SPIRE-AST-REP-003165

Title: **Herschel Instruments / Telescope Alignment Test Report**

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Prepared by:	Dr. E. Hölzle / D. Schink	Date:	10.10.08
Checked by:	J. Kroeker		10.10.08
Product Assurance:	R. Stritter		14.10.08
Configuration Control:	W. Wietbrock		15.10.08
Project Management:	Dr. W. Fricke		15/10/2008

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Issue	Date	Sheet	Description of Change	Release
1	31.07.08	All	First formal issue	
2	10.10.08	All	Changes as agreed during the Alignment TRB implemented. All changes marked by a vertical bar.	

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1 INTRODUCTION

1.1 Scope

This report provides the results of alignment measurements performed since closure of the upper bulkhead (UB) and telescope integration.

The integration of the instruments had already been performed in summer/autumn 2007 and the related alignment measurements are documented in [RD 8].

Since then, after the UB was closed, a sequence of activities has been performed having an influence on the positioning and orientation of the OBA, e. g., tank-strap-re-tensioning, bake-out, CVV cool-down and pressure change. Since the upper bulkhead has been closed the position/orientation OBA/CVV has been traced by monitoring the X and Z position and Rx, Ry and Rz orientation of the HIFI-FPU alignment devices (AD) relative to the alignment windows in the CVV. The last step was the integration and alignment measurement of the telescope.

This report collects all relevant measurement data and presents the results derived in order to give an overview on focus, pupil mismatch and LOS.

1.2 Objective

The alignment measurements documented here shall demonstrate that the positions and orientations of the Herschel PFM instruments HIFI, PACS and SPIRE within the Herschel CVV are within their specified position and orientation ranges wrt. the telescope.

2 Applicable and Reference Documents

2.1 Applicable Documents

[AD 1]	Procedure for PFM Alignment of Herschel Instruments wrt. PLM, HP-2-ASED-TP-0111, Issue 1, 20.07.2007
[AD 2]	HP-2-ASED-SD-0177: HIFI AD Stability Check after Harness Rail Final Fixation.
[AD 3]	HP-2-ASED-SD-0179: Determination of CVV Flange Orientation
[AD 4	H-EPLM Requirement Specification H-P-2-ASPI-SP-0250, Issue 3.3, 20.10.2004

2.2 Reference Documents

[RD 1]	Herschel Telescope User Manual, HER.NT.1034.T.ASTR, Issue 1, 15.12.2006
[RD 2]	Alignment Method, Plan & Results HP-2-ASED-TN-0097, Issue 2
[RD 3]	Inputs to System Level Alignment PACS-ME-TN-069, Issue 3
[RD 4]	SPIRE FPU External Alignment Report SPIRE-RAL-REP-002948, Issue 1
[RD 5]	HIFI FPU External ADs Alignment Test Results FPSS-01068, Issue 3
[RD 6]	SPIRE Alignment Data Summary SPIRE-RAL-REP-002876, Issue 1
[RD 7]	Alignment Results of HIFI FPU Flight Model FPSS-00963 Issue 1
[RD 8]	Herschel Instrument Alignment w.r.t. CVV Test Report HP-ASED-TR-0219, Issue 1 (19.10.2007)
[RD 9]	Determination of CVV Interface Flange Orientation and CVV Reference Cube Rotational Offset wrt. Rx HP-2-ASED-SD-0179
[RD 10]	Lateral Alignment Check of HIFI FPU AD versus CVV Alignment Windows, HP-2-ASED-SD-0184
[RD 11]	Lateral alignment check of HIFI FPU AD versus CVV alignment windows before and after tank-strap re-tensioning, HP-2-ASED-SD-0226
[RD 12]	Lateral alignment check of HIFI FPU AD versus CVV alignment windows, HP-2-ASED-SD-0238
[RD 13]	Herschel EPLM LOU Alignment Procedure for PFM HP-2-ASED-TP-0112, issue 3
[RD 14]	Procedure for Herschel Telescope Alignment wrt. CVV HP-2-ASED-TP-0113, issue 2
[RD 15]	Mechanical Interface Control Report HER.RPT.1036.T.ASTR.Issue 1
[RD 16]	Herschel Telescope Alignment at S/C Level Measurement Evaluation Report, H-P-2-ASP-RP-1599
[RD 17]	TRR for Telescope Alignment HP-2-ASED-MN-1536
[RD 18]	Herschel Telescope Alignment Procedure with laser Tracker HP-2-ASED-TP-0225, issue 1
[RD 19]	ACS for CVV Cubes Alignment Measurement by Triangulation HP-2-ASED-SD-0357
[RD 20]	Distance Measurement of CVVRC4 HP-2-ASED-SD-0361

[RD 21]	ACS for Telescope Alignment Measurements vs CVV by Triangulation in LEAF HP-2-ASED-SD-0362
[RD 22]	HIFI E-Mail, dated 24.05.02

3 Report Summary

The tests described in this document have been carried out between August 2007 and June 2008 as identified in the following list:

List of alignment measurement tests

1) 02.-04.08.2007:	Instrument alignment wrt. OBA / CVV
2) 22.10.2007	Lateral Alignment Check of HIFI FPU AD versus CVV Alignment Windows.
3) 19.12.2007	Lateral Alignment Check of HIFI FPU AD versus CVV Alignment Windows, before and after tank strap re-tensioning before transport to ESTEC.
4) 28.-29.01.2008	Lateral Alignment Check of HIFI FPU AD versus CVV Alignment Windows, before and after tank strap re-tensioning after bake-out.
5) 04.-05.03.2008	Lateral Alignment Check of HIFI FPU AD versus CVV Alignment Windows, before and after tank strap re-tensioning after cool-down.
6) 05.-11.03.2008	Lateral Alignment Check of HIFI FPU AD versus CVV Alignment Windows, before and after LOU-adjustment.
7) 24.04-9.6-2008	Telescope Alignment w.r.t. CVV

A complete overview is given in Table 3-1

3.1 Test Article

For 1): Herschel PFM PLM with instruments HIFI, PACS and SPIRE integrated onto Optical Bench. PLM mounted on the rotary table.

For 2: as 1) plus UB mounted for lateral alignment check of HIFI AD wrt. CVV windows.

For 3) – 6) Herschel PFM PLM with instruments HIFI, PACS and SPIRE integrated onto Optical Bench. CVV upper bulkhead mounted, PLM mounted on the VSS.

For 7: as 3) – 6), plus telescope mounted, including cover.

3.2 Applied Procedure

The Herschel instrument alignment tests have been performed according to the procedures applicable for alignment measurements with the PFM PLM, as listed in Sect. 2 as reference documents.

3.3 Procedure Variations:

All necessary procedure variations have been recorded in the procedure variation sheets of the applicable “as-run” procedures.

3.4 Non-Conformance Summary:

One minor NCR raised: HP-121000-ASED-NC3516 (after Instrument alignment w.r.t. CVV) against ASED Alignment Procedure

This NC concerns only tolerances which have been derived in order to establish an overall budget. So, not achieving individual values only reduces the margin, but does not violate an overall alignment budget. NC only concerns success criteria of test procedure.

The I/F definition of the FPU does not allow a lateral alignment versus the OB.

- OB position slightly exceeds position tolerance: Limit. 1 mm, measured 1.01mm.
- Rotation of OB about X exceeds angle tolerance of 0.0333 deg, measured 0.1015 deg. This value has been defined by ASED assuming that the instrument FPUs are nominally aligned wrt. I/F. This, however, is not the case, but the actual FPU alignments are all in spec, except PACS.
- Rotation of OB about Z exceeds tolerance of 0.0333 deg (measured 0.0442 deg). Here the same argument as above is valid.
- PACS rotation about X exceeds tolerance of 0.0389 deg (measured 0.0 564 deg). Allowed tolerance was derived from alignment budget. Excess rotation reduces overall margin, but margin is still positive

One NCR has been raised during Telescope alignment.

HP-125400-ASED-NC-4214: “Telescope alignment measurement results doubtful.” NCR can be closed with the Herschel Telescope Alignment at S/C Level Measurement Evaluation Report, [RD 16].

3.5 Open work:

None

The following table summarizes the activities performed since July 2007 and the CVV configuration w.r.t. cryostat temperature, pressure and tank straps tension.

