TITLE: **LFI ALIGNMENT EVALUATION AND RECOVERY PROPOSAL**

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CHANGE RECORD

Issue	Date	Sheet	Description of Change	Release
1.0	30/04/04	All	First Issue of the Document	IHDR
1.1	11/05/04	4.1.1, 4.1.2,	Total sigma definition corrected in formula according to tables.	==
		4.2	Sigma breakdown (σ_{wa} ,σ_{th}) included in table	==
2.0	20/12/04	All	General updating based on the latest LFI thermal elastic analysis	==
2.1	09/02/2005	All	Update based on new HFI thermo elastic data	==

TABLE OF CONTENTS

1 INTRODUCTION AND SCOPE

Scope of this technical note is to assess the alignment of LFI starting from the thermo–elastic analysis performed by LABEN. Displacement and rotation of each feed horn has been evaluated by LABEN at the LFI operational temperature. In chapter 4 we report the results of this analysis, and in chapter 0 we evaluate the impact on the LFI performances.
The alignment requirements at a level of horn for both LFI and HFI instruments are specified in the Planck Alignment Plan – H-P-3-TN-0078, page 42:

6.3.3 At FPU level

The horns must be located (in-orbit) with the following accuracy w.r.t the mounting interface to the telescope FPU:

#

+/-0.4mm translation (position and stability) along each X and Y axis, and +/-0.5mrad rotation around each X Y axis

#

#

+/-0.5mm translation (manufacturing + cool-down)along Z axis of the actual average focal plane surface wrt its theoretical Z position (manufacturing + cool-down)

#

#

+/-0.1mm maximum deviation (position and stability) along Z axis wrt to actual average focal plane surface

#

#

+/-0.1mm knowledge accuracy of the actual average focal plane surface Z axis position wrt its theoretical Z position.

#

#

Each horn position (X and Y) will have to be known wrt telescope/FPU mechanical interface with a accuracy better than +/-0.1mm

#

#

Each detector line will have to be known to be aligned parallel to Y axis wrt to telescope/FPU mechanical interface with a 0.1 arcmin accuracy – this has a direct impact on around LOS knowledge.

#

The results of the thermo– elastic analysis show that the requirements above are not satisfied.

2 APPLICABLE DOCUMENTS

[AD 1] Herschel Planck Plance Alignment Plan - H-P-3-ASPI-PL-0078, Issue/Rev. 4.0, dated July 23rd, 2004

3 REFERENCE DOCUMENTS

[RD 1] M.Sandri, C.Burigana, F.Villa, *A note on the pointing error impact on the recovery of the Stokes parameters of CMB polarization anisotropy,* IASF Internal Report 347/2002. available for download at the LFI optical working group web page (http://planck.bo.iasf.cnr.it/lfi_owg).

[RD 2] HFI/LFI interface and alignment meeting – 08/04/2003 – LABEN – Vimodrone, MoM LA–PG–DT–MN–0007/03

[RD 3] JJ. Fourmond, *Reference Loads IF points Displacement from 295K to 4K,* TN-PHA-500118-IAS, Rev. 1.0, 24/01/2005

4 LFI THERMO/ELASTIC ANALYSIS RESULTS

LABEN updated the complete thermo/elastic analysis of LFI with respect to the analysis reported in the version 1.1 of this document.

This new analysis has been improved in the following points:

- Aluminium CTE as measured on samples. The uncertainty on the measurement is +/ – 5% reflecting in a +/ – 2.5 % in the final result of this analysis. This final uncertainty has been evaluated by varying on the model the Aluminium CTE.
- Temperature distribution as derived from the thermal model considering the temperature distribution on the Primary Reflector panel.
- Interface between bipods and Primary Reflector panel (including tolerances) as described in the Annex 7 of the IID–A

The uncertainty has been improved at +/ – 2.5% instead of +/ – 5% as reported in the version 1.1 of this document.

To get nominal displacement and uncertainties, the analysis has been performed on the nominal temperature (22.5 at LR2) and ± 10 %. Temperatures are taken directly from the thermal simulation, considering 22.5K on LR2. The uncertainty has been improved at +/ – 2.5% instead of +/ – 5% as reported in the version 1.1 of this document.

Several nodes have been calculated in displacements along the three axes in the Reference Detector Plane (RDP) coordinate system (see Figure 1). For the feed analysis the following nodes have been considered:

- ♦ 20 nodes on the 70 and 40 GHz feed top and 30 nodes for the 44 GHz feed top.
- ♦ 2 nodes at the 70 GHz FH/OMT interface and 3 nodes at the 30 and 44 GHz FH/OMT interface (at the flange alignment pins and center of the circular waveguide)

The cases have been analyzed in order to get nominal displacement and uncertainty are reported in TABLE 1).

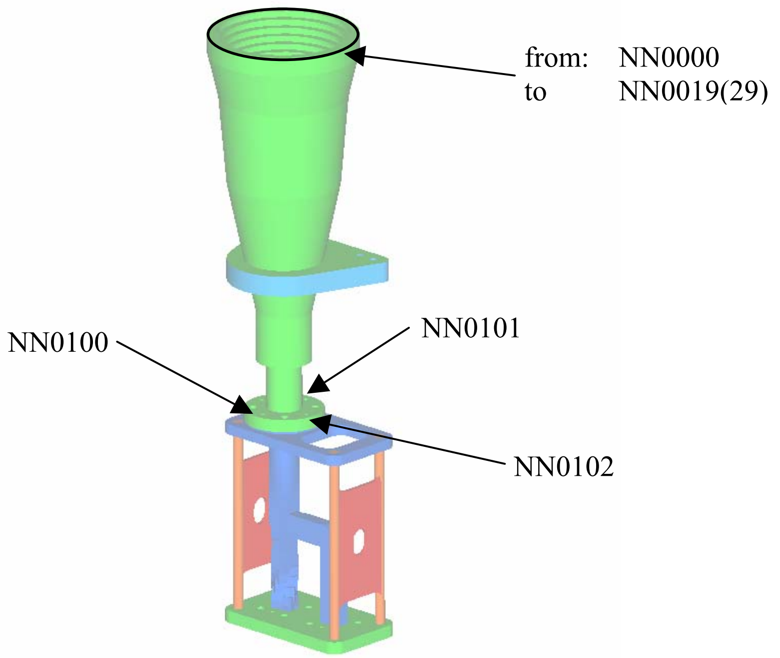

Figure 1: Identification of the nodes used by LABEN for the analysis. NN is the feed number. Points on the OMT interface are the intersection of pin axes with interface contact plane.

