0.0022 Linear conductance: 1.093 e-3
Sunshade	20	0.015
Sunshield	20	0.012
SVM shield +X	20	0.015
LOU	20	0.02

3.2.1.2.3 Nodal break down modifications

The nodal breakdown of the CVV MLI has been updated w.r.t. Astrium original modelling in order to be more representative of the thermal environment.

The single MLI nodes closed to the SVM Shield have been split in two nodes (see Figure 3.2.1-7):

- one facing the top of the SVM shield and having a view factor with the CVV radiator
- one facing the bottom of the SVM Shield and having a view factor with the MLI on top of the SVM

This nodal breakdown is justified by the two different thermal environments on both sides of the SVM shield:

- a warm one on the SVM side,
- a coldest one on the PLM side.

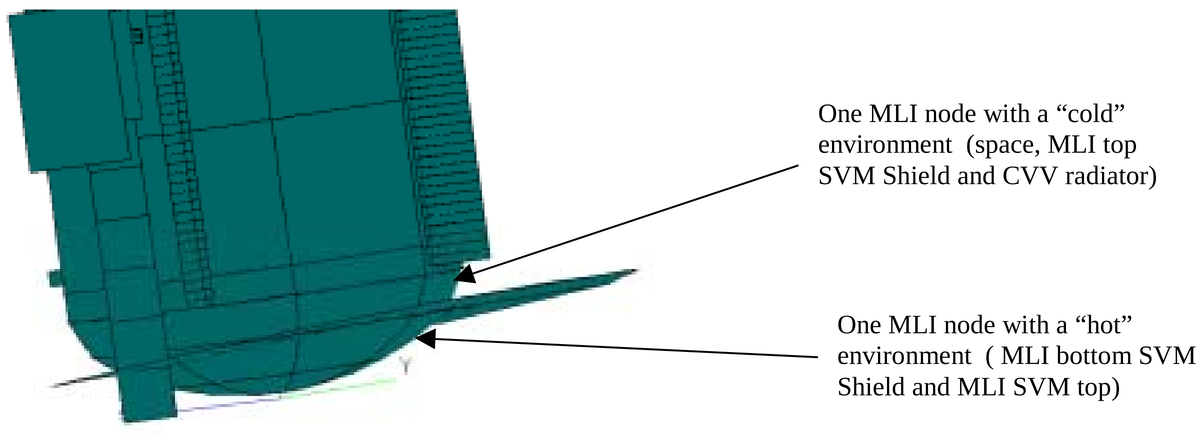


Figure 3.2.1-7: MLI Local nodal breakdown

3.2.2 Interface description

The modelling of the H-PLM has been slightly modified at the level of the interfaces with the SVM.

First of all, the geometry of the MLI between the Sun Shield and the SVM has been updated in order to prevent solar entrance inside the PLM.

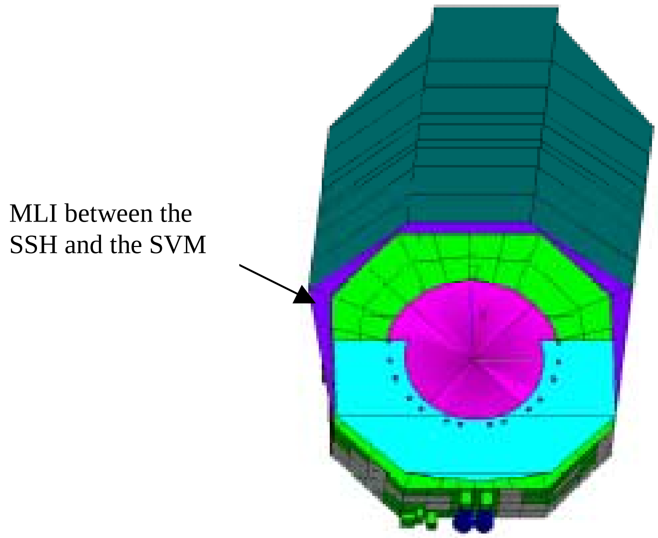


Figure 3.2.2-1: MLI enclosure overview

The second modification deals with the PLM interface points. The payload is accommodated on the top of the SVM cone. The main interfaces with the SVM are provided by the cryostat supporting structure. It is made of a set of 24 struts interfacing with the upper cone by 12 adapter brackets. The struts must conductively insulate the cryostat from the SVM.

The Alenia SVM/PLM Interface model has been updated to match with the actual design (see Figure 3.2.2-2). The interface was indeed modelled by a ring located on top of the central cone. This ring has been deleted in the TMM and replaced by two interface nodes: one located on the H-PLM side and one on the H-SVM side.

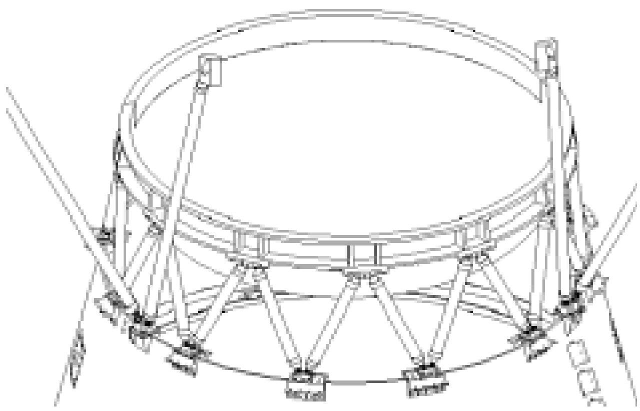


Figure 3.2.2-2: SVM/ PLM Interface design

The SVM/PLM interface has been modelled as followed:

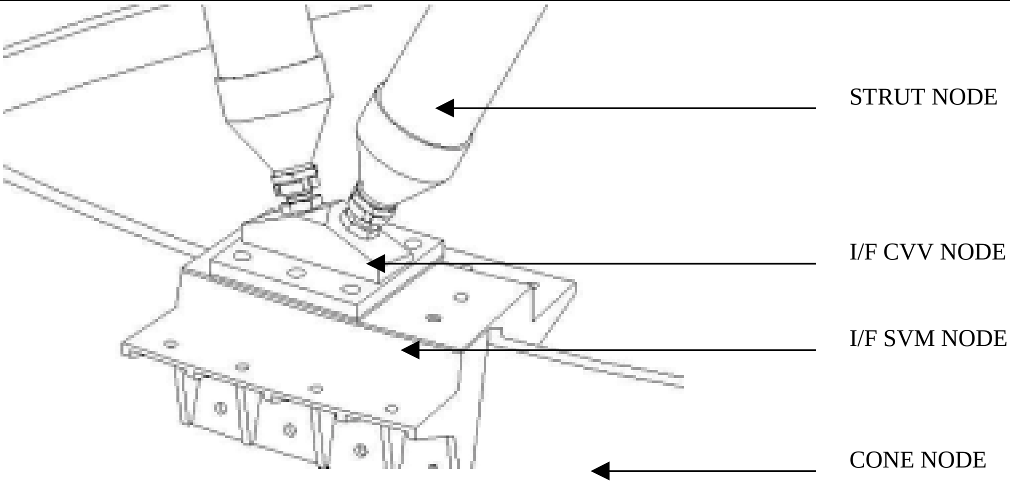


Figure 3.2.2-3: SVM/PLM Interface thermal model

The Interface locations are shown in the following figure.