Date	Activity	Output	CVV Configuration		
			Cryostat Temperatue	CVV Pressure	Tank staps tension
2.08.07-4.08.07	Instrument Alignment w.r.t. CVV	Instrument position and orientation w.r.t. CVVRC4	Ambient	Ambient	5kN
22.10.07	HIFI AD vs CVV Window	1. HIFI vignetting check w.r.t. CVV Window 2. This position serves as reference position and orientation for OBA shifts due to e.g. tank straps re-tensioning	Ambient	Ambient	5kN
19.12.07	HIFI AD vs CVV Window	1. HIFI vignetting check w.r.t. CVV Window 2. OBA position/ orientation evolution	Ambient	Vacuum	5kN
	Tank strap tensioning for transport to ESTEC		Ambient	Vacuum	19.3kN
19.12.07	HIFI AD vs CVV Window	1. HIFI vignetting check w.r.t. CVV Window 2. OBA position/ orientation evolution	Ambient	Vacuum	19.3kN
	Transport to ESTEC		Ambient	Vacuum	19.3kN
11.01.08	Tank strap tensioning		Ambient	Vacuum	6.5kN
	Bake-out			Vacuum	6.5kN

28.01.08	HIFI AD vs CVV Window	1. HIFI vignetting check w.r.t. CVV Window 2. OBA position/ orientation evolution	Ambient	Vacuum	6.5kN
29.01.08	Tank strap re-tensioning		Ambient	Vacuum	20kN
29.01.08	HIFI AD vs CVV Window	1. HIFI vignetting check w.r.t. CVV Window 2. OBA position/ orientation evolution	Ambient	Vacuum	20kN
	Cryostat Cool down		HTT 4.2K	Vacuum	20kN
4.03.08	HIFI AD vs CVV Window	1. HIFI vignetting check w.r.t. CVV Window 2. OBA position/ orientation evolution	HTT 4.2K	Vacuum	20kN
4.03.08	Tank strap re-tensioning		HTT 4.2K	Vacuum	25.9kN
5.03.08	LOU alignment w.r.t. FPU	To check PPB w.r.t. FPU AD alignment after LOU integration and determine correct strap length if necessary	HTT 4.2K	Vacuum	25.9kN
	LOU strap adjustment		HTT 4.2K	Vacuum	25.9kN
11.03.08	LOU w.r.t. FPU alignment check	1. To check correct alignment 2. HIFI vignetting check w.r.t. CVV Window 3. OBA position/ orientation evolution	HTT 4.2K	Vacuum	25.9kN
16.04.08	Telescope integration		HTT 4.2K	Vacuum	25.9kN

24.04..08 -9.6.08	Telescope alignment	Determine position / orientation of the Telescope w.r.t. CVV and instruments	HTT 4.2K	Vacuum	25.9kN
30.05.08	LOU w.r.t. FPU alignment check	1. To check relative PPB orientation before LOR integration 2. To check LOU w.r.t. HIFI FPU alignment			
30.05.08	LOU radiator integration		HTT 4.2K	Vacuum	25.9kN
30.05.08	LOU w.r.t. FPU alignment check	1. To check relative PPB orientation after LOR integration 2. To check LOU w.r.t. HIFI FPU alignment	HTT 4.2K	Vacuum	25.9kN

Table 3-1: Alignment Activities Overview

4 Alignment Activities Description

The following activities have been performed:

- Instruments alignment wrt. CVV:
- Measurement of HIFI FPU AD lateral position (x, z) wrt. CVV windows after UB closure in order to monitor instrument positioning wrt. CVV due to tank strap re-tensioning, bake-out and cryostat cool-down.
- Measurement of HIFI FPU AD lateral position (x, z) w.r.t. CVV windows during tank strap re-tensioning and LOU alignment.
- Telescope alignment w.r.t. CVV

The LOU Alignment is covered in a separate report: HP-2-ASED-TR-0247.

5 Alignment Measurement Data

Results of the instrument alignment measurements have already been reported in [RD 8] including impact on focus and pupil mismatch.

In this report we present the alignment status of instruments wrt. Telescope.

5.1 Instrument Orientations and Positions

The values contained in the following tables are taken from [RD 8]. They are used to determine focus and pupil mismatch after instrument integration before strap-tensioning, bake-out and cool down and telescope integration.

5.1.1 Rotation about Y-axis: Rot Y

	Rot Y: Instr. mechanical I/F wrt. UB-flange 1)	Remark
HIFI	+0.13 arcmin	As measured
PACS	-2.32 arcmin	As measured
SPIRE	-5.57 arcmin	As measured

Table 5-1: Orientation of instrument cube and Instrument I/F wrt. UB flange

1) rotational offsets of instrument reference cube subtracted

(Table 6-2 from RD 8)

A graphical representation of Table 5-1 is shown in Fig. 5-1.

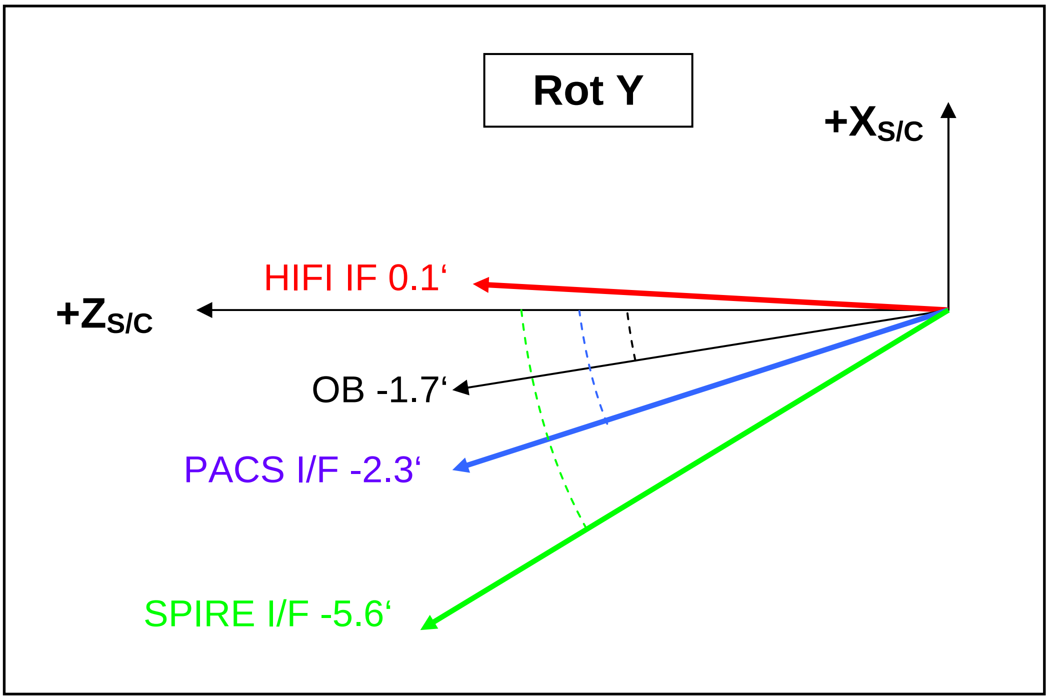

Figure 5-1: Graphical representation of Rot Y values.

5.1.2 Rotation about Z-axis: Rot Z

	Rot Z: Instr. mechanical I/F wrt. UB-flange 1)	Remark
HIFI	+1.35 arcmin	As measured
PACS	-3.38 arcmin	As measured
SPIRE	-2.84 arcmin	As measured

Table 5-2: Orientation of instrument cube and Instrument I/F wrt. UB flange

1) rotational offsets of instrument reference cube subtracted
(Table 6-3 from RD 8)

A graphical representation of Table 5-2 is shown in Fig. 5-2.

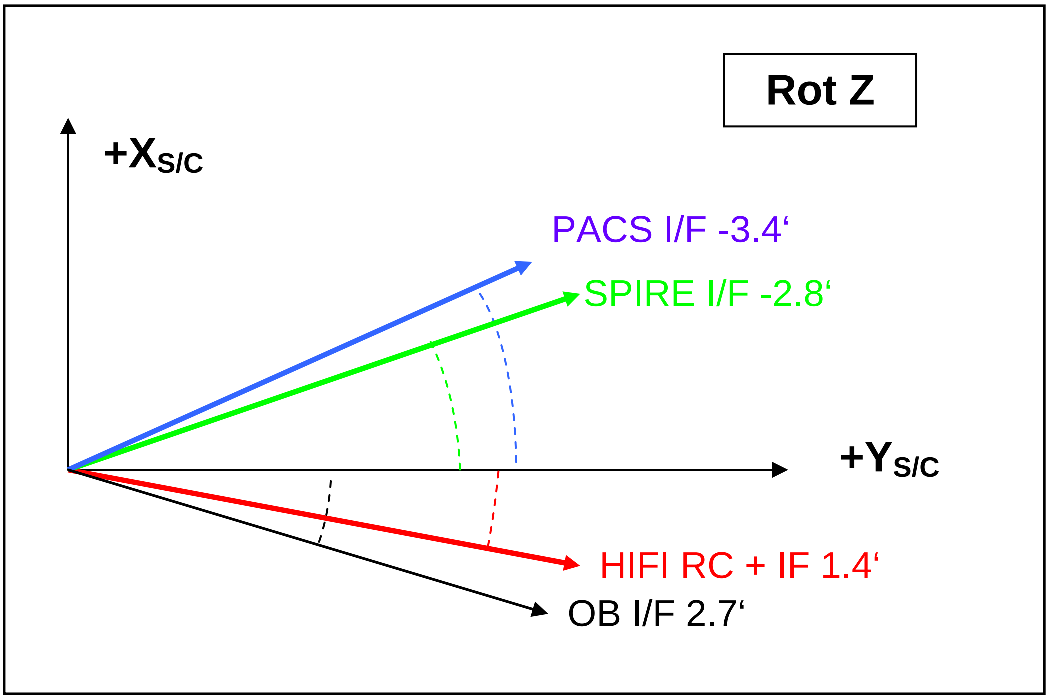

Figure 5-2: Graphical representation of Rot Z values.

5.1.3 Rotation about X-axis: Rot X

	Rot X: Instr. Cube wrt CVVRC4	Rot X: Instr. Cube wrt. UB flange)	Rot X Instr. I/F wrt. UB flange
HIFI	+2.4 arcmin	+4.4 arcmin	+4.4 arcmin
PACS	6.4 arcmin	+8.4 arcmin	+10.5 arcmin
SPIRE	38.4.arcmin	40.4 arcmin	Not known
OB	10.8 arcmin	+12.8 arcmin	+10.1 arcmin

Table 5-3: Orientation of instrument wrt. CVVRC4 and UB flange(“S/C system”)
Here, column 1 is the direct measurement of instrument cube wrt. CVVRC4.
Column 2 takes into account the rotation of CVVRC4 wrt. S/C coordinate system (2 arcmin) determined by marks on CVV and TTAP.
Column 3 takes into account the offset between instrument cube and instrument mechanical I/F (as provided by the instruments).
(Table 6-3 from RD 8)

A graphical representation of Table 5-3 is shown in Fig. 5-3.