TABLE 1: ANALYSED CASES

MAINFRAME TEMPERATURE	CONFIGURATION					
	NOMINAL	BIPODE 1 E+10%	BIPODE 2 E+10%	BIPODE 3 E+10%	BIPODE 1 L ±0.1 MM	BIPODE 2 L ±0.1 MM
NOMINAL.....................	X	X	X	X	X	X
+10%...........................	X	X	X	X	X	X
–10%...........................	X	X	X	X	X	X

In appendix A we reports the displacement of each node and the nominal position.
Results are shown as nominal value plus min/max range. The range takes into account both the above cases and a +/– 2.5% uncertainty of the numerical simulation. Results are displacement from undeformed position. Units are millimeters.
Points on the OMT interface are the intersection of pin axes with interface contact plane (i.e. plane defined by the step).

4.1 LFI FEED HORNS APERTURE CENTER DISPLACEMENT AND ROTATION DUE TO THERMO-ELASTIC AND WARM TOLERANCES COMBINED.

From the above results the aperture center displacement and rotation has been calculated as a mean value plus a standard deviation form the unperturbed position (warm nominal position).

4.1.1 Aperture center displacement

Since the feed horns undergo deformations while shrinking, the aperture center has been defined as an average point. The aperture center displacement mean value has been defined as the average displacement of the feed aperture nodes in the nominal analysis. Displacements are defined in the RDP coordinate frame and are expressed in mm.

Let consider the calculated displacements (minimum, nominal, maximum) as $\Delta^{(i)}_{MIN}$, $\Delta^{(i)}_{NOM}$, $\Delta^{(i)}_{MAX}$ where (i) is the node at the horn aperture (i = 0...19 for the 70 and 30 GHz horns and i = 0...29 for the 44 GHz horns). Then the average displacement is defined as

$$\overline{\Delta}_{NOM} = \frac{1}{N+1}\sum_{i=0}^{N}\Delta^{(i)}_{NOM}$$

$$\overline{\Delta}_{MIN} = \frac{1}{N+1}\sum_{i=0}^{N}\Delta^{(i)}_{MIN}$$

$$\overline{\Delta}_{MAX} = \frac{1}{N+1}\sum_{i=0}^{N}\Delta^{(i)}_{MAX}$$

and the standard deviation has been calculated in using the following equation:

$$\sigma^{(1)}_{NOM} = \frac{1}{k}\cdot\frac{\left|\overline{\Delta}_{MIN} - \overline{\Delta}_{NOM}\right| + \left|\overline{\Delta}_{MAX} - \overline{\Delta}_{NOM}\right|}{2}$$

where k is a factor depending at which sigma – level one would consider the data. We assumed 3 sigma level (99.7%) so that $k = 3$. This method considers the average of the differences between the minimum and nominal, and the maximum and nominal conditions at the 3–sigma level of statistical error.

These values (mean value plus standard deviation) have been combined with warm tolerances analysis output, which consists of a second standard deviation figure together with a mean value equal to zero. Results have been combined as follows:

$$M = M_{th} + M_{wa}$$

$$\sigma = \sqrt{\sigma^2_{th} + \sigma^2_{wa}}$$

where M_{th} = mean value from thermo-elastic analysis, M_{wa} = mean value from warm tolerance analysis (equal to zero), σ_{th} = standard deviation calculated from thermo-elastic analysis, and σ_{wa} = standard deviation coming from warm tolerance analysis.

Final value has been defined as: $M + 3\sigma$, giving 99.7% confidence.

DISPLACEMENT ALONG X RDP (MM)					
FH	MEAN	SIGMA TH	SIGMA WA	SIGMA	MAX 99.7% CONF.
18.................	0.304	0.024	0.135	0.137	0.714
19.................	0.370	0.025	0.134	0.136	0.778
20.................	0.406	0.025	0.141	0.143	0.834
21.................	0.408	0.025	0.134	0.136	0.816
22.................	0.370	0.025	0.133	0.135	0.775
23.................	0.306	0.024	0.136	0.138	0.719

DISPLACEMENT ALONG X RDP (MM)					
FH	MEAN	SIGMA TH	SIGMA WA	SIGMA	MAX 99.7% CONF.
24................	0.533	0.027	0.126	0.128	0.919
25................	-0.158	0.020	0.074	0.076	-0.386
26................	-0.252	0.019	0.074	0.076	-0.480
27................	0.493	0.027	0.121	0.124	0.864
28................	0.499	0.027	0.131	0.133	0.899

DISPLACEMENT ALONG Y RDP (MM)					
FH	MEAN	SIGMA TH	SIGMA WA	SIGMA	MAX 99.7% CONF.
18................	0.279	0.021	0.133	0.134	0.681
19................	0.176	0.020	0.137	0.138	0.590
20................	0.073	0.020	0.149	0.150	0.523
21................	-0.070	0.018	0.146	0.147	-0.510
22................	-0.173	0.018	0.147	0.148	-0.616
23................	-0.277	0.017	0.132	0.133	-0.675
24................	0.054	0.020	0.142	0.143	0.483
25................	-0.485	0.015	0.066	0.067	-0.686
26................	0.452	0.023	0.064	0.067	0.654
27................	-0.202	0.018	0.139	0.140	-0.621
28................	0.200	0.022	0.140	0.141	0.623

DISPLACEMENT ALONG Z RDP (MM)					
FH	MEAN	SIGMA TH	SIGMA WA	SIGMA	MAX 99.7% CONF.
18................	-1.972	0.034	0.065	0.073	-2.191
19................	-1.970	0.035	0.066	0.075	-2.194
20................	-1.967	0.036	0.065	0.074	-2.189
21................	-1.967	0.036	0.064	0.073	-2.187
22................	-1.970	0.035	0.065	0.074	-2.191
23................	-1.974	0.034	0.067	0.075	-2.198
24................	-2.122	0.040	0.068	0.079	-2.358
25................	-2.044	0.038	0.079	0.088	-2.308
26................	-2.037	0.023	0.075	0.078	-2.272
27................	-2.092	0.039	0.076	0.086	-2.348
28................	-2.093	0.039	0.080	0.089	-2.361

4.1.2 Horn rotation

For rotations the deformed feed axis has been defined considering two points: the aperture center and the center of the feed/OMT flange. Rotation mean value is the angle between the original position of the feed axis and the position of this deformed axis in the nominal analysis. Rotation standard deviation has been evaluated considering the same percentage of error as for the displacement case and the feed length.
Rotations have been defined as *pitch*, *yaw* and *roll* with reference to the local coordinate frame for each feed horn. *Pitch* is the rotation around the tangential direction, i.e. moving the top of the feed towards the center of the focal plane. *Yaw* is the rotation around the radial direction and *roll* is around the feed axis. Rotations are expressed in radians.
Again, this values (mean value plus standard deviation) have been combined with warm tolerances analysis output, which consists of a second standard deviation figure together with a mean value equal to zero. Results have been combined as follows:

$$M = M_{th} + M_{wa}$$

$$\sigma = \sqrt{\sigma_{th}^2 + \sigma_{wa}^2}$$

where M_{th} = mean value from thermo-elastic analysis, M_{wa} = mean value from warm tolerance analysis (equal to zero), σ_{th} = standard deviation calculated from thermo-elastic analysis, and σ_{wa} = standard deviation coming from warm tolerance analysis.
Final value has been defined as: $M + 3\sigma$, giving 99.7% confidence.