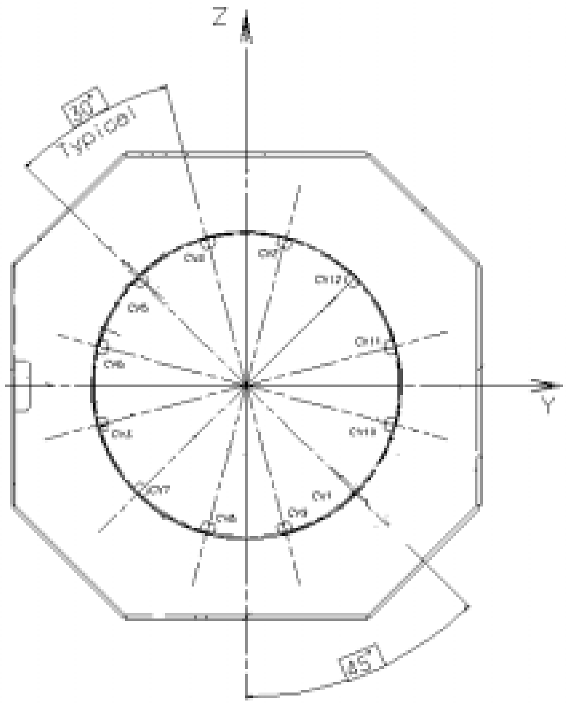


Figure 3.2.2-4: CVV I/F points onto the SVM

In the H-PLM radiative model, the location of the CVV struts interface points is 15 ° shifted from the actual one. Because the strut radiative heat loads is low compared to the conductive heat load (strut emissivity of 0.03), the H-PLM GMM has been used as it was delivered. Only the conductive model has been corrected.

The CVV struts material is Glass Fiber Re-inforced Plastics. The conductance value versus temperature are recalled hereafter (ASTRIUM data).

Temperature (K)	Conductivity (W/mK)
50	0.347
120	0.477
300	0.811
400	0.997

The Sunshield support structure interfacing with the SVM is made of a set of 4 struts attached on the central cone by 2 adapter brackets. The struts material is Carbon Fiber, no stringent thermal constraints being applicable. There is anyway a requirement to limit the heat flux from the hot sunshield (T ~140 °C in operation) to the SVM. The I/F locations are shown hereafter:

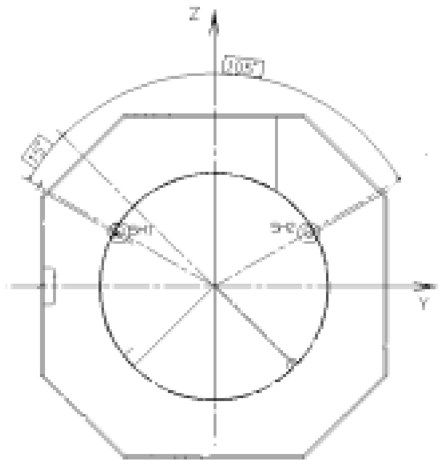


Figure 3.2.2-5: SunShield I/F points on the SVM

3.2.3 Hypothesis for computation

The spacecraft will operate on a Lissajous orbit around the L2 Lagrangian point the Sun / Earth system. This point is aligned with the Earth and the Sun (anti-sun direction), and located at around 1.5 10^6 Km away from the Earth. During operation around L2, the extreme solar constant values to be used for computation are:

- 1405 W/m² during Winter Solstice (WS)
- 1287 W/m² during Summer Solstice (SS)

Due to the long distance between HERSCHEL orbit and the Earth, only solar fluxes have been taken into account for the thermal analyses.

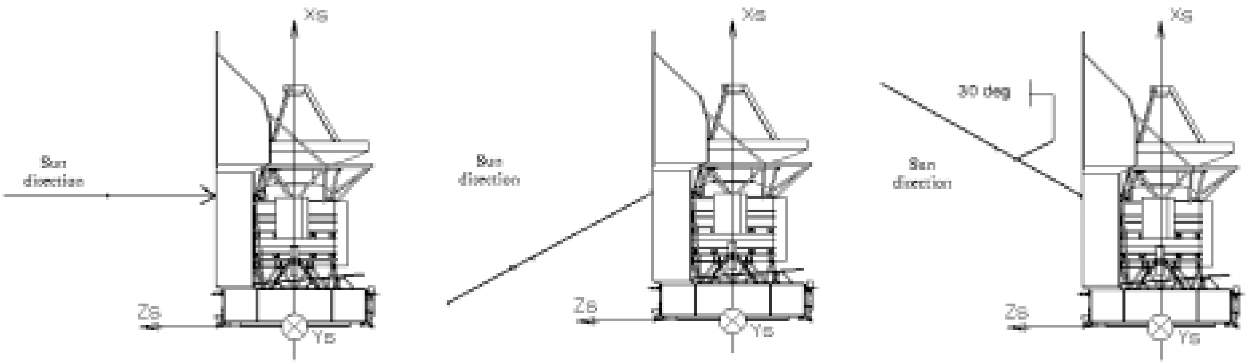
During HERSCHEL missions phases and operational modes, the solar aspect angle will be maintained at ± 30° around the Y-axis (Pitch angle) and at ± 1° around the X-axis (Roll angle).

The global thermal analyses have been performed in hot conditions, i.e.

- WS solar constant
- End Of Life thermo-optical properties
- Units nominal thermal dissipation + 10% margin

This case is considered the sizing ones w.r.t. interface conditions, and consequently H-PLM thermal performances. For the defined above sizing case, three different pitch angle are considered (see Figure 3.2.3-1).

The instruments warm unit dissipations are compliant with the Interface Document IID-B iss. 2.0. For the spacecraft units, the thermal dissipations have not been updated w.r.t. original Alenia data.



Pitch 0° Roll 0° **Pitch 30° Roll 0°** **Pitch –30° Roll 0°**

Figure 3.2.3-1: Global TMM sizing cases

3.2.4 Results

The temperatures and the heat budgets presented hereafter are calculated ones, i. e. without margins and uncertainties.

3.2.4.1 Thermal Interfaces

This chapter deals with the establishment of the interface requirements between the H-SVM and H-PLM modules.

3.2.4.1.1 SVM Thermal Environment

At SVM level, the specifications are split into environmental specifications and interfaces requirements. The first ones deal with the H-PLM thermal input to be taken into account for SVM thermal analyses. The second ones establish the thermal performances required to the SVM in order to achieve the thermal performances at H-PLM level. The SVM radiative environmental specifications, which are not critical for the SVM thermal control will be presented and justified in a technical note, available at time of PDR co-location.

3.2.4.1.1.1 Conductive Flux Environment Specifications

The H-PLM exchanges conductive heat flux with the H-SVM via the following items:

- CVV supporting struts
- SVM shield supporting struts
- Sunshield struts
- Wave-guides and harnesses

The results are gathered in the next table.

Remark: **the reported heat fluxes are related to SVM/CVV interface only, and are not fluxes onto the CVV neither on the SVM shield.**

	Pitch 0° Roll 0°	**Pitch 30° Roll 0°**	**Pitch –30° Roll 0°**	**SPEC**
CVV STRUTS	**4.4W**	**5.1W**	**4.1W**	1W
SUNSHIELD STRUTS	2.3W	1.5W	2.1W	15W
SVM SHIELD STRUTS	0.3W	0.3W	0.3W	1W
WG & Harness	**2.6W**	**2.6W**	**2.7W**	1W

Table 3.2.4-1: Conductive heat loads at SVM/PLM interfaces

The observed out of specifications for some of the conductive heat loads between the CVV and the SVM are not critical. Indeed, the above heat loads are only input data for the SVM thermal control, and represent a negligible amount of the total SVM heat exchange with environment.