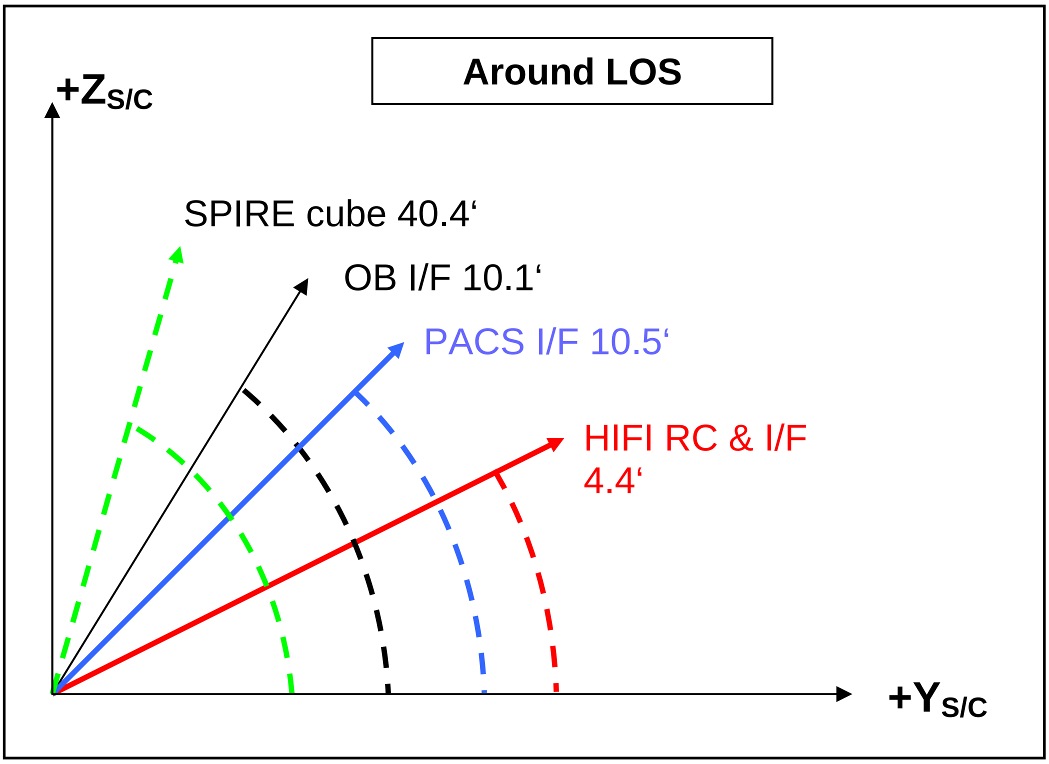

Figure 5-3: Graphical representation of Rot X values.

5.1.4 Measured Instrument Focus Position and Uncertainties

	Measured position bias wrt. nominal pos. 1)	Instrument internal uncertainty	Telescope internal uncertainty	Telescope/ CVV Measurement Uncertainty
HIFI	-0.65 mm	±2.7 mm (RD 22)	±3 mm (RD 1)	±1.0 mm (RD 2)
PACS	+0.09 mm	±1.0 mm (RD 3)	±3 mm (RD 1)	±1.0 mm (RD 2)
SPIRE	-0.06 mm	±2.25 mm (RD 6)	±3 mm (RD 1)	±1.0 mm (RD 2)

Table 5-4: Measured Focus Offset and uncertainty contributions
Measured after instrument integration, 1) Instrument reference cube measured wrt. CVVRC4 as integrated (Table 6-4 from RD 8)

5.1.5 Calculated Impact of Instrument Tilt Components on Pupil Mismatch

	Rot Y	Rot Z	ΔY(Pupil) at M2	ΔZ(Pupil) at M2
HIFI	+0.13 arcmin	+1.35 arcmin	**+1.04 mm**	**-0.10 mm**
PACS	-2.32 arcmin	-3.38 arcmin	**-2.60 mm**	**+1.78 mm**
SPIRE	-5.57 arcmin	-2.84 arcmin	**-2.18 mm**	**+4.28 mm**

Table 5-5: Instrument-tilt components of pupil mismatches

Distance focus-M2 multiplied with tan (Rot y, z), rotation measured wrt. UB.I/F) The distance focus-M2 is shown in the header of the Excel sheet on page 43.

Note: The above Figures 5-1 and 5-2 show that an overall adjustment of the OBA can improve the pupil mismatch for SPIRE and PACS, however with the severe drawback that the vignetting for HIFI is increased (see also Sect. 7, Conclusion).

5.1.6 Internal Instrument Alignment Offsets and Uncertainty

	Internal Position / Error		Thermoelastic Effects In-orbit	
	ΔY Int	ΔZ Int	ΔY TE	ΔZ TE
HIFI 1)			4)	4)
Channel 1	-2 mm ± 2	+2 mm ± 2	±0.1 mm	±0.1 mm
Channel 2	-3 mm ± 2	+2 mm ± 2	±0.1 mm	±0.1 mm
Channel 3	+5 mm ± 2	0 mm ± 2	±0.1 mm	±0.1 mm
Channel 4	0 mm ± 2	-6.5 mm ± 2	±0.1 mm	±0.1 mm
Channel 5	-5 mm ± 2	+0.5 mm ± 2	±0.1 mm	±0.1 mm
Channel 6	0 mm ± 2	0 mm ± 2	±0.1 mm	±0.1 mm
Channel 6b	-4 mm ± 2	+4.0 mm ± 2	±0.1 mm	±0.1 mm
PACS 2)	0.0 mm ± 0.6	0.0 mm± 0.6	±0.1 mm	±0.1 mm
SPIRE 3)	-1.70 mm ±0.5	-0.70 mm ±0.5	+0.8 mm	+0.2 mm

Table 5-6: Pupil mismatch: Instrument internal errors and thermoelastic effects

1) from [RD 7]

2) from [RD 3] but uncertainties scaled for 2 σ

3) from [RD 6]

4) taken from [RD 2] (original allocation as given by the instruments

(Table 6-9 from RD 8)

5.1.7 Telescope Focus and Lateral Pupil Position

	ΔX	ΔY	ΔZ	Remark
Telescope	-0.0 mm ± 3.0	-0.45 mm ± 0.5	-0.60 mm ± 0.5	According to RD 1

Table 5-7: Telescope focus, lateral pupil position and measurement uncertainty

(Table 6-10 from RD 8)

5.1.8 CVV uncertainty

The CVV overall uncertainty for focus deviation and pupil mismatch is 1.0 mm in x, y and z direction as per RD 2. (Measurement accuracies for telescope alignment are taken from RD 16.) This value corresponds to the accuracy of the measurement at ambient and monitoring of the OBA position (during strap-re-tensioning, bake-out and cool-down) through the CVV-alignment windows.

5.2 Instrument HIFI FPU AD Monitoring Measurement Data

Activities like strap re-tensioning, bake-out and cool-down may have an impact on OBA positioning and orientation and, therefore, may influence pupil mismatch, focus and line of sight. For this reason, before and after any of the a. m. activities the relative position of OBA versus CVV was observed using the HIFI FPU AD and the CVV alignment windows as relative references.

Note: The strap-tensioning procedure is devised symmetrically, such that – in principle – no shift of the OBA should occur. The HIFI FPU AD allow to monitor the actual OBA position (represented by the HIFI AD) wrt. the CVV alignment windows in x and z-direction. Since a similar monitoring is not possible in y-direction, we have used for the shift in y-direction the same values as measured in z-direction and added as contribution to the pupil mismatch budget in a worst-case sense (taking its sign such that a maximum contribution to pupil mismatch occurs).

The results of all monitoring activities since instrument alignment are collected in the following table. The measurements have been performed for –Z and +Z alignment window in x- and z-direction. The first column indicates the test dates, the second one recalls the activity, and further columns contain the measurement data.

			x Direction [mm]			**z Direction [mm]**	
			AD wrt.	AD wrt.		AD wrt.	AD wrt.
Date	Act. No.	Alignment	**+Z** window	**-Z** window		**+Z** window	**-Z** window
22.10.2007	1	After OB Alignment	-1,27	-1,27		-0,90	-1,02
19.12.2007	2	Before tank strap re-tensioning	-1,00	-0,97		-0,47	-0,7
19.12.2007	3	After tank strap re-tensioning	-1,43	-1,42		-0,57	-0,6
28.01.2008	4	After back out	-0,73	-0,78		-0,28	-0,57
29.01.2008	5	After tank strap re-tensioning	-0,93	-1,08		-0,10	-0,40
		Cool Down					
04.03.2008	6	Before tank strap re-tensioning	-4,27	-4,50		-1,00	0,50
05.03.2008	7	After tank strap re-tensioning	-4,70	-4,80		-1,10	0,40
	8	Before LOU strut adjustment	-4,80	-4,80		-1,10	0,40
	9	LOU Strut Adjustment					
11.03.2008	10	After LOU Strut Adjustment	-4,60	-4,98		-1,00	0,40

Table 5-8: Results of monitoring of HIFI AD wrt. CVV windows

Note: The mean effect of activities 7 – 10 wrt. activity. No 6 (≈ 0.4 mm) is reversed under in-orbit conditions. This has been considered in the attached Excel sheet (see step “a67”) for “Instrument/ Telescope Alignment”.