PITCH (AROUND TANGENTIAL AXIS)

FH	MEAN	SIGMA TH	SIGMA WA	SIGMA	MAX 99.7% CONF.
18................	2.02E-04	1.01E-05	1.80E-03	1.80E-03	5.60E-03
19................	2.74E-04	1.37E-05	1.70E-03	1.70E-03	5.37E-03
20................	2.50E-04	1.25E-05	1.70E-03	1.70E-03	5.35E-03
21................	3.47E-04	1.73E-05	1.70E-03	1.70E-03	5.45E-03
22................	2.98E-04	1.49E-05	1.70E-03	1.70E-03	5.40E-03
23................	2.50E-04	1.25E-05	1.80E-03	1.80E-03	5.65E-03
24................	2.67E-04	1.33E-05	1.70E-03	1.70E-03	5.37E-03
25................	3.70E-05	1.85E-06	1.80E-03	1.80E-03	5.44E-03
26................	1.11E-04	5.56E-06	1.70E-03	1.70E-03	5.21E-03
27................	3.23E-04	1.61E-05	1.70E-03	1.70E-03	5.42E-03
28................	3.23E-04	1.61E-05	1.80E-03	1.80E-03	5.72E-03

YAW (AROUND RADIAL AXIS)

FH	MEAN	SIGMA TH	SIGMA WA	SIGMA	MAX 99.7% CONF.
18................	6.45E-05	3.23E-06	1.80E-03	1.80E-03	5.46E-03
19................	6.45E-05	3.23E-06	1.80E-03	1.80E-03	5.46E-03
20................	2.42E-05	1.21E-06	1.90E-03	1.90E-03	5.72E-03
21................	2.42E-05	1.21E-06	1.90E-03	1.90E-03	5.72E-03
22................	7.26E-05	3.63E-06	1.90E-03	1.90E-03	5.77E-03
23................	4.84E-05	2.42E-06	1.80E-03	1.80E-03	5.45E-03
24................	4.67E-05	2.33E-06	1.70E-03	1.70E-03	5.15E-03
25................	2.30E-04	1.15E-05	1.70E-03	1.70E-03	5.33E-03
26..............	2.30E-04	1.15E-05	1.70E-03	1.70E-03	5.33E-03
27..............	1.94E-04	9.68E-06	1.70E-03	1.70E-03	5.29E-03
28..............	1.94E-04	9.68E-06	1.70E-03	1.70E-03	5.29E-03

ROLL (AROUND FEED AXIS)

FH	MEAN	SIGMA TH	SIGMA WA	SIGMA	MAX 99.7% CONF.
18..............	7.77E-04	3.89E-05	1.10E-03	1.10E-03	4.08E-03
19..............	3.89E-04	1.94E-05	1.10E-03	1.10E-03	3.69E-03
20..............	3.89E-04	1.94E-05	1.10E-03	1.10E-03	3.69E-03
21..............	3.89E-04	1.94E-05	1.10E-03	1.10E-03	3.69E-03
22..............	3.89E-04	1.94E-05	1.00E-03	1.00E-03	3.39E-03
23..............	7.77E-04	3.89E-05	1.10E-03	1.10E-03	4.08E-03
24..............	4.86E-04	2.43E-05	1.10E-03	1.10E-03	3.79E-03
25..............	4.86E-04	2.43E-05	1.10E-03	1.10E-03	3.79E-03
26..............	4.86E-04	2.43E-05	1.20E-03	1.20E-03	4.09E-03
27..............	1.71E-04	8.56E-06	1.10E-03	1.10E-03	3.47E-03
28..............	1.71E-04	8.56E-06	1.10E-03	1.10E-03	3.47E-03

4.2 HFI INTERFACE FLANGE AVERAGE CENTER DISPLACEMENT AND ROTATION ROTATION DUE TO THERMO-ELASTIC AND WARM TOLERANCES COMBINED.

Results have been taken from the same thermo-elastic analysis cases shown above. Values are shown as nominal value plus min/max range. The range takes into account both the above cases and a ± 5% uncertainty of the numerical simulation. Results are displacement from undeformed position. Units are millimeters.

	UX (+/– 2.5% MARGIN) [MM] RADIAL (+ TOWARDS EXT)			UY (+/– 2.5% MARGIN) [MM] TANGENTIAL (+ CLOCKWISE)			UZ (+/– 2.5% MARGIN) [MM] VERTICAL		
NODE	MAX	NOMINAL	MIN	MAX	NOMINAL	MIN	MAX	NOMINAL	MIN
26621...........	-6.68E-01	-6.48E-01	-6.26E-01	2.87E-03	3.91E-03	4.88E-03	-1.12E+00	-1.01E+00	-9.22E-01
26622...........	-6.70E-01	-6.49E-01	-6.28E-01	-5.19E-03	-3.98E-03	-2.83E-03	-1.12E+00	-1.01E+00	-9.18E-01
26623...........	-6.72E-01	-6.51E-01	-6.30E-01	-1.29E-02	-1.15E-02	-1.03E-02	-1.12E+00	-1.01E+00	-9.17E-01
26624...........	-6.82E-01	-6.62E-01	-6.42E-01	6.43E-03	7.19E-03	7.90E-03	-1.12E+00	-1.02E+00	-9.22E-01
26625...........	-6.80E-01	-6.60E-01	-6.40E-01	8.03E-04	1.80E-03	2.74E-03	-1.12E+00	-1.02E+00	-9.18E-01
26626...........	-6.79E-01	-6.60E-01	-6.40E-01	-4.81E-03	-3.65E-03	-2.54E-03	-1.12E+00	-1.02E+00	-9.17E-01
26627...........	-6.63E-01	-6.43E-01	-6.22E-01	7.23E-03	7.73E-03	8.19E-03	-1.10E+00	-9.97E-01	-8.99E-01
26628...........	-6.58E-01	-6.37E-01	-6.16E-01	-1.44E-03	-7.42E-04	-7.37E-05	-1.10E+00	-9.95E-01	-8.96E-01
26629...........	-6.64E-01	-6.43E-01	-6.21E-01	-1.04E-02	-9.52E-03	-8.72E-03	-1.10E+00	-9.97E-01	-8.99E-01