3.2.4.1.2 SVM thermal interface requirement

The interface temperature of the MLI external layer on upper closure panels and sub-platform, the CVV and the SVM shield struts attachment points are required to stay below a maximum value to guarantee a suitable thermal environment for the H-PLM. The relevant temperature levels computed with the spacecraft TMM as well as the requirements are reported on the next table.

		Pitch 0° Roll 0°	**Pitch 30° Roll 0°**	**Pitch –30° Roll 0°**	**SPEC**
SVM MLI	**Minimum**	195K	204 K	191 K	<220 K
	Maximum	207K	**215** K	199 K	
CVV struts attachment points	**Minimum**	277K	**291** K	270 K	<293 K
	Maximum	280K	**295**K	272 K	
SSH struts attachment point	**Minimum**	278K	**294** K	270K	<293 K
	Maximum	280K		272 K	
SVM shield stuts attachment point	**Minimum**	277K	**290** K	271 K	<293K
	Maximum	281K	**297** K	274 K	

Table 3.2.4-2: HERSCHEL I/F temperatures

These temperatures are calculated ones, without temperature margin. Adding 7 °C as agreed by all parties at the beginning of phase B, most of the interface temperatures are out of specification in case Pitch 30° and Roll 0°. The results obtained by ALENIA point out non-compliance too, since temperature at the CVV as well as at SVM shield interface struts may reach 313 K, margin included.

The impact of the SVM/PLM interface truss at 313K has been estimated using ASTRIUM TMM issue 2.0. The lifetime reduction is about 1 week. However, The computation has been performed setting all the interfaces thermal nodes at 313K, which is a sizing case w.r.t. Alenia results. The impact on lifetime is consequently less than one week, and is not considered as critical.

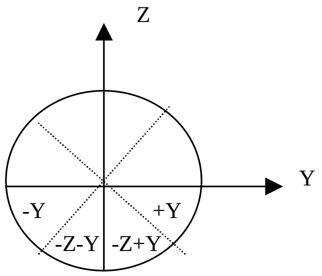
Only one-day impact on lifetime has been observed with the SVM shield struts interface temperatures at 313K.

Concerning the temperatures of the MLI blanket, impact on the H-PLM will be assessed soon. Again, it is considered not critical due to the high level of radiative insulation at H-PLM side. The specification will be nevertheless re-formulated whether in maximum AVERAGE temperature, whether in maximum heat fluxes exchanged with the H-PLM.

3.2.4.2 Thermal Model Optimisation

3.2.4.2.1 MLI CVV Nodal Break-down

The aim of this study was to refine the nodal break down of the CVV main radiator, in order to assess the impact of the modelling on the CVV temperatures and therefore on the lifetime. The results have been obtained with the detailed MLI model on the CVV near the SVM shield in Pitch 0° Roll 0°.



Detailed Model			ASTRIUM Nodal Break down		
CVV MLI under SVM Shield	**-Y**	126.3	**CVV MLI**	**-Y**	116.4
	-Y-Z	116.8		**-Y-Z**	107.2
	+Y-Z	115.6		**+Y-Z**	106.1
	+Y	121.2		**+Y**	111.1
CVV MLI above SVM Shield	**-Y**	90.5			
	-Y-Z	65.2			
	+Y-Z	64.9			
	+Y	83.8			

The temperatures of the CVV MLI above the SVM shield are lower in the refined model than in the nominal one. This modelling has no significant impact onto the CVV lifetime, but should be taken into account as a general modelling rule.

3.2.4.2.2 SVM Shield

The baseline proposed by ASTRIUM, is to cover the +X side of the SVM shield with a MLI blanket. An alternative solution is to use a low emissive and highly reflective Aluminium coating (ε=0.05 and 70% infrared specularity ratio) on the upper skin shield. Comparison between the two design solution are presented hereafter:

		SVM Shield covered with MLI on the +X side	SVM Shield in aluminium
SVM SHIELD on +X SIDE	**+Y**	116K	108K
	-Y		
	-Z		
SVM SHIELD on -X SIDE	**+Y**	105K	108K
	-Y	105K	
	-Z	88K	
Telescope		81.4K	81.5K
CVV main radiator		69.5K	69.8K
CVV Radiator -Z		68.4K	68.7K

Table 3.2.4-3: SVM shield design evolution

This modification has an impact of only 5 days on the CVV lifetime.

4. PLANCK SYSTEM THERMAL ANALYSES

4.1 Spacecraft thermal modelling

4.1.1 Model Description

The PLANCK spacecraft geometrical and mathematical thermal Models (GMM and TMM) have been built merging the GMM and TMM of each module:

- PLANCK Service Module (SVM)
- PLANCK Payload Module (PLM)

PLANCK SVM GMM and TMM have been built by ALENIA, whereas the PLANCK PLM GMM and TMM have been developed by ALCATEL as P-PLM main contractor. Each model of the modules as well as the overall model is described in the next chapters.

4.1.1.1 PLANCK SVM Geometrical and Mathematical Model

The GMM used for computation of the radiative exchange factor is the ALENIA GMM issue 0 delivered in February 2002. This GMM is greatly based on the one used for SRR thermal analyses. It has been slightly modified at some area for the purpose of the study. The modifications will be described hereafter. The SVM components geometrically modelled are described below.

The SVM structure is an octagon-shaped box made of 8 lateral panels, around a central cone. The lateral panels accommodate both sub-system equipment and payload warm units. SVM lateral panels are modelled by mean of two sets of nodes: a set for the internal part of the panel and a set for the external one, to take into account the temperature difference across the panel thickness. The SVM lateral panels are used as radiators for the overall SVM. The radiative area are covered with Optical Solar Reflectors (OSR) on the required size, in order to maintain all the units within their temperature design range in hot thermal conditions. MLI blankets are used to insulate the remaining surface of the lateral panels not used as radiator, to minimise the heater power need in cold cases.

Remark: In the GMM used for system analyses, the coating of the radiators is OSR. Actually, black paint is foreseen since no solar impingement will occur during the whole nominal PLANCK mission. This design difference compared to the PDR working baseline has no consequence on the present study.

The upper and lower closure panels establish the upper and lower limit of the octagonal box. Both closure panels are free from dissipative equipment. They only accommodate Reaction Control Subsystem (RCS) lines and harnesses.

Inside the SVM box are installed eight shear panels, which main function is to stiffen the SVM structure. They do not support dissipative equipment in this version of the model. As for the closure panels, they accommodate harness and RCS lines. The central cone is connected to the lateral panels by means of these shear panels. The RCS panel is located inside the central cone. The solar array closes the octagonal box at the launcher interface side.

The units belonging to the same functional group are accommodated on the same dedicated panel. All spacecraft and instrument warm units are geometrically modelled. The Units Size has not been modified w.r.t. Alenia input GMM issue 0.