The evolution of the OB position in the course of the a. m. activities (Table 5-8) is shown in the following two Figures 5-1 and 5-2.

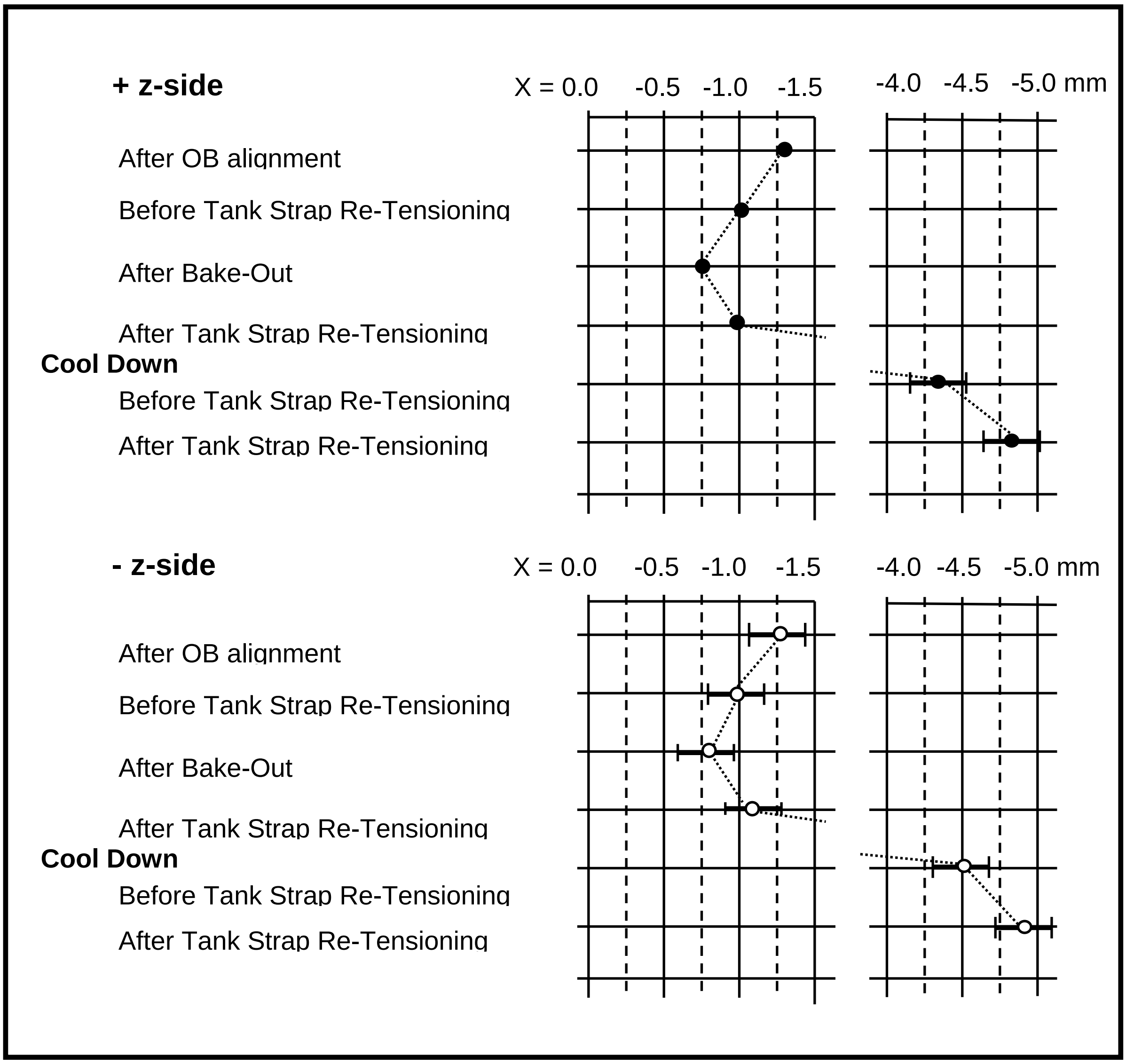

Figure 5-4: Position evolution in X of the OB

Effects due to strap re-tensioning, bake-out and cool-down (for cryostat cold inside, ambient outside).

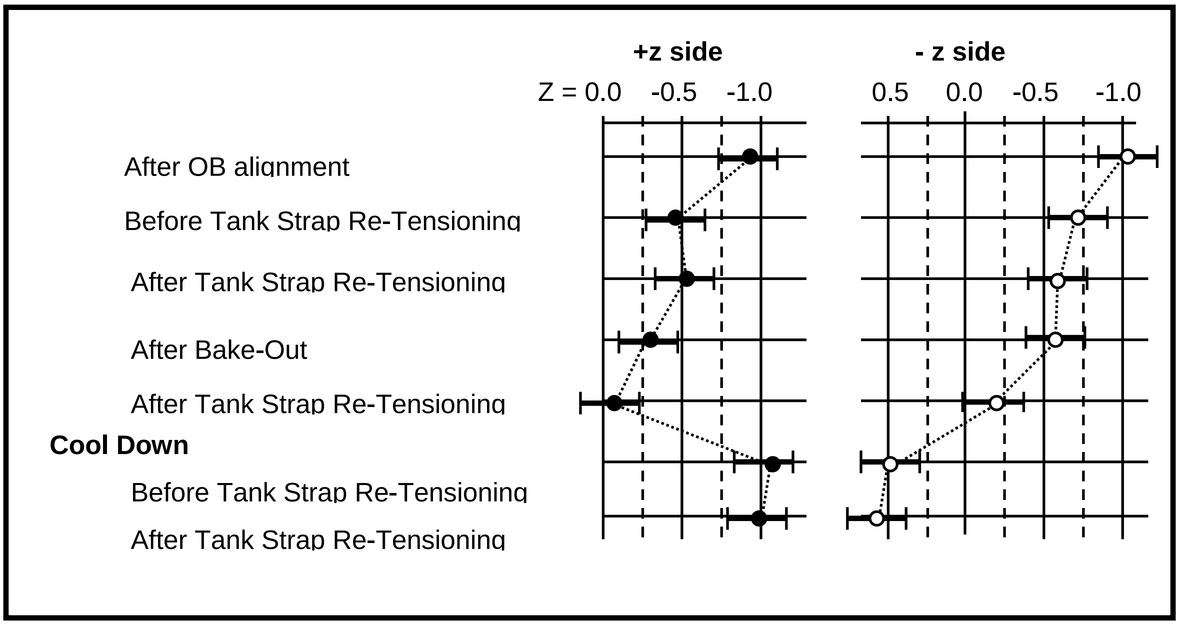

Figure 5-5: Position evolution in Z of the OB

Effects due to strap re-tensioning, bake-out and cool-down (for cryostat cold inside, ambient outside)

From Table 5-8 the following input data for computation of focus and pupil mismatch have been derived (for cryostat cold inside, ambient outside):

Total shift in x-direction: (-4.78 – (-1.27)) mm: **Tx = -3.51 mm**
[-4.78 mm: mean of +Z/-Z of act. No 7, 8, 10
-1.27 mm: mean of no 1]

X-shift due to cool-down: mean of shift on +z side and –z side: mean of difference of no 5 an 6 on either side: **Tx_{cool} = -3.38 mm**

Rotation about y: From the +z and –z final x positions: mean of 7, 8, 9, 10 on either side: Tx = 0.16 mm over 400 mm :
Ry = 0.0229 deg.
Start value (no 1): 0.0 deg, i. e. Ry = 0.0229 deg is total rotation.

Total shift in z: Mean of difference of no 5 – no1 on each side
Tz = + 0.71 mm
(cool-down step 6 is not considered, since here we have only symmetrical shrinkage of AD position towards OB-centre, i. e. no net movement of OBA.)

5.3 Telescope Angular Alignment Measurement Data

After integration of the telescope the telescope alignment (orientation and position) has been measured with a combination of theodolite and laser tracker. The position measurements failed, however the angle measurements were acceptable.

Therefore, the position measurements were repeated with two independent methods, using a laser tracker and a triangulation with theodolites. The results are reflected in RD 16 and summarized in Table 5-11

The results of the Telescope angular alignment are summarised in the following table. It is also indicated from which CVV side each measurement has been performed. This determines Ry and Rz.

Telescope Alignment Measurement Data Hz:Azimuth
V: Elevation

Cube	from side	Angle	dim	Meas 1	Meas 2	Meas 3	Mean
CVVRC 1	-z	Hz	deg	359,9997	360,0000	359,9998	359,9998
		V	deg	89,9268	89,9269	89,9267	89,9268
CVVRC 2	-z	Hz	deg	359,7522	359,7521	359,7523	359,7522
		V	deg	89,9273	89,9267	89,9268	89,9269
TRC3	-z	Hz	deg	359,6506	359,6510	359,6522	359,6513
		V	deg	90,1895	90,1897	90,1896	90,1896
CVVRC1	-y	Hz	deg	0,0042	0,0043	0,0042	0,0042
		V	deg	89,9446	89,9449	89,9455	89,9450
TRC1	-y	Hz	deg	0,3926	0,3925	0,3927	0,3926
		V	deg	90,1792	90,1792	90,1787	90,1790
CVVRC1	+y	Hz	deg	0,0028	0,0029	0,0029	0,0029
		V	deg	90,0542	90,0539	90,0537	90,0539
CVVRC2	+y	Hz	deg	359,7512	359,7507	359,7508	359,7509
		V	deg	90,0357	90,0358	90,0354	90,0356
CVVRC3	+y	Hz	deg	359,4942	359,4939	359,4938	359,4940
		V	deg	90,1041	90,1039	90,1038	90,1039
CVVRC4	+y	Hz	deg	359,7425	359,7423	359,7426	359,7425
		V	deg	90,3646	90,3648	90,3650	90,3648

Table 5-9: Results of Telescope angular alignment measurements

All values theodolite readings. CVVRC1 was chosen as reference.