From the above results the HFI center displacement and rotation has been calculated as a mean value plus a standard deviation.
Since the interface flange undergoes deformations while shrinking, the HFI center has been defined as an average point.
In particular, the HFI center displacement mean value has been defined as the average displacement of the interface nodes in the nominal analysis.
The HFI center displacement standard deviation has been defined as the range of uncertainty divided by 3 (99.7% confidence). The range of uncertainty has been defined as the difference between the average of the max displacements of the interface nodes (i.e. max displacement of the HFI center as defined above) and the HFI center mean value.
Displacements are defined in the RDP coordinate frame and are expressed in mm. Rotations have been defined in the RDP coordinate frame, considering the relative displacements of the interface nodes and the distance between them. Mean value for rotations has been calculated from the nominal analysis values, while standard deviation has been calculated using max and min values for displacement on the different flanges.
Rotations are expressed in rad. These values (mean value plus standard deviation) have been combined with warm tolerances analysis output, which consists of a second standard deviation figure together with a mean value equal to zero. Results have been combined as follows:

$$M = M_{th} + M_{wa}$$

$$\sigma = \sqrt{\sigma_{th}^2 + \sigma_{wa}^2}$$

where M_{the} = mean value from thermo-elastic analysis, M_{wa} = mean value from warm tolerance analysis (equal to zero), σ_{th} = standard deviation calculated from thermo-elastic analysis, and σ_{wa} = standard deviation coming from warm tolerance analysis.
Final value has been defined as: $M + 3\sigma$, giving 99.7% confidence.

	NOMINAL	3-SIGMA	MAX 99.7% CONF.
MAX AVERAGE HFI CENTRE DISPL. X RDP (MM)	-1.12E-02	9.25E-02	-1.04E-01
MAX AVERAGE HFI CENTRE DISPL. Y RDP (MM)	-5.95E-03	9.25E-02	-9.84E-02
MAX AVERAGE HFI CENTRE DISPL. Z RDP (MM)	-1.01E+00	1.34E-01	-1.14E+00
MAX AVERAGE HFI CENTRE ROT. X RDP (RAD)	2.36E-05	9.13E-04	9.36E-04
MAX AVERAGE HFI CENTRE ROT. Y RDP (RAD)	5.97E-05	1.12E-03	1.18E-03
MAX AVERAGE HFI CENTRE ROT. Z RDP (RAD)	3.94E-05	7.91E-04	8.30E-04

5 LFI PERFORMANCE VERIFICATION

In this section, the impact of displacement and tilt as derived from the thermo–elastic analysis on the LFI performances is evaluated.

5.1 DISPLACEMENT ALONG Z–RDP

Displacement along the Z–rdp axis will be reflected mainly in a displacement along the horn axis, thus a displacement of the feed phase center with respect to the nominal focus position. Because of the tilting of the horns in the focal plane w.r.t. the Z–rdp axis, the displacement along the horn axis results less than the calculated displacement on the RDP coordinate system.
The analysis of the main beam characteristics has been limited for one feed (LFI #23) at 70 GHz considering a displacement of – 2mm along the horn axis. This is the worst case for mainly three reasons:

- The 70 GHz channel is the most sensitive to displacement because is the LFI highest frequency
- The LFI #23 is the most external horn at 70 GHz
- The –2 mm along to the Z–horn axis means a displacement of 1.95 mm along the Zrdp (because of the inclination of the horn which is ~ 12 degrees)

The results of main beam calculations are reported here (see table)

TABLE 2: LFI #23 MAIN BEAM CHARACTERISTIC. NOMINAL AND SHIFTED POSITIONS

		NOMINAL	SHIFTED♣
CO – POLAR DIRECTIVITY	dBi	58.82	58.82
X –POLAR DIRECTIVITY	dBi	30.44	30.51
CROSS – POLAR DISCRIMINATION	dB	28.39	28.30
FWHM MAXIMUM	arcmin	11.76	11.78
FWHM MINIMUM	arcmin	14.37	14.36
FWHM AVERAGE	arcmin	13.07	13.07
ELLIPTICITY		1.22	1.22
TILT	degree	–2.79	–9.27
BEAM EFFICIENCY (CO–POLAR^2 + X–POLAR^2)			
–3 .0 dB	%	50.83	50.69
–10.0 dB	%	89.70	89.58
–20.0 dB	%	98.20	98.16
BEAM SOLID ANGLE			
–3 .0 dB	Sr.	0.116E–04	0.116E–04
–10.0 dB	Sr.	0.371E–04	0.371E–04
–20.0 dB	Sr.	0.738E–04	0.741E–04

♣70 GHZ LFI#23 SHIFTED AT –2.0 MM ALONG THE Z – HORN AXIS

As readily seen the differences between the nominal and shifted positions do not reflect in worrying discrepancies in the main beam characteristics (see also Figure 2, Figure 3, and Figure 4). This is in agreement with the sensitivity analyses performed years ago by the LFI team (Z_displacement < ± 1 Lambda = ± 4.29 mm @ 70GHz) .