The SVM is finally on top of the central cone by the P-PLM sub-platform. Major evolutions have occurred since time of the delivery of Alenia TMM issue 0. The platform accommodates now the PAU and BEU/DAE control box on the upper side +X, and the DAE power box on the lower side –X. Alenia TMM has been updated accordingly to perform local analyses on this critical area.

- The sub-platform is covered by MLI blankets with low emissivity to insulate the SVM from the cold PLM

  MLI external layer black painted => with aluminised external layer MLI

  [ε , α BOL, α EOL] = [0.9, 0.9, 0.9] => [0.05 , 0.15 , 0.15]

- The sub-platform warm units (BEU and PAU) are covered with aluminised external layer MLI. Only the BEU –Z side and 56% of PAU –Z side, which are used as radiative area, are still black painted.

  Unit Black painted => with aluminised external layer MLI

  [ε , α BOL, α EOL] = [0.9, 0.9, 0.9] => [0.05 , 0.15 , 0.15]

The DAE power box is shifted on the other side of the sub-platform (side –X), and black painted to enhance thermal coupling with the internal part of the SVM.

The geometrical and radiative modelling of the SVM is depicted in Figure 4.1.1-1, Figure 4.1.1-2, Figure 4.1.1-3 and Figure 4.1.1-4.

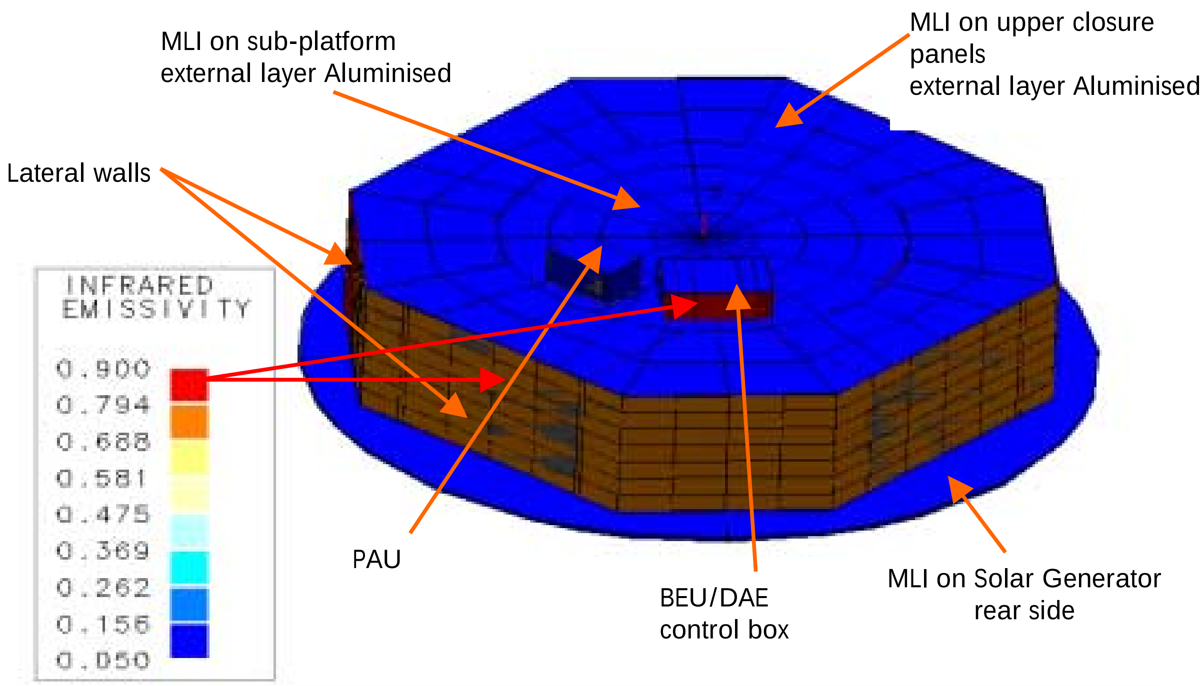


Figure 4.1.1-1: SVM GMM external view

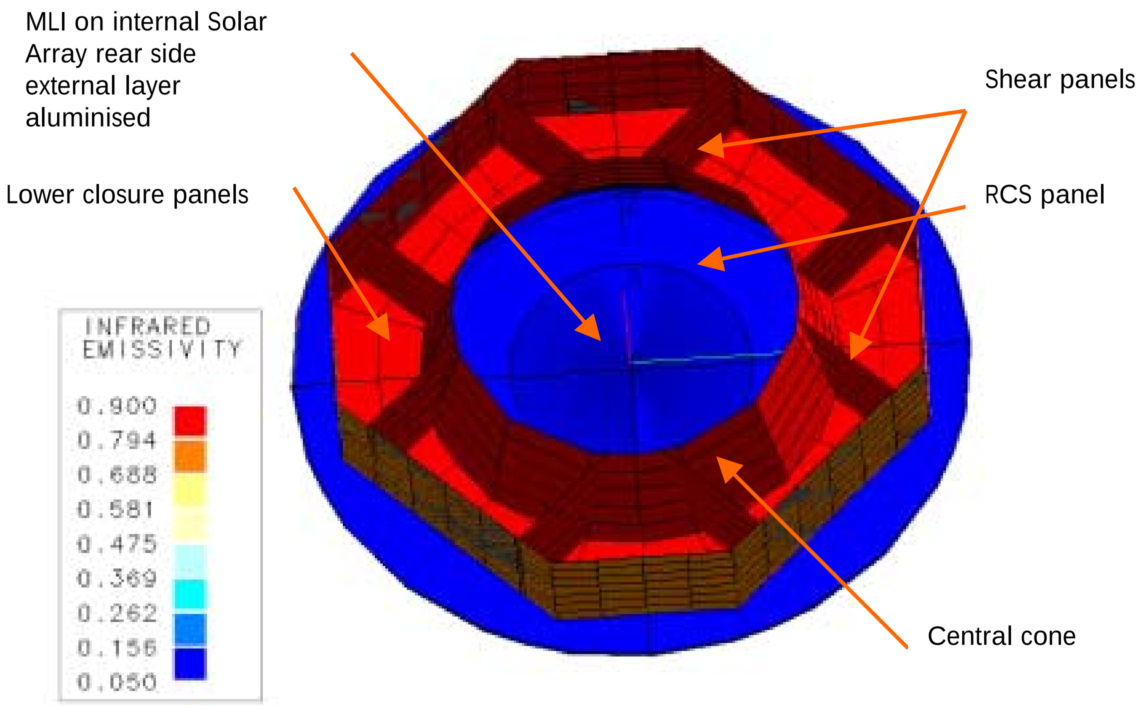