The following Telescope internal reference cubes offset values are given by ASEF:

Cube	Nominal Elevation V [deg]
TRC1 -y	90.2175
TRC2 -y	90.1494
TRC3 -z	90.2856
TRC4 -z	90.2581

Table 5-10: Internal telescope offset angles

According to RD 15 (theodolite readings).

5.4 Telescope Position Measurement Data

The telescope position as derived in “Herschel Telescope Alignment at S/C Level Measurement Evaluation Report” [RD 16] is given by the following values:

The average shift between the telescope and the best-fitted CVV is:

Deviation	Value
Tx	0.5 +/- 0.56 mm
Ty	0.9 +/- 0.44 mm
Tz	1.5 +/- 0.25 mm

Table 5-11: Average shift between telescope and the best-fitted CVV (according to [RD 16])

6 Data Evaluation and Results

The results presented in the subsequent sections comprise the following contributions:

1. - The instrument tilts, transferred into lateral displacements in the M2-plane.
   - Rotation-induced lateral shifts combined with the linear instrument displacements as measured after instrument integration.
   - Instrument-internal position errors as provided by the instruments.
2. - Telescope tilt wrt. UB flange plane
   - Telescope internal contributions to focus and pupil mismatch.

3. - Position and orientation changes of the OBA wrt. the CVV due strap-re-tensioning, bake-out and cool-down.

6.1 Results

6.1.1 *Focus*

The individual contributions for de-focus for on-ground and in-obit conditions are listed in Tables 6-1 and 6-3.

Cryostat condition: Inside cold (Helium I), outside RT				
	FPU / CVV After Integration 1) [mm]	FPU / CVV (strap re-tensioning, bake-out, cool down) 5) [mm]	Telesc Align./ CVV 3) [mm]	Overall de-focus 2) [mm]
HIFI	-0.65	-3.51	0.5	-4.66 4)
PACS	+0,09	-3.51	0.5	-3.92
SPIRE	-0,06	-3.51	0.5	-4.07

Table 6-1: Individual de-focus instrument/telescope

1) Difference between nominal and actual distance between instrument ref. cube and CVVRC4 as measured.

2) The calculation is performed according to the following relation (using the nomenclature of the Excel sheet “Instrument / Telescope Alignment in the annex):

$\Delta X = a11 + a52 – a42.$

3) Average shift between the telescope and the best-fitted CVV according to RD 16.

4) The relatively large error for HIFI in x-direction is due to the relatively large internal error of 2.7 mm as given by HIFI (see Table 5-4)

5) See footnotes Fig. 5-5

Measurement Uncertainties RMS

Instrument internal		Telescope Internal	CVV	Total
PACS				
x	1,0	3,0	1	3,32
y,z	0,6	0,5	1	1,27
SPIRE				
x	2,3	3,0	1	3,88
y,z	0,5	0,5	1	1,22
HIFI				
x	2,7	3,0	1	4,16
y,z	2,0	0,5	1	2,29

Table 6-2: Position measurement accuracies (RMS).
All values in mm.
“CVV” uncertainty comprises all measurement errors occurring during alignment measurements including 0.56 mm for telescope. This implies, that (instrument and telescope) internal errors are not included here. They are, however, considered in the total error.

Cryostat condition: Inside cold, outside cold (in-orbit)						
	Overall de-focus on-ground from Tab. 6-1 [mm]	Expected shrinkage [mm]	Strap tension release in orbit 1) [mm]	Instrument in orbit variation [mm]	Relative change Measmt. uncertainties from Tab. 6-2 [mm]	Requiremt./ Margin [mm]
HIFI	-4.66	-4.5	0.4	-0.1	0.14 ± 4.2	8.5 / 4.2
PACS	-3.92	-4.5	0.4	-0.1	0.88 ± 3.3	7.0 / 2.8
SPIRE	-4.07	-4.5	0.4	-01.	0.73 ± 3.9	7.7 / 3.1

Table 6-3: Individual de-focus instrument/telescope in orbit

1) as mentioned with Table 5-8, the effect of strap tension-release (0.4 mm) is due to in-orbit changes (external pressure, CVV temperature).

Please note: The given requirement is valid for in-orbit conditions (cryostat cold/CVV cold). Therefore, the expected shrinkage has been subtracted, to show the residual defocus for in-orbit conditions. With the nomenclature of the appended Excel sheet "Instrument / Telescope Alignment" the relation to calculate the overall change is:

Overall change = overall defoc (Tab- 6-1) + instr. thermo-elastics + in-orbit strap release – warm/cold corr.(expected value).

With the nomenclature of the Excel sheet "Instrument / Telescope Alignment" in annex, the used relation becomes:

$\Delta X_{total} = \Delta X(\text{overall de-focus, Tab. 6-1}) + a57 + a67 - a62$

6.1.2 *Pupil Mismatch*

The individual contributions for pupil mismatch are listed in the attached EXCEL working sheet (annex). The table below shows a summary of the achieved pupil mismatches for in-orbit conditions and compares the results to the requirements.

The given requirements are valid for in-orbit conditions (cryostat cold/CVV cold). Therefore, the expected shrinkage values have been subtracted, to show the residual pupil mismatches expected for in-orbit conditions. The available margins are shown.

Instrument	ΔY [mm]	ΔZ [mm]	Measuremt. Uncertainty 1) [mm]	Radius incl. error [mm]	Requiremt. [mm]	Margin [mm]
HIFI					±24.0	
Channel 1	-2.47	0.14	±2.30	5.4		18.6
Channel 2	-3.47	0.14	±2.30	6.3		17.7
Channel 3	4.53	-1.86	±2.30	8.0		16.0
Channel 4	-0.47	-8.36	±2.30	11.0		13.0
Channel 5	-5.47	-1.36	±2.30	8.6		15.4
Channel 6	-0.47	-1.86	±2.30	5.0		19.0
Channel 6b	-4.47	2.14	±2.30	8.1		15.9
PACS	-4.09	1.09	±1.30	5,9	±7.0	1.1
SPIRE	-5.77	2.27	±1.20	7.8	±9.5	1.7

Table 6-4: Pupil mismatch and related requirements and residual margins.

This table represents a combination of instrument internal offsets, telescope internal offsets and the measured actual positions and orientations in the M2-plane. The values include effects due to strap tensioning, bake-out and cool-down (details see EXCEL sheet “Instrument / Telescope Alignment” in annex). The values above are calculated in the following way:

Pupil mismatch (Y) = Instr. alignmt (nominal – measured) + Instr Rz(impact in y) + Instr. internal alignmt. + sum (strap re-tens., bake-out,cool down) + instr thermoelastics + CVVRC4(pos. revision) – (telesc. Internal pupil pos. + telesc. Alignmt + telesc. Rz(impact in y)

With the nomenclature of the Excel sheet “Instrument / Telescope Alignment” in annex, the used relation becomes:

$\Delta Y = a15 + a27 + a31 + a53 + a58 + a71 - (a38 + a43 + a49)$

ΔZ analogous to ΔY.

The results compiled in this table are shown in Figures 6-1 through 6-3.