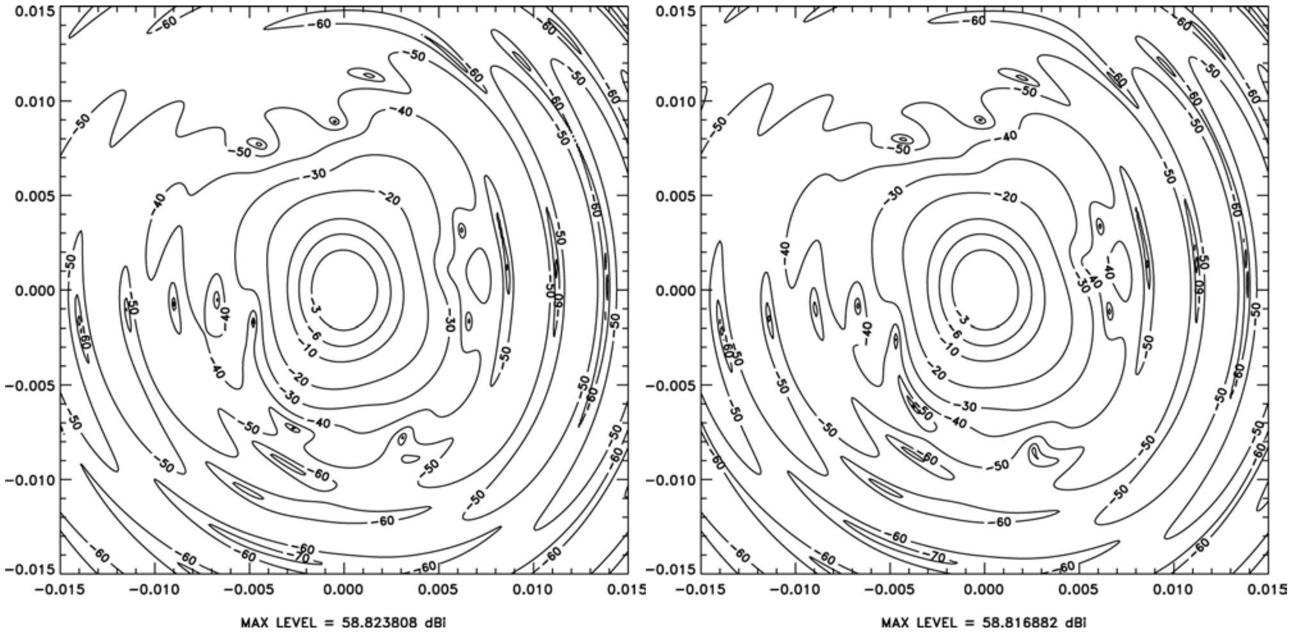

Figure 2: Copolar radiation patterns: left: nominal position; right: –2mm shifted position

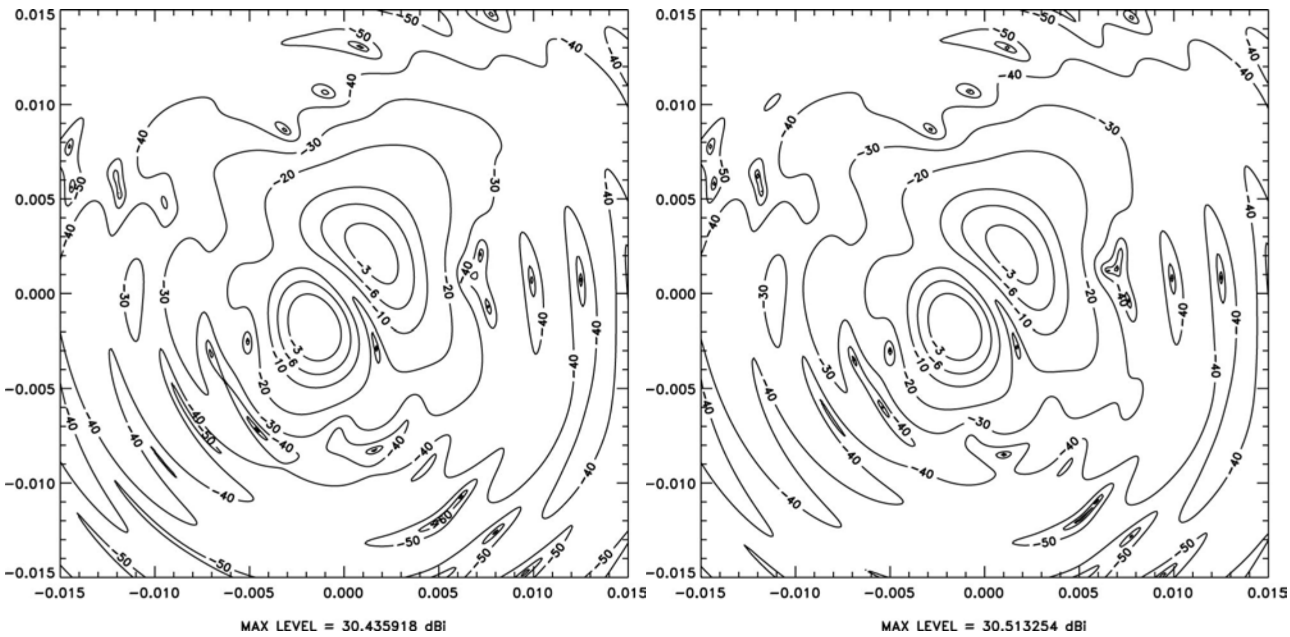

Figure 3: Xpolar radiation patterns: left: nominal position; right: –2mm shifted position

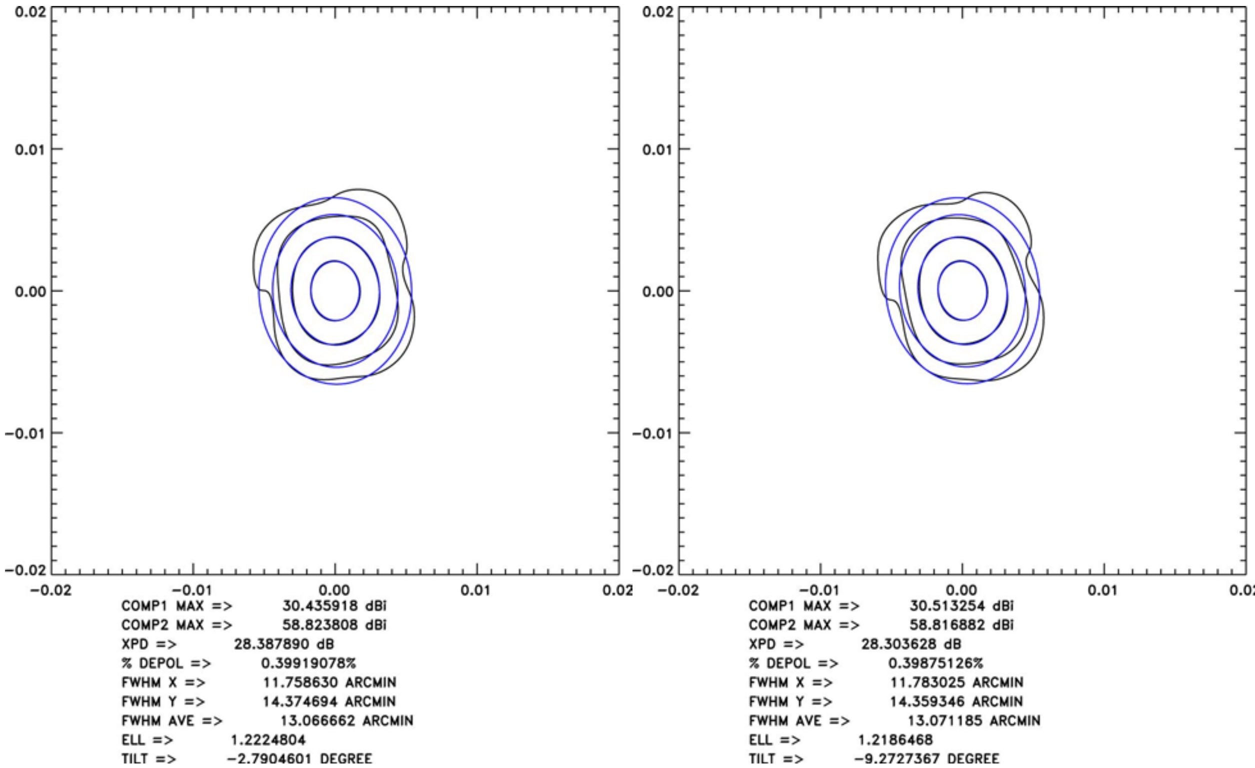

Figure 4: Beam elliptical gaussian interpolations: left: nominal position; right: –2mm shifted position

5.2 DISPLACEMENT ALONG THE X–RDP AND Y–RDP AXES

Displacements along Xrdp and Yrdp will reflect mainly in a different location of beams of on the sky.