Figure 4.1.1-2: SVM GMM structural view

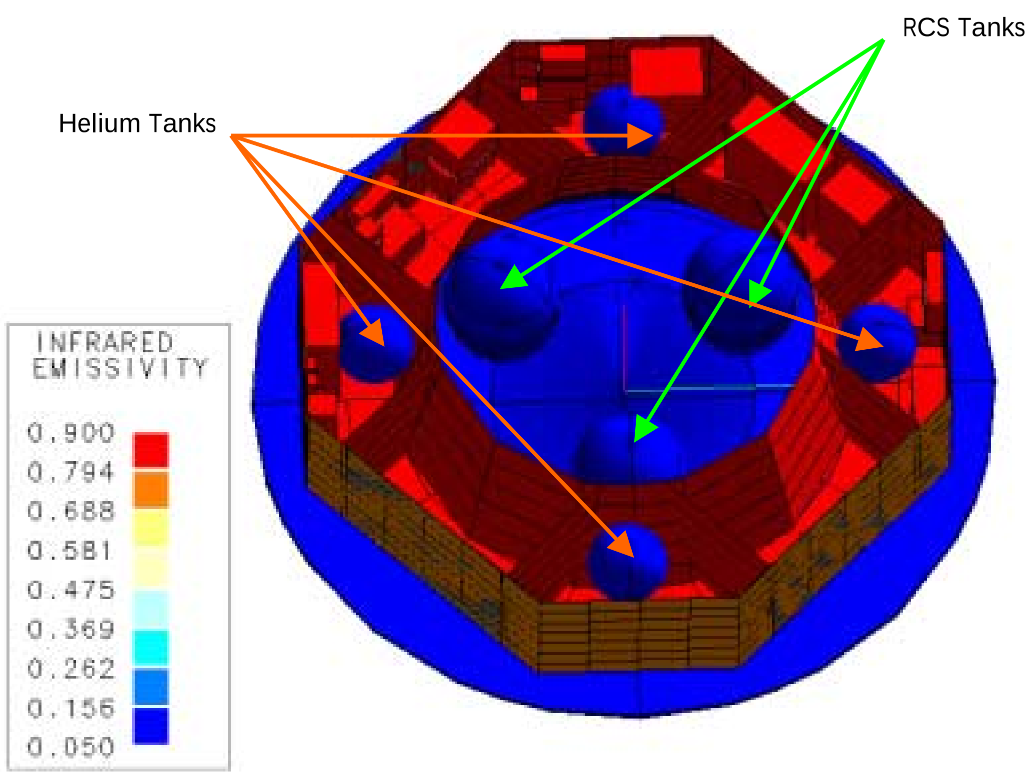


Figure 4.1.1-3: SVM equipment/units accommodation

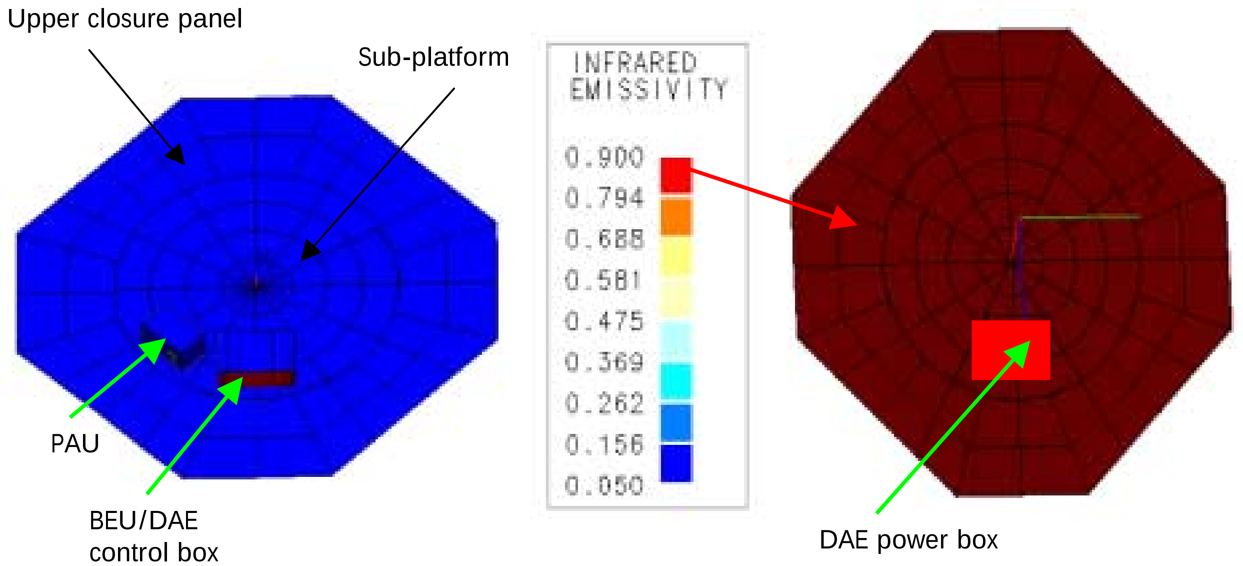


Figure 4.1.1-4: Top of SVM side +X and -X

4.1.1.2 SVM Thermal and Mathematical Modelling

The SVM Thermal and Mathematical model contains:

- The thermal nodes description
- The thermal conductivity network
- The radiative exchange factors
- The unit dissipations

One of the main modifications brought to the Alenia SVM TMM concerns the conductive modelling of the P-PLM sub-platform. The sub-platform is a critical area regarding the operating temperature range of the warm units, which are fixed on. In the purpose cross-checking the temperatures results, ASPI has modelled the sub-platform with an internal software (CORATHERM) which computes the conductive couplings with accuracy. We have in the same time updated the sub-platform skins material, from Carbon Fiber Re-inforced Plastic 0.3 mm thickness to Aluminium 0.3 mm thickness. The internal software method is equivalent to a very detailed meshing, as depicted in Figure 4.1.1-5

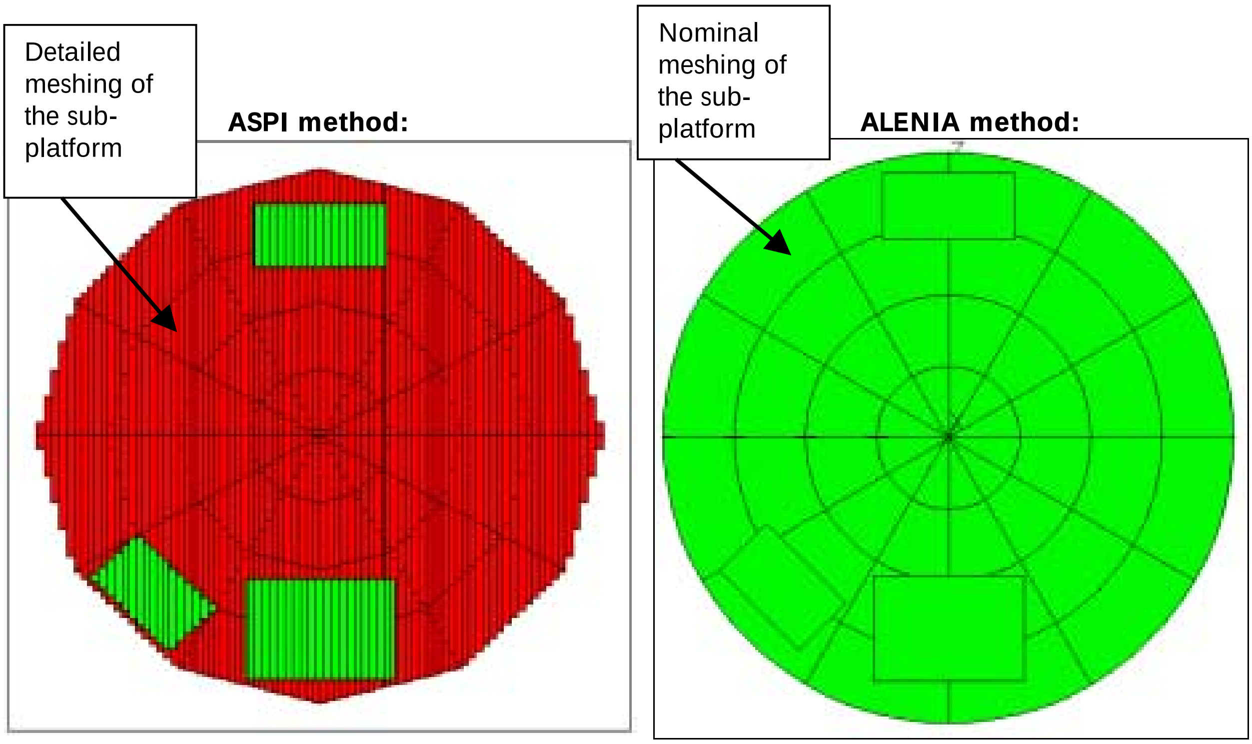


Figure 4.1.1-5: Sub-platform conductive modelling

Rk: The sub-platform definition is not updated w.r.t. the baseline configuration. A sub-platform without a hole in its middle is considered in the present analyses.