1) according to Tab. 6-2

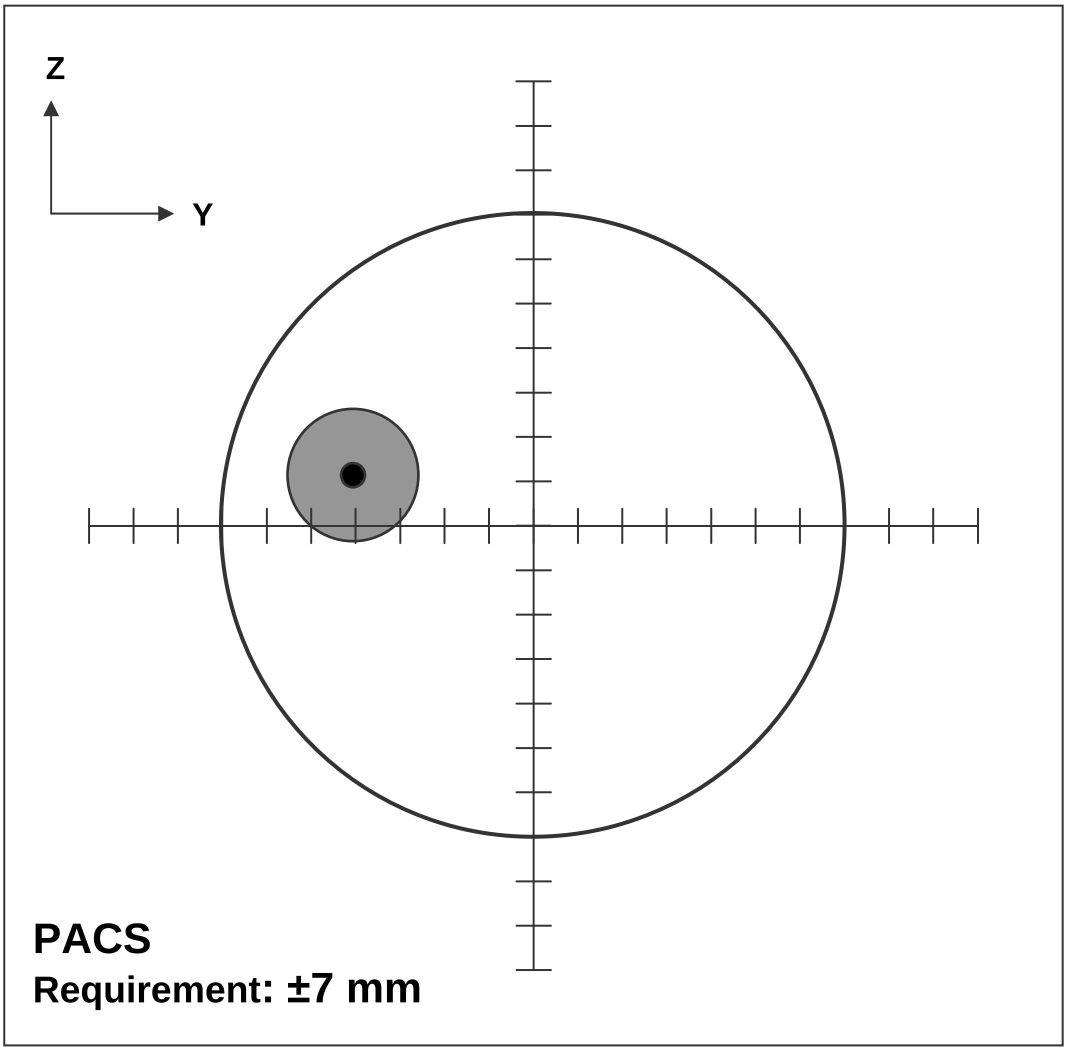

Figure 6-1: Pupil mismatch for PACS in M2-plane

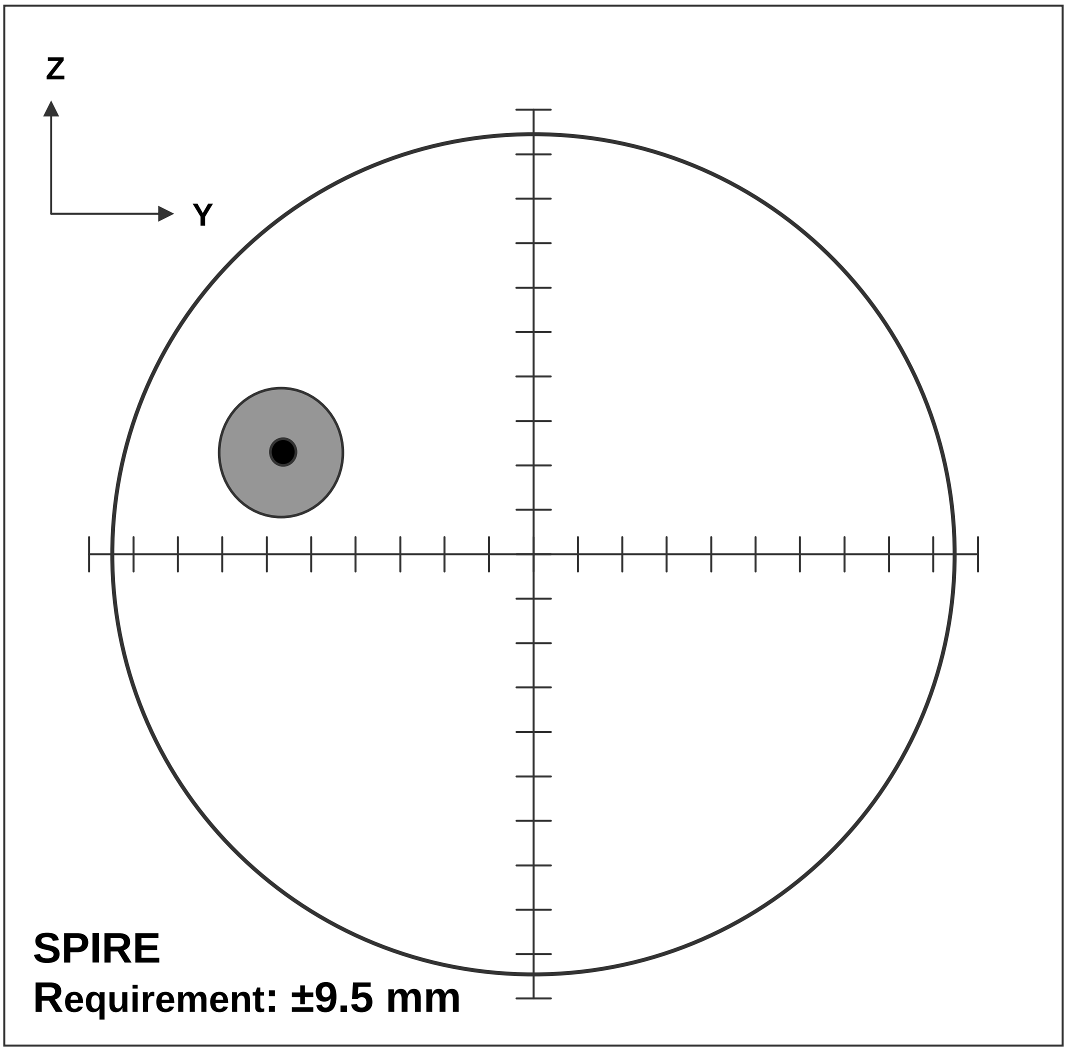

Figure 6-2: Pupil mismatch for SPIRE in M2-plane

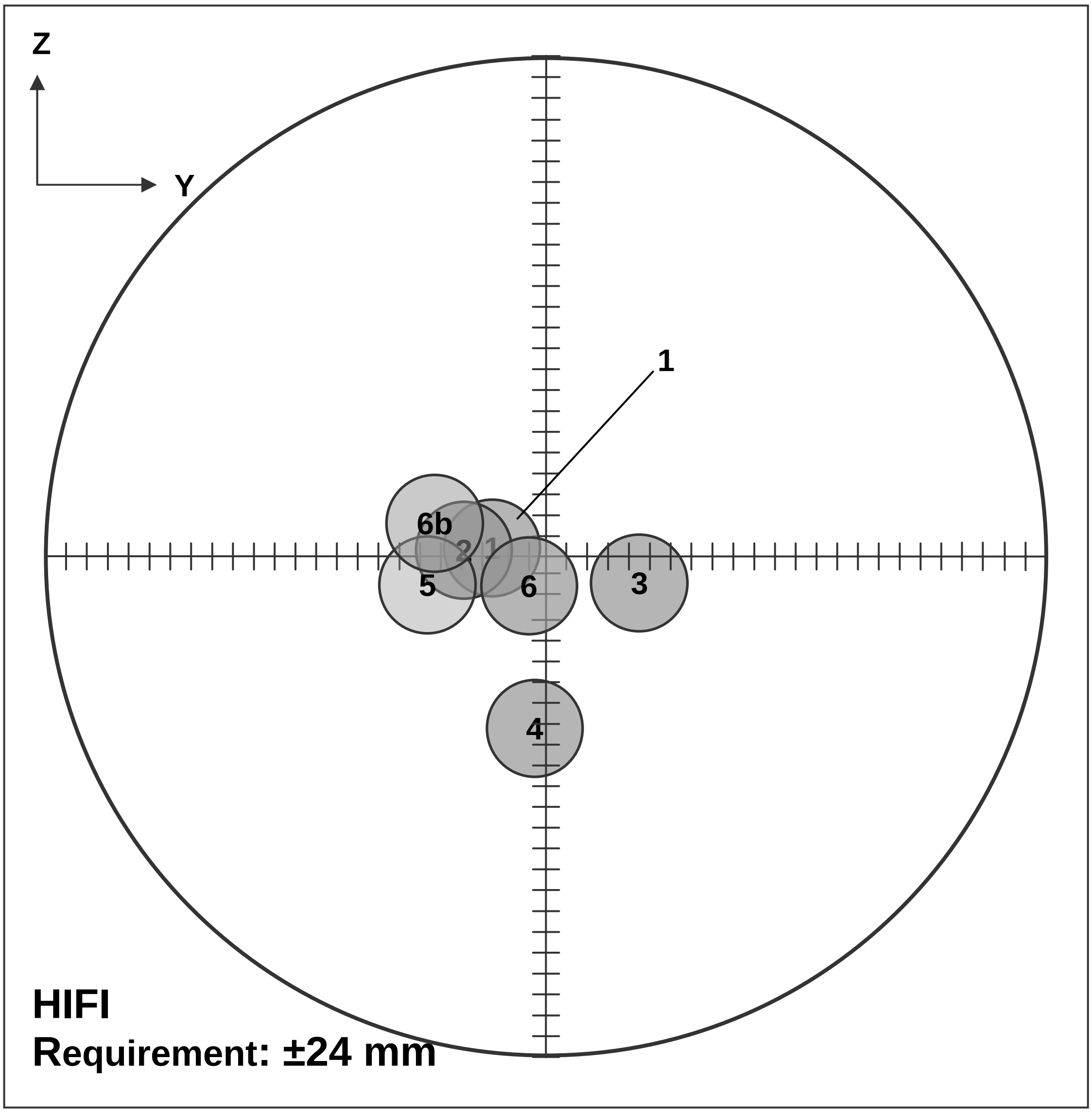

Figure 6-3: Pupil mismatch for HIFI in M2-plane

The instruments have originally been measured wrt. CVVRC4. Since then the UB was closed, the CVV was evacuated, the tank-straps were re-tensioned and the cryostat was cooled down. All these activities may have a slight impact on the nominal position of CVVRC4. This deviation needs to be considered for pupil mismatch and is given below:

Change in y direction: +0,23mm (larger distance)

Changes is x and z direction are negligible and have not been considered.