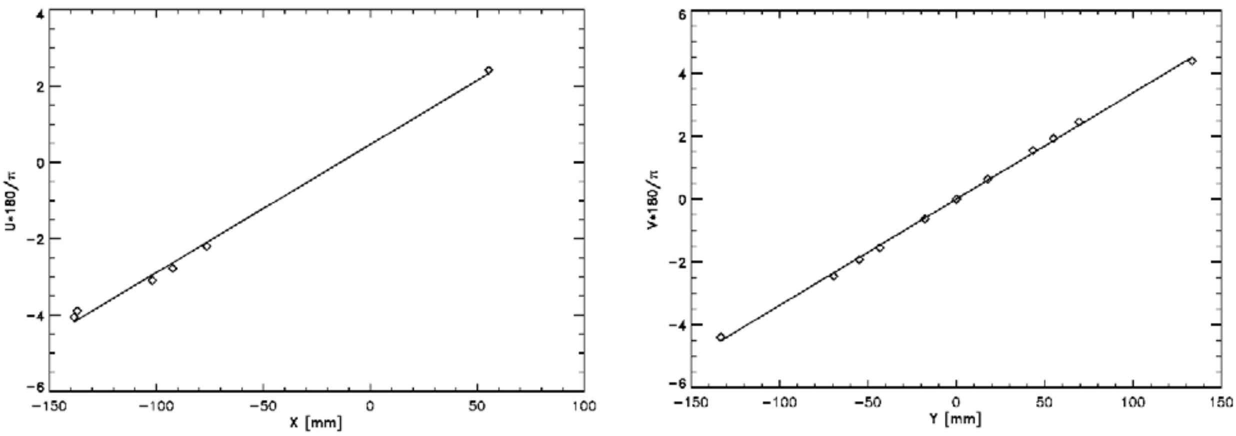

Figure 5: Plate scale of the Planck telescope as derived from LFI feed horn nominal locations and relative beam location on the sky in (u,v) coordinates.

This effects has not been investigated in this study. However, the plate scale of the Planck telescope is ~ 2 arcmin/mm . Then, a displacement of about 1 mm is reflected on the sky to a displacement of about 2 arcmin. Of course, this effect should be taken into account for the calculation of the beam location on the sky in flight configuration.

5.3 HORN TILTING

Pitch and *Yaw* of the horns due to the cool–down has an impact on the stray light rather than on the main beam shape. Edge taper degradation has been evaluated in the past. Based on previous study a 0.25° of tilting gives a degradation of the edge taper less than 1dB. The worst case of horn tilting has been evaluated as follows:

$$\delta Tilt = \sqrt{\left(\max(Yaw)^2 + \max(Pitch)^2\right)} = 0.46°$$

1

where for *Yaw* and *Pitch* values the "max 99.7% confidence level" has been taken (last column of table reported above). Since the warm random tolerances dominate the angular displacements, direction of tilting is not predictable. Dedicated simulations have been performed in order to quantify a possible stray light degradation effect.

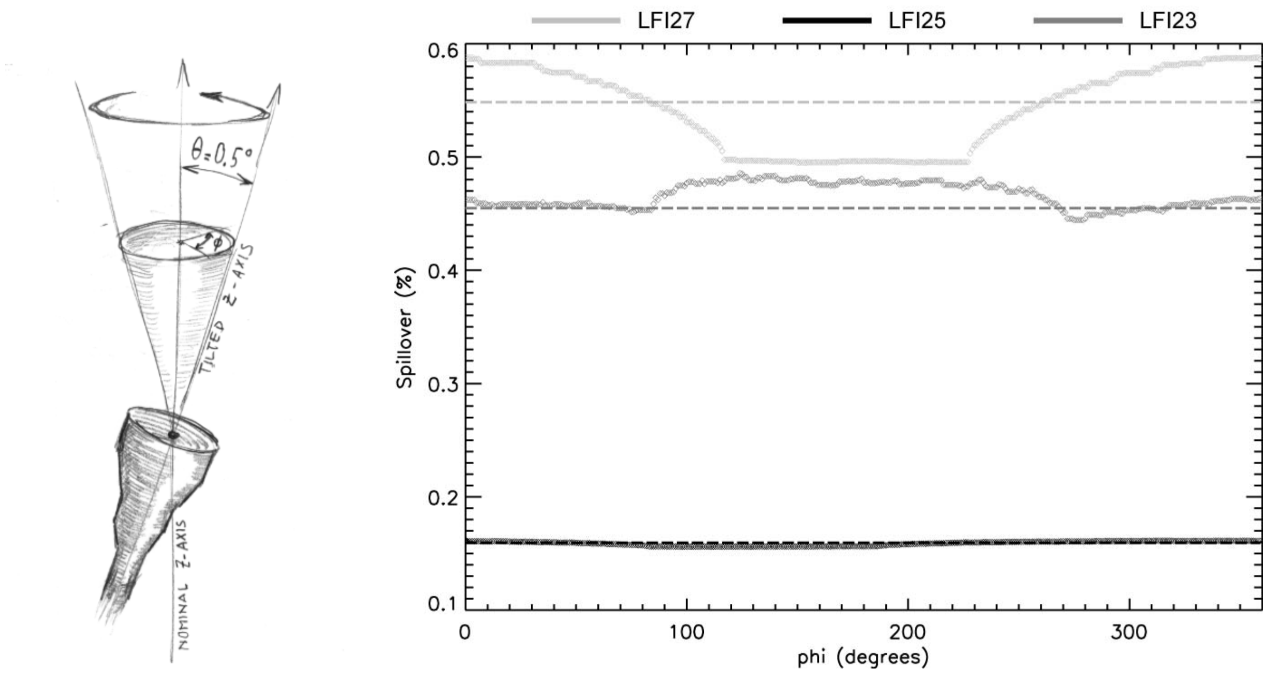

Figure 6: Left: sketch of the analysis, performed moving the horn around a cone of 0.5° of apex semi–angle. The vertical axis is the nominal horn inclination. Left: Spillover percentage as a function of azimuthal angle (Phi) in the feed local coordinate system for the LFI23(gray 50%), LFI25 (black), and LFI27 (gray 25%) FM designs. The horizontal lines are the spillover percentages in the nominal feed location (no Yaw and no Pitch angles).