The same modelling modifications have been applied on the three Sorption Cooler sub-System walls, which is another critical item from a thermal point of view. The heat pipes network definition and parameters have been updated to match with the PDR baseline (RD-1).

The heat pipes implementation is described in Figure 4.1.1-6. Basically, the two Sorption Cooler Compressors (SCC) and the relevant electronics units (SCE) are fixed on a complex heat pipe network, which is mounted onto three lateral panels (+Y, -Z), (-Z) and (-Y, -Z). The network is made of:

- a layer of longitudinal heat pipes directly mounted onto the panels.
- a layer of crossing heat pipes, mounted between the longitudinal ones and the Sorption Cooler Compressors.

The longitudinal network is composed of two parts (one for each SCC), thermally connected to each other thanks to an overlapping at the (-Z) panel level.

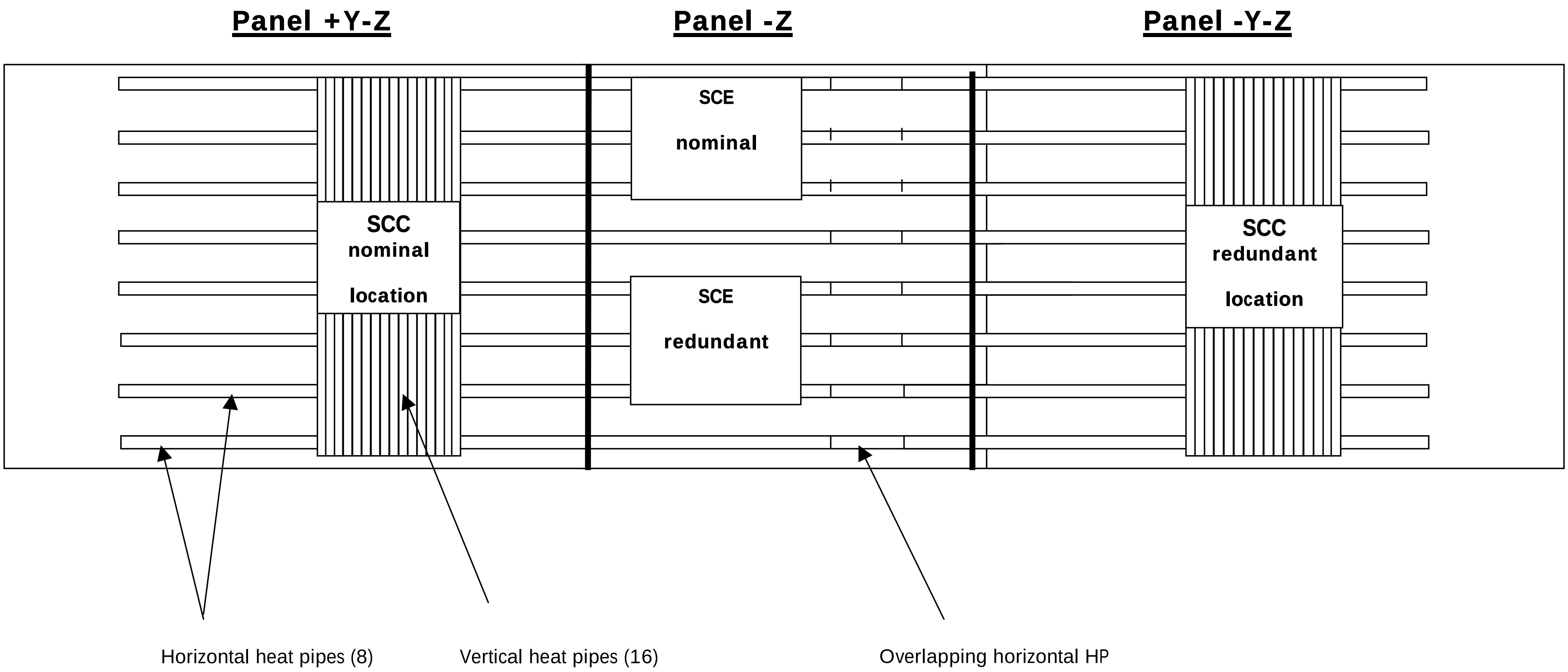


Figure 4.1.1-6: Heat pipes network design

4.1.1.3 Spacecraft overall GMM and TMM

The PLANCK global GMM/TMM results from the merging of:

- the updated ALENIA P-SVM thermal model as described above.
- the P-PLM TMM (H-P-ASPI-DD-1568).

The considered PLM is in accordance with the design at time of PDR. The complete PLM model description is available in AD-2 document.

This TMM is composed of 1900 thermal nodes:

- P-SVM = 1061 nodes.
- P-PLM = 839 nodes among which 41 are dedicated to the instruments.

The overall geometrical model is depicted in Figure 4.1.1-7.

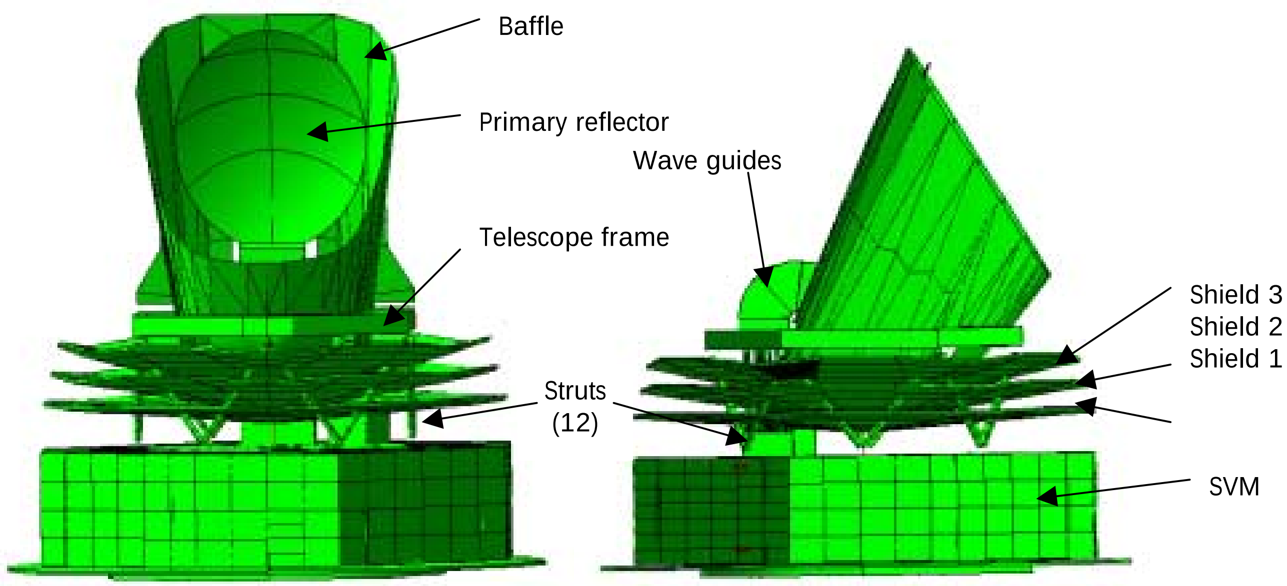


Figure 4.1.1-7: Spacecraft overall view

The SVM and PLM TMM are conductively connected at the level of the six PLM struts interface points.