6.1.3 *Instrument Line of Sight (LOS)*

The following Sections 6.1.3 and 6.1.4 are given for information only.

The instrument LOS is defined as

LOS(instr) = -arctan R / f

where R is the position vector of the instrument aperture in the focal plane and f is the telescope focal length (28623 mm, RD 1). In components y and z of the position vector the LOS then becomes)

LOS Y(instr) = -arctan y / f and

LOS Z(instr) = -arctan z / f.

Since the LOS shall be given in the CVVRC1 system, the instrument positions have to be determined in this system. However, the instrument positions have originally been measured in the XCVVRC4 system. To find the coordinates in CVVRC1, the following method is used:

The first measurement (at instrument integration with UB open) of instrument positions in CVVRC4 includes also measurement of CVVRC2. From this measurement, we find the transition from CVVRC4 to CVVR2 system (rotation translation).

The second measurement wrt. CVVRC1 (after telescope integration) includes also measurement of CVVRC2. From this measurement, we find the transition from CVVRC2 to CVVRC1 (rotation translation).

Combining both transitions CVVRC4 ➔ CVVRC2 and CVVRC2 ➔ CVVRC1 yields direct transition CVVRC4 ➔ CVVRC1.

From the measured orientations of the CVV reference cubes (see Table 5-9) we find that the CVVRC1 system is rotated wrt. CVVRC4 (transition CVVRC4 ➔ CVVRC1) by the following angles and translations (cryostat inside cold, outside warm):

During instrument level tests, the relation between CVVRC4 and CVVRC2 has been measured. At that time CVVRC1 was not available, since the CVV had to remain open for instrument reference cube access. Later on, after telescope integration CVVRC1 was measured wrt. CVVRC2. From the two measurements we have derived the relation between CVVRC1 and CVVRC4.

In the following the two LOS (from +y and from +z side) of CVVRC1 wrt CVVRC4 are given (as fictitious theodolite measurements) by their azimuth (Hz, wrt. y-axis) and elevation (V, wrt x-axis) angles.

LOS(y): Hz = 359.7295 deg, V = 90.3119 deg

LOS(z): Hz = 89.7484 deg, V = 90.0353 deg.

To perform the transition from the CVVRC4-system to CVVRC1-system, we have established a transfer matrix which was then applied to the CVVRC4 instrument LOS vectors to obtain the LOS vectors in the CVVRC1 reference system:

The following table compiles instrument entrance nominal positions in the focal plane in instrument coordinate system (corresponding to OBA coordinate system) at cold conditions and modifications due to instrument and telescope alignment, strap re-tensioning, cool-down etc. as calculated in the attached Excel sheet.

	HIFI Ch 6	PACS	SPIRE	Remark
x [mm]	202.0	202.0	202.0	Nominal
y [mm]	0.0 -1.83 -1.83	0.06 -1.81 -1.75	0.0 -3.71 -3.71	Nominal changes resulting pos. in CVVRC4
z [mm]	0.0 -0.70 -0.70	79.85 +0.37 80.22	-80.0 -0.95 -80.95	Nominal changes resulting pos. in CVVRC4
LOS y LOS z	+0.0037 deg +0.0014 deg	+0.0035 deg -0.1606 deg	+0.0074 deg +0.1620 deg	For resulting pos.

Table 6-5: Instrument entrance positions and LOS components in CVVRC4 system.

Values refer to focal plane at cold conditions. LOS is given in lateral components.

(Nominal values need to be confirmed by instruments, except for PACS, here we have measured values, [RD 3])

The above y- and z-coordinates are used to calculate the LOS. Therefore these coordinates include all effects which have an impact on the distances between the telescope focus and instrument aperture (strap re-tensioning, cool-down, telescope tilt etc. see EXCEL sheet “LOS” in annex). The following relation is used:

Total ΔY = Instr. alignmt (nominal –measured) + instr. internal misalignmt. + OB shift (strap re-tension., cool-down, bake-out) + instr. thermoelastics + – (linear y shift due to Rz + telesc./CVV misalign.). Using the symbols of the appended Excel sheet, the relation becomes:

$\Delta Y = a13 + a28 + a47 + a51 – (a44 + a38)$

ΔZ: analogous to ΔY.

To the above values ΔY, ΔZ, the internal telescope LOS deviation (from [RD 1]) has to be added.

The following data are taken from (from [RD1]):

Telescope-internal LOS-deviation

$\Delta\Theta_y$ = -0.003 ± 0.1 mrd = -0.00017 ± 0.0057 deg = -0.6 ± 20.6 arcsec)

$\Delta\Theta_z$ = -0.017 ± 0.1 mrd = -0.00097 ± 0.0057 deg = -3.5 ± 20.6 arcsec)

Telescope focal length:

f = 28623 mm.

Adding above telescope internal LOS deviation components $\Delta\Theta_y$ and $\Delta\Theta_z$ to the instrument LOS components of Table 6-5 leads to resulting LOS as compiled in the following table. These results are given wrt. the CVVRC4 reference system.

	HIFI Ch 6	PACS	SPIRE
LOS y	+0.00387 deg	+0.00367 deg	+0.00757deg
LOS z	+0.00237 deg	-0.15963 deg	+0.16297 deg

Table 6-6: Resulting instrument LOS including telescope internal LOS deviation

The telescope related LOS deviations are rather small, therefore, their impact on the values of Table 6-5 is very small.

On system level, it is requested to report the LOS wrt. the CVVRC1 reference system. As described above, the transfer from CVVRC4 to CVVRC1 is achieved by applying the following transfer matrix.:

Input data : LOS(y): Hz = 359.7295 deg, V = 90.3119 deg

LOS(z): Hz = 89.7484 deg, V = 90.0353 deg.

Rotation CVVRC1/CVVRC4 input matrix

LOSy	1	359,7295	90,3119
LOSz	1	89,7484	90,0353
	1	7,07752	0,31446

Related **direction cosine matrix** (DCM) : **M**

$$\begin{vmatrix} 0{,}9999740389 & -0{,}0047210281 & -0{,}0054436551 \\ 0{,}0043912335 & 0{,}9999901687 & -0{,}0006161012 \\ 0{,}0054465102 & 0{,}0005921808 & 0{,}9999849390 \end{vmatrix}$$

Related **inverse direction cosine matrix**: $\mathbf{M^{-1}}$

$$\begin{vmatrix} 0{,}9999740389 & 0{,}0043912335 & 0{,}0054465102 \\ -0{,}0047210281 & 0{,}9999901687 & 0{,}0005921808 \\ -0{,}0054436551 & -0{,}0006161012 & 0{,}9999849390 \end{vmatrix}$$

The instrument LOS in the CVVRC1 system are obtained by the relation:

$$\mathbf{DCM\text{-}LOS_{instr}(CVVRC1) = DCM\text{-}LOS_{inst}(CVVRC4) * M^{-1}}$$

Instrument input matrices in CVVRC4 system according to the values of Table 6-6:

HIFI:	LOS y	1	0,0000	0,0039
	LOSz	1	90,0000	0,0024
		1	90,0024	90,0000
PACS:	LOSy	1	0,0000	0,0037
	LOSz	1	270,0000	0,1596
		1	89,8404	90,0000
SPIRE:	LOSy	1	0,0000	0,0076
	LOSz	1	90,0000	0,1630
		1	90,1630	90,0000

The **instrument DCM** related to above input matrices are:

		Y	Z	X
HIFI:	LOSy	0,0000675442	0,0000000000	0,9999999977
	LOSz	0,0000000000	0,0000413643	0,9999999991
		-0,0000413643	-0,0000675442	0,0000000028
PACS:	LOSy	0,0000640536	0,0000000000	0,9999999979
	LOSz	0,0000000000	-0,0027860655	0,9999961189
		0,0027860655	-0,0000640533	-0,0000001785
SPIRE:	LOSy	0,0001321214	0,0000000000	0,9999999913
	LOSz	0,0000000000	0,0028443592	0,9999959548
		-0,0028443592	-0,0001321209	0,0000003758

Finally, the related **LOS(CVVRC1)** are:

		Y	Z	X
HIFI:	LOSy	90,30803	90,03528	0,31062
	LOSz	90,31191	90,03293	0,31421
		90,00235	90,00388	90,00002
PACS:	LOSy	90,30823	90,03528	0,31082
	LOSz	90,31115	90,19493	0,36769
		89,84036	90,00297	89,99914
SPIRE:	LOSy	90,30433	90,03527	0,30695
	LOSz	90,31267	89,87233	0,33821
		90,16293	90,00829	90,00087

7 Conclusions

From the above presented evaluation of the Herschel instrument alignment, we conclude, that all instruments fulfil their focus and pupil mismatch requirements.

All requirements are valid for in-orbit conditions. However, the instrument alignment measurements have been performed with the CVV under warm conditions. In order to compare the achieved values to the in-orbit-requirements, the expected shrinkage value in x-direction for in-orbit conditions have been taken from FEM analysis. With these numbers the measured values have been corrected for cold conditions. The requirements are compared to the resulting values at cold conditions and the residual margins have been determined.