Figure 6 shows the results of such analysis. The LFI23 (70 GHz), LFI25 (44 GHz), and LFI27 (30 GHz) have been tilted in a cone of 0.5° of apex semi–angle. The spillover has been calculated for each azimuthal angle from 0° to 360°. The percentage of spillover degradation is resulting between 6 – 8 %, however below 10%. This is reflected in a degradation of the stray light <10%. Of course, for some phi angle the spillover becomes better than in the nominal horn pointing.

Roll of the horns impacts the polarization performances since it is reflected in a non perfect polarization alignment between main polarization axes. The impact on science has been envisaged for pointing [RD 1], but it could be applied also for alignment.

$$Q^m = F_{QQ} \cdot Q + F_{QU} \cdot U$$

$$U^m = F_{UQ} \cdot Q + F_{UU} \cdot U$$

where Q^m and U^m are the measured Stokes parameters which differ from the true Q and U. The factors "*F*" depends on the angles between the polarization axes of two 45 degree tilted pairs. The factor of interest are F_{QU} and F_{UQ} since they represent the contamination of the measured stokes parameters. These are related to the angles between the pairs of horns being their values $\approx \sin(2\delta\phi)$, if $\delta\phi$ is the roll uncertainty. (see [RD 1] for details). Roll maximum 3–sigma uncertainty is 14 arcmin. This means a 28 arcmin on respective polarization rotation angle between the pairs of the horn. Then $F_{QU} \approx 1.6\%$.

6 RESULTS Vs ALIGNMENT REQUIREMENTS

In this section the numbers derived from the thermo – elastic analysis have been compared with the requirements, when specified.
At the horn level requirements are met for X Y displacements, except for horn LFI24, LFI27, LFI28 whose numbers are slightly grater than requirements. For Z displacement requirements are not satisfied for all the horn. The 2 mm displacement in Zrdp is not critical for the LFI performances as stated and well established above.

TABLE 3: RESULTS VS REQUIREMENTS FOR LFI HORN DISPLACEMENT. GREY CELLS ARE NUMBER THAT DO NOT FULFILL REQUIREMENTS

	DISPLACEMENT ALONG X				DISPLACEMENT ALONG Y				DISPLACEMENT ALONG Z			
FH	DISP	REQ	SIGMA	KNOW	DISP	REQ	SIGMA	KNOW	DISP	REQ	SIGMA	KNOW
18	0.3	0.4	0.1	0.1	0.3	0.4	0.1	0.1	-2.0	0.5	0.1	0.1
19	0.4	0.4	0.1	0.1	0.2	0.4	0.1	0.1	-2.0	0.5	0.1	0.1
20	0.4	0.4	0.1	0.1	0.1	0.4	0.2	0.1	-2.0	0.5	0.1	0.1
21	0.4	0.4	0.1	0.1	-0.1	0.4	0.1	0.1	-2.0	0.5	0.1	0.1
22	0.4	0.4	0.1	0.1	-0.2	0.4	0.1	0.1	-2.0	0.5	0.1	0.1
23	0.3	0.4	0.1	0.1	-0.3	0.4	0.1	0.1	-2.0	0.5	0.1	0.1
24	0.5	0.4	0.1	0.1	0.1	0.4	0.1	0.1	-2.1	0.5	0.1	0.1
25	-0.2	0.4	0.1	0.1	-0.5	0.4	0.1	0.1	-2.0	0.5	0.1	0.1
26	-0.3	0.4	0.1	0.1	0.5	0.4	0.1	0.1	-2.0	0.5	0.1	0.1
27	0.5	0.4	0.1	0.1	-0.2	0.4	0.1	0.1	-2.1	0.5	0.1	0.1
28	0.5	0.4	0.1	0.1	0.2	0.4	0.1	0.1	-2.1	0.5	0.1	0.1

DISP IS THE DISPLACEMENT OBTAINED WITH THE COMPELTE ANALYSIS REPORTED IN THE PREVIOUS CHAPTERS
REQ IS THE REQUIREMENT IN DISPLACEMENT AS DERIVED FROM THE PLANCK ALIGNMENT PLAN
SIGMA IS THE STANDARD DEVIATION DIRECTY RELATED TO THE KNOWLEDGE
KNOW IS THE REQUIREMENT ON THE KNOWLEDGE OF THE DISPLACEMENT

At the LFI / HFI interface ring, the displacement along X and Y are within requirements, while the displacement along Z is not. The cool down effect translate HFI of –1.01 mm along Zrdp axis. This has an impact on the

- HFI internal requirement
- 4K Load.

The HFI requirement can be met if the whole LFI (with HFI) is shifted of 1.01 mm w.r.t. best telescope focus in the Zrdp coordinate system.

TABLE 4: RESULTS VS REQUIREMENTS FOR THE HFI CENTRE AT THE INTERFACE DISPLACEMENT

	DISP	REQ	SIGMA	KNOW
MAX AVERAGE HFI CENTRE DISPL. X RDP (MM)	-0.01	?	0.03	?
MAX AVERAGE HFI CENTRE DISPL. Y RDP (MM)	-0.01	?	0.03	?
MAX AVERAGE HFI CENTRE DISPL. Z RDP (MM)	-1.01	?	0.04	?

DISP IS THE DISPLACEMENT OBTAINED WITH THE COMPELTE ANALYSIS REPORTED IN THE PREVIOUS CHAPTERS
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SIGMA IS THE STANDARD DEVIATION DIRECTY RELATED TO THE KNOWLEDGE
KNOW IS THE REQUIREMENT ON THE KNOWLEDGE OF THE DISPLACEMENT

TABLE 5: RESULTS VS REQUIREMENTS FOR HFI INTERFACE ROTATION

	ROT	REQ	SIGMA	KNOW
MAX AVERAGE HFI CENTRE ROT. X RDP (RAD)	2.36E-05	?	3.04E-04	?
MAX AVERAGE HFI CENTRE ROT. Y RDP (RAD)	5.97E-05	?	3.73E-04	?
MAX AVERAGE HFI CENTRE ROT. Z RDP (RAD)	3.94E-05	?	2.64E-04	?

ROT IS THE ROTATION OBTAINED WITH THE COMPELTE ANALYSIS REPORTED IN THE PREVIOUS CHAPTERS
REQ IS THE REQUIREMENT IN ROTATION AS DERIVED FROM THE PLANCK ALIGNMENT PLAN
SIGMA IS THE STANDARD DEVIATION DIRECTY RELATED TO THE KNOWLEDGE
KNOW IS THE REQUIREMENT ON THE KNOWLEDGE OF THE ROTATION

The 4K load alignment displacement has been evaluated considering the displacement at the 4K horn as derived from the LFI Thermo elastic model, and the displacement of the HFI 4K as reported in HFI technical note TN–PHA–500118–IAS issue 1.0 of 24/01/2005.