4.1.2 Hypotheses for computation

The radiative exchange factor between the SVM and the PLM are in accordance with the actual design. The instruments warm units dissipation are the one as defined in the instruments IID-B 2.0, except for the warm units on the PLM sub-platform. In this case, the thermal dissipations are in accordance with the last issue of the IID-B's, which is the working baseline for the PDR data package (see next table). The spacecraft units dissipation are the ones used by Alenia at time of the model delivery.

UNITS	POWER DISSIPATION (W)
Back End Unit (BEU)	58.7
Pre Amplifier Unit (PAU)	15
Data Acquisition Electronics (DAE control box)	20

Table 4.1.2-1: PLM sub-platform warm units dissipation

All the equipment within the SVM are maintained at constant dissipation, especially TTC units whatever the operation mode.
The thermal case defined to perform the thermal analyses is reported hereafter:

Case	Sun on …	Solar constant	Sun temperature	Attitude	Esarad angle	Units power dissipation (W)
Hot case EOL	-X panel	1405 W/m²	5792 K	0°	Psi = -90°	Nominal +10%

Hot case

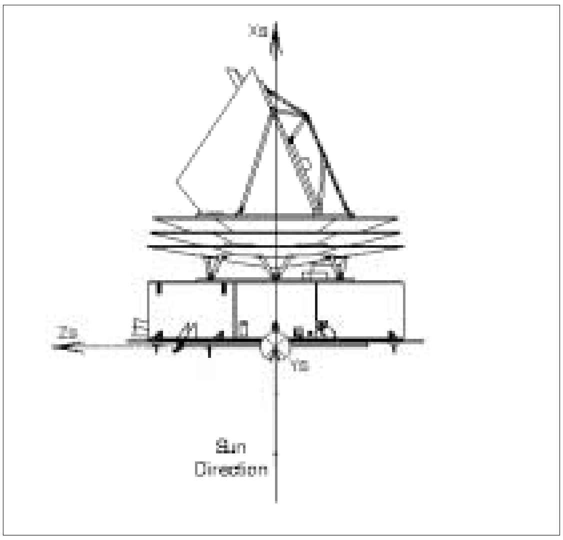


Table 4.1.2-1: PLANCK sizing case

4.2 Thermal analyses results

4.2.1 Thermal interfaces validation

4.2.1.1 Modules Interface temperatures assessment

The results reported in the table hereafter are obtained with the global PLANCK TMM. We have considered a worse case situation with regards to the heat fluxes onto the P-PLM, which is the most critical module. Computations have been therefore performed with hot case conditions for the SVM, and nominal ones for the P-PLM:

The results computed with the overall TMM are reported without temperatures margin.

4.2.1.1.1 Temperature level requirements assessment

The next table allows a comparison between the computed temperature levels to the required data as reported in the SVM interface specification (AD-3).

Elements	MLI on Sub-platform	MLI on Upper Closure panel	SVM Interface struts	MLI on Solar Array back side	MLI on warm units
Computed Temperature (K)	[197 K – 243 K]	[193 K – 200 K]	[283.4 K – 291.7 K]	[272 K-278 K]	211.5 K for BEU 165.8 K for PAU
Requirement	< 200 K	< 200 K	< 293 K	< 300 K	< 200 K
Ref. Requirement in AD-3	ITP-150-P	ITP-150-P	ITP-210-P	ITP-200-P	ITP-180-P

Table 4.2.1-1: SVM/PLM I/F temperatures

<u>Comments:</u>

The sub-platform and upper closure panel MLI temperatures are not totally within the requirements. Anyway, this is not considered as critical for the following reasons.

- the MLI efficiency introduced in the Alenia TMM is 0.048 W/Km² at 273 K. This value is very conservative and is usually adopted for small MLI size with high density singularities. Blankets foreseen on top of the SVM should present very large surfaces, therefore better insulation capacity.

We have performed a sensitivity analysis improving the MLI efficiency down to 0.02 W/Km². This figure is widely used on telecommunication satellites for blankets similar to the one suggested by ALS (same number of layer, composition, material….). The results are reported hereafter:

MLI efficiency	0.048 W/Km² (ALS data)	0.02 W/Km² (ASPI data)
MLI on sub-platform	[197 K – 243 K]	[178 K – 217 K]
MLI on upper closure panel	[193 K – 200 K]	[174 K – 185.6 K]

Table 4.2.1-2: SVM/PLM I/F MLI temperatures

The temperature reduction is significant, and could be increased even more using MLI with 15 or even 20 layers if necessary.

- The “out of specification” areas are limited around the units mounted onto the sub-platform.

The maximum temperature requirement of 200 K is related to a maximum heat load acceptable on the first "V-groove". The P-PLM thermal budget is built assuming **5.25 W** heat parasitic from the MLI blanket on top SVM (including warm units MLI). The values computed with the overall TMM are:

radiative flux emitted by the MLI on BEU/DAE box:	0.23W
radiative flux emitted by the MLI on PAU:	0.03W
radiative flux emitted by the MLI on the sub-platform:	1.60W
radiative flux emitted by the MLI on the upper closure panel:	1.90W
TOTAL:	**3.76W**

The total radiative exchanged flux is lower that the current input data for the P-PLM thermal performances elaboration. According to the results reported above, there is a possibility to decrease the radiative flux to the P-PLM using a more efficient thermal insulation. This point shall be discussed with the SVM contractor. The next issue of the SVM interface specification will be also refined, dealing whether with a maximum heat flux or an average temperature in order to take into account the temperature gradient at the MLI interface.

The PLM struts attachment point temperatures range from 283,4 K up to 291,7 K. These temperature are out of specification if we consider a margin of 7 K.

Anyway, the impact on the most critical level of the P-PLM (coldest Sorption Cooler Pipes interface on "V-groove 3" is lower than 0.1 K. This is therefore not considered as a critical issue. The specification will be however re-written in term of maximum allowable conductive flux.

4.2.1.1.2 Heat Fluxes requirements assessment

Due to the specific thermal control of the BEU/DAE control box and PAU unit, the heat flux from their radiative area must be limited no to degrade the P-PLM performances. The specified data of 2.3 W is the one used as an input for the P-PLM thermal budget.

The radiative loads from both radiative area of the warm units to the first PLM “V-groove” shield are:

radiative flux emitted by the BEU/DAE box:	1.8W
radiative flux emitted by the PAU:	0.7W
TOTAL:	**2.5W**

The total flux is slightly higher than the specified value (0.2 W out of specification). Alenia computation for PDR analyses with the updated SVM TMM shows results within the requirements (2 W), but with a lower radiative area (0.09 m² against 0.114 m²). The trimming between the radiative area and MLI size of the unit impacts the P-PLM temperature level. A compromise shall be obtained between the BEU/DAE temperature and the P-PLM thermal performances.

4.2.1.1.3 SVM thermal environment assessment

This session is dedicated to the verification of the SVM thermal environment specifications, i.e. validation of the input parameters to be used by Alenia to carry out the SVM thermal analyses.

Remark: **the reported heat fluxes are related to SVM/PLM interface only, and are not fluxes onto the P-PLM**

Elements	Interface SVM/PLM struts conductive flux	wave-guides conductive flux	warm "V-groove"
results	3.9 W	12.4	162 K in SVM hot case
specification	1 W	5 W	80 K in SVM cold case 160 K in SVM hot case
Ref. specification in AD-3	ITP-080-P	ITP-010-P	ITP-070-P

Table 4.2.1-2: PLANCK I/F heat loads

The results are slightly above the requirements. However, as for Herschel, these specifications have been edited in order to define the thermal environment for SVM thermal analyses. The heat exchange between the SVM and the PLM is much lower than the SVM thermal budget.

4.2.2 Spacecraft temperature fluctuations assessment

The temperature fluctuation level at the SVM/PLM interfaces is computed by Alenia with a SVM TMM which do not include the PLM, in term of thermal inertia. The aim of this section is to evaluate the damping factor brought by the PLM to the SVM oscillations. For this purpose, we have compared results obtained with the SVM TMM alone on one side, and with the spacecraft overall TMM on the other side. The results are reported inFigure 4.2.2-1.

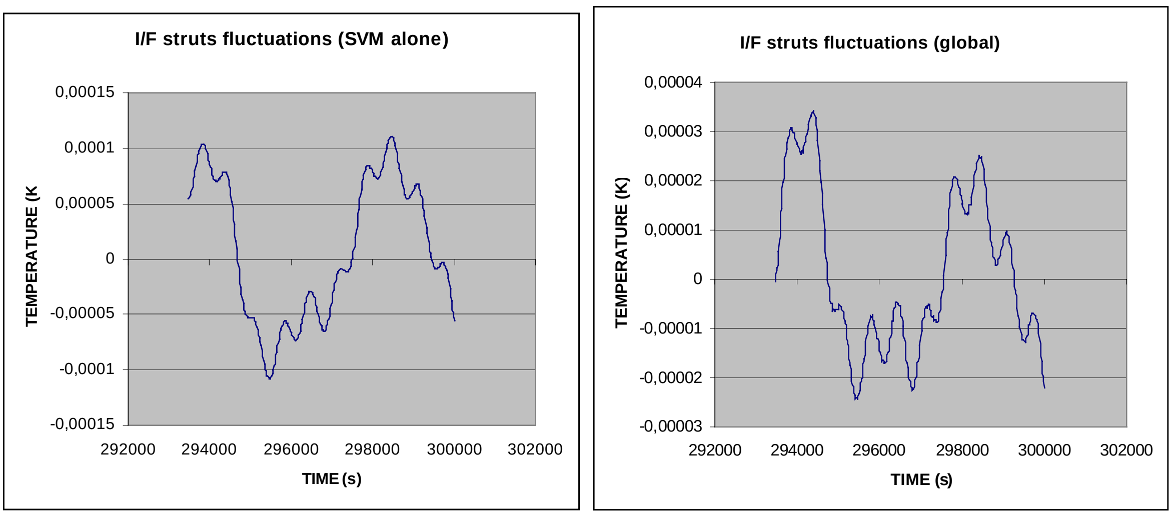


Figure 4.2.2-1: I/F struts temperature fluctuations

The fluctuations amplitude are divided by a factor 5 on average. If necessary, this could allow some relaxation of the requirement at the interface struts. Anyway, comparison of the ASD level between the two configurations would be mandatory before reducing any requirements. Temperature stability requirements for Straylight purpose are indeed expressed now in Amplitude Spectral Density ($K/Hz^{0.5}$).

4.2.3 BEU/DAE cpntrol box thermal interface

4.2.3.1 Temperature levels

The computed temperatures of the BEU/DAE control box and the PAU unit are reported in the next table, as well as their thermal requirements. No temperature margin is applied on the presented results. We have recalled Alenia results obtained with the actual configuration.

Elements	BEU/DAE	PAU
thermal dissipation	57 W	15 W
Temperature (°C) w/o margin	25.5 °C	11.2 °C
Alenia Results w/o margin	33 °C	31.4 °C
Operating Design Temperature Range (RD-2 and RD-3) Rk: not agreed by ALCATEL/ALENIA	[-10 °C , 28 °C]	[-10 °C , 30 °C]

Table 4.2.3-1: PLM warm units temperature

The discrepancy between Alenia results and the one obtained with the overall TMM can be explained by the presence of a large hole in the middle of the sub-platform, which is not modelled in spacecraft TMM. Indeed, it has been checked with previous configuration that there is no difference between Alenia and ASPI results for an identical configuration. The results are given on one side to have an idea of the impact of the sub-platform surface reduction, and on the other side to exactly know the difference between the two TMM with regards to the next study.

4.2.3.2 BEU/DAE Reduced TMM

In the frame of a recovery action related to the BEU/DAE interface temperature, LFI team has provided a Reduced TMM (RTMM) based on their working detailed TMM. As some information is still missing for official delivery to the SVM contractor, it has been included first in the overall spacecraft TMM. We have therefore performed computation for assessment of the interface temperature requirement. Conductive flux towards the P-PLM sub-platform, as well as radiative exchange with space, is computed with a better accuracy than using one single thermal node for the unit.

This BEU RTMM is composed of 15 thermal nodes, and takes into account the following hypothesis:

- Total BEU power dissipation: 57.8W.
- Radiative area located on BEU side. S ≈ 0.114 m^2 (Alenia hypothesis for computation: 0.09 m^2)

The results are reported in the next table.

	BEU RTMM included in TMM w/o margin
BEU RTMM nodes label	**Temperature (K)**
DAE space side	299.0
Board signal acquisition	320.7
BEU bottom environment (baseplate)	298.8
BEMTray space side	298.7
BEMs R	304.2
FEMdx space side	293.0
FEMdx space side	293.05
FEMdx space side	293.0
FEM board R	302.6
BEMTray space side	299.0
BEMs L	304.4
FEMsx space side	293.8
FEMsx space side	293.8
FEMsx space side	293.8
FEM board L	303.5

Table 4.2.3-2: BEU/DAE internal elements temperature

The temperature of 298.8 K at the BEU bottom environment can be directly compared to the BEU temperature of 299 K (25.8 °C) obtained with a single node. There is consequently no difference in the results obtained with a BEU modelled as a single thermal node or with several nodes representative of its thermal behaviour. This conclusion can therefore be applied on the updated results computed by Alenia. Including a margin of 7°C, the BEU interface temperature is 40 °C. This value shall be taken into account by the unit supplier for the thermal control of its unit. Let's note that the radiative flux onto the "V-groove" 1 is 1.8 W, as computed also with a single node. The previous results are logical since there is almost no temperature gradient within the unit.