TABLE 6: THERMO – ELASTIC DISPLACEMENT ALONG RADIAL AND Z DIRECTIONS OF THE 4K TARGET AS DERIVED FROM HFI DATA. NUMBERS ARE DISPLACEMENT W.R.T. HFI/LFI INTERFACE FLANGE

FH	RADIAL DISPLACEMENT (I/F)	RADIAL DISPLACEMENT (RDP)	Z DISPLACEMENT (I/F)	Z DISPLACEMENT (RDP)
18	–0.382	–0.382	–0.082	-1.092
19	–0.382	–0.382	–0.082	-1.092
20	–0.382	–0.382	–0.082	-1.092
21	–0.382	–0.382	–0.082	-1.092
22	–0.382	–0.382	–0.082	-1.092
23	–0.382	–0.382	–0.082	-1.092
24	–0.472	–0.472	+0.338	-0.672
25	–0.472	–0.472	+0.338	-0.672
26	–0.472	–0.472	+0.338	-0.672
27	–0.472	–0.472	+0.462	-0.548
28	–0.472	–0.472	+0.462	-0.548

HFI data have been provided w.r.t. HFI / LFI interface. To get displacements w.r.t. RDP reference system the following formulas have been applied:

$$Z_{DISP}^{(RDP)} = Z_{DISP}^{(I/F)} + Z_{I/F}^{(RDP)}$$
$$R_{DISP}^{(RDP)} = R_{DISP}^{(I/F)}$$

where $\text{Disp}_{I/F} = -1.01mm$
For the radial displacement, the displacement of the centre of the interface ring has been neglected.

The relative displacement between the 4K–load and the 4K–horn has been evaluated as follows:

$$\text{Disp} = \text{Disp}_{LOAD} - \text{Disp}_{HORN}$$

both taken as displacement w.r.t. RDP coordinate system.
Along Zrdp axis, a negative relative displacement means that the 4K load is shifted down w.r.t the 4K horn

We did not evaluate the displacement of the 4K targets along X and Y because we have only radial displacement for the load.

We assumed here the following numbers:

Disp_{LOAD} as derived from the previous table;
Disp_{HORN} as derived form thermo – elastic model and reported in the following table;

TABLE 7: RESULTS VS REQUIREMENTS FOR LFI 4K HORNS DISPLACEMENT. GREY CELLS ARE NUMBER THAT DO NOT FULFILL REQUIREMENTS

	DISPLACEMENT ALONG X				DISPLACEMENT ALONG Y				DISPLACEMENT ALONG Z			
FH	DISP	REQ	SIGMA	KNOW	DISP	REQ	SIGMA	KNOW	DISP	REQ	SIGMA	KNOW
18	0.3	0.5	0.1		0.3	0.4	0.1		-1.63	0.5	0.1	
19	0.4	0.5	0.1		0.2	0.4	0.1		-1.63	0.5	0.1	
20	0.4	0.5	0.1		0.1	0.4	0.1		-1.60	0.5	0.1	
21	0.4	0.5	0.1		-0.1	0.4	0.1		-1.60	0.5	0.1	
22	0.4	0.5	0.1		-0.2	0.4	0.1		-1.61	0.5	0.1	
23	0.3	0.5	0.1		-0.4	0.4	0.1		-1.62	0.5	0.1	
24	0.6	0.5	0.1		-0.0	0.4	0.1		-1.28	0.5	0.1	
25	-0.3	0.5	0.1		-0.6	0.4	0.1		-1.29	0.5	0.1	
26	0.3	0.5	0.1		0.6	0.4	0.1		-1.27	0.5	0.1	
27	0.7	0.5	0.1		-0.4	0.4	0.1		-1.14	0.5	0.1	
28	0.7	0.5	0.1		0.3	0.4	0.1		-1.16	0.5	0.1	

DISP IS THE DISPLACEMENT OBTAINED WITH THE COMPELTE ANALYSIS REPORTED IN THE PREVIOUS CHAPTERS
REQ IS THE REQUIREMENT IN DISPLACEMENT AS DERIVED FROM THE PLANCK ALIGNMENT PLAN
SIGMA IS THE STANDARD DEVIATION DIRECTY RELATED TO THE KNOWLEDGE
KNOW IS THE REQUIREMENT ON THE KNOWLEDGE OF THE DISPLACEMENT

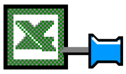
TABLE 8: RELATIVE DISPLACEMENT BETWEEN 4K–HORN AND 4K–LOAD GREY CELLS ARE NUMBER THAT DO NOT FULFILL REQUIREMENTS. NUMBERS ARE DERIVED ASSUMING THE I/F FLANGE DISPLACEMENT AND HFI ANALYSIS

	DISPLACEMENT ALONG X				DISPLACEMENT ALONG Y				DISPLACEMENT ALONG Z			
FH	DISP	REQ	SIGMA	KNOW	DISP	REQ	SIGMA	KNOW	DISP	REQ	SIGMA	KNOW
18		0.5	0.1			0.4	0.1		-0.5	0.5	0.1	
19		0.5	0.1			0.4	0.1		-0.5	0.5	0.1	
20		0.5	0.1			0.4	0.1		-0.5	0.5	0.1	
21		0.5	0.1			0.4	0.1		-0.5	0.5	0.1	
22		0.5	0.1			0.4	0.1		-0.5	0.5	0.1	
23		0.5	0.1			0.4	0.1		-0.5	0.5	0.1	
24		0.5	0.1			0.4	0.1		-0.6	0.5	0.1	
25		0.5	0.1			0.4	0.1		-0.6	0.5	0.1	
26		0.5	0.1			0.4	0.1		-0.6	0.5	0.1	
27		0.5	0.1			0.4	0.1		-0.6	0.5	0.1	
28		0.5	0.1			0.4	0.1		-0.6	0.5	0.1	

DISP IS THE DISPLACEMENT OBTAINED WITH THE COMPELTE ANALYSIS REPORTED IN THE PREVIOUS CHAPTERS
REQ IS THE REQUIREMENT IN DISPLACEMENT AS DERIVED FROM THE 4K ALIGNMENT REQUIREMENTS
SIGMA IS THE STANDARD DEVIATION DIRECTY RELATED TO THE KNOWLEDGE
KNOW IS THE REQUIREMENT ON THE KNOWLEDGE OF THE DISPLACEMENT

Appendix A

Data are included in this Excel chart. Please double click on the icon if you like to view the data.



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