Compared to in-orbit conditions the margins for focus alignment (x direction) of SPIRE (3.1 mm), PACS (2.8 mm) and HIFI (4.2 mm) is considered comfortable.

For pupil mismatch the margin is very comfortable for HIFI (see Fig. 6-3, Tab. 6-4). For PACS (1.1 mm) and SPIRE (1.7 mm) the margin is still sufficient. The larger pupil mismatch of PACS and SPIRE can be explained by their tilts wrt. the OBA plane and to the UB flange plane, being relatively large compared to HIFI. In principle, this unequal mismatch could be balanced between the three instruments by rotating the OBA, however with the drawback that HIFI vignetting wrt. CVV windows would become larger. Otherwise, a balancing of mismatches could only be achieved by individually shimming the instruments which would represent a highly complex, extremely time consuming activity.

Lines of sight for the instruments have been calculated taking into account alignment of instruments and telescope, strap re-tensioning, bake-out and cool-down. Finally the instrument LOS are given in CVVRC1 system which will be used later on system level.

8 Attachment

8.1 Excel Evaluation Sheets

The following Excel sheet summarises the measurement data as collected in the previous chapters and provides the result for focus and pupil mismatch alignment. The impact for strap re-tensioning in z direction is a combination of the linear shift and a shift induced by the rotation about the y axis. Both have been calculated using the mean between +z and -z window.

a0	**Instrument / Telescope Alignment**										
a1											
a2	Focus		2643,5								
a3	Pupil position		1843,5								
a4							Accuracy				
a5	**Instrument Alignment**										
a6			**PACS**	**SPIRE**	**HIFI**		PACS	Instrument	Telescope	CVV	Total
a7							x	1	3	1	3,32
a8	**x**	mm					y,z	0,6	0,5	1	1,27
a9	Nominal		1000,6	1021	903,3		SPIRE				
a10	Measure		1000,69	1020,94	902,65		x	2,25	3	1	3,88
a11	Delta		0,09	-0,06	-0,65		y,z	0,5	0,5	1	1,22
a12	**y**	mm					HIFI				
a13	Nominal		852,5	861,8	1088,1		x	2,7	3	1	4,16
a14	Measured		853,31	863,01	1089,13		y,z	2	0,5	1	2,29
a15	Delta		-0,81	-1,21	-1,03						
a16	**z**	mm									
a17	Nominal		7,7	128,4	72						
a18	Measued		6,82	128,14	71,99						
a19	Delta		0,88	0,26	0,01						
a20											
a21											
a22											
a23	**Ry**	arcmin	-2,32	-5,57	0,13						
a24	Impact z	mm	1,78	4,28	-0,10						
a25											
a26	**Rz**	arcmin	-3,38	-2,84	1,35						
a27	Impact y	mm	-2,60	-2,18	1,04						
a28											
a29	**Instrument internal**										
a30	**x**	mm			ch6	ch1	ch2	ch3	ch4	ch5	ch6b
a31	**y**	mm	0	-1,7	0	-2	-3	5	0	-5	-4
a32	**z**	mm	0	-0,7	0	2	2	0	-6,5	0,5	4
a33											
a34											
a35	**Telescope**										
a36	**Telescope internal (Pupil Position)**										
a37	**x**	mm	0	0	0						
a38	**y**	mm	-0,45	-0,45	-0,45						
a39	**z**	mm	-0,6	-0,6	-0,6						
a40											
a41	**Telescope Alignment**										
a42	**delta x**	mm	0,5	0,5	0,5						
a43	**delta y**	mm	0,9	0,9	0,9						
a44	**delta z**	mm	1,5	1,5	1,5						
a45	**Rx**	deg									
a46	**Ry**	deg	-0,0131								
a47	**Impact z**	mm	0,42	0,42	0,42						
a48	**Rz**	deg	0,0003								
a49	**Impact y**	mm	0,01	0,01	0,01						
a50											
a51	**Strap re-tensioning OB Shift, bake out, cool down**										
a52	x	mm	-3,51	-3,51	-3,51						
a53	y	mm	-0,35	-0,35	-0,35						
a54	z	mm	-0,35	-0,35	-0,35	incl Ry	Ry= 0,0229 deg, dz= 0,71mm				
a55											
a56	**Thermoelastic Instruments**										
a57	**x**	mm	-0,1	-0,1	-0,1						
a58	**y**	mm	-0,1	-0,1	0,1						
a59	**z**	mm	0,1	0,1	-0,1						
a60											
a61	**Warm-cold corr**		Expected values								
a62	**x**	mm	-4,5	-4,5	-4,5						
a65											
a66	**Strap release in-orbit**										
a67	**x**	mm	0,4	0,4	0,4						
a68											
a69	**CVVRC4 revised nominal correction (without man. Error)**										
a70	**x**	mm	negl	negl	negl						
a71	**y**	mm	0,23	0,23	0,23						
a72	**z**	mm	negl	negl	negl						
a73											
a74	**De-Focus**										
a75	Actual	mm	-3,92	-4,07	-4,66						
a76											
a77	**De-Focus (in-orbit)**										
a78		mm	0,88	0,73	0,14						
a79											
a80	Error		3,3	3,9	4,2						
a81											
a82	De-focus incl. Error		4,18	4,63	4,34						
a83											
a84	Requirement		7,0	7,7	8,5						
a85											
a86	Margin (abs value)		2,8	3,1	4,2						
a87											
a88	**Pupil Mismatch (in-orbit)**				ch6	ch1	ch2	ch3	ch4	ch5	ch6b
a89	in y	mm	-4,09	-5,77	-0,47	-2,47	-3,47	4,53	-0,47	-5,47	-4,47
a90											
a91	in z	mm	1,09	2,27	-1,86	0,14	0,14	-1,86	-8,36	-1,36	2,14
a92											
a93	Radius	mm	4,23	6,20	1,92	2,48	3,47	4,90	8,37	5,64	4,96
a94											
a95	Error	mm	1,3	1,2	2,3	2,3	2,3	2,3	2,3	2,3	2,3
a96											
a97	Radius incl Error		5,9	7,8	5,0	5,4	6,3	8,0	11,0	8,6	8,1
a98											
a99	Requirement		7,0	9,5	24,0	24,0	24,0	24,0	24,0	24,0	24,0
a100											
a101	Margin (abs value)		1,1	1,7	19,0	18,6	17,7	16,0	13,0	15,4	15,9

a0	**LOS**							
a1								
a2	Focal Length		28623	mm				
a3	Pupil position		2643,5	mm				
a4	Focus position		800	mm				
a5								
a6								
a7	**Instrument Alignment**							
a8			**PACS**	**SPIRE**	**HIFI Channel 6**			
a9								
a10	**y**	mm						
a11	Nominal		852,5	861,8	1088,1			
a12	Measured		853,31	863,01	1089,13			
a13	Delta		-0,81	-1,21	-1,03			
a14	**z**	mm						
a15	Nominal		7,7	128,4	72			
a16	Measued		6,82	128,14	71,99			
a17	Delta		0,88	0,26	0,01			
a18								
a19								
a20	**Ry**	arcmin	-2,32	-5,57	0,13			
a21	Impact z	mm	0,00	0,00	0,00	OB tilt does not contribute to LOS		
a22								
a23	**Rz**	arcmin	-3,38	-2,84	1,35			
a24	Impact y	mm	0,00	0,00	0,00	OB tilt does not contribute to LOS		
a25								
a26	**Instrument internal**							
a27								
a28	**y**	mm	0	-1,7	0			
a29	**z**	mm	0	-0,7	0			
a30								
a37	**Telescope Alignment**							
a38	**delta y**	mm	0,9	0,9	0,9			
a39	**delta z**	mm	1,5	1,5	1,5			
a40	**Rx**	deg						
a41	**Ry**	deg	-0,0131					
a42	**Impact z**	mm	-0,18	-0,18	-0,18			
a43	**Rz**	deg	0,0003					
a44	**Impact y**	mm	-0,0042	-0,0042	-0,0042			
a45								
a46	**Strap re-tensioning OB Shift, bake out, cool down**							
a47	y	mm	0	0	0			
a48	z	mm	0,71	0,71	0,71			
a49								
a50	**Thermoelastic Instruments**							
a51	**y**	mm	-0,1	0,1	0,1			
a52	**z**	mm	0,1	0,1	-0,1			
a53								
a58	**Position changes Instrument vs Telescope**							
a59	in y	mm	-1,81	-3,71	-1,83			
a60								
a61	in z	mm	0,37	-0,95	-0,70			
a62								
a63	Radius	mm	1,84	3,82	1,95			

8.2 Excel Performance Sheets

This section contains the Excel sheets from the document "Alignment Methods Plan & Results" [RD 2].

Here, we have replaced the predicted values by measured values as far as available. In case a value has not been measured directly but is included in the measurement chain it has been set to zero (e.g. the flatness of the OB has not been measured directly but has an impact on Instrument position and, therefore, is included in the instrument cube measurement value). In the same sense the shrinking uncertainty for the OB w.r.t. CVV is now set to zero because it is part of the measurements performed after cryostat cool down. On the other hand the shrinking uncertainty of the Telescope w.r.t. the CVV the prediction is still there and can only be confirmed after TB/TV testing.

PACS		Focus	
	Error class	x [mm]	Rx[arcsec]
Instrument internal	t	0,10	
	u	1,00	
	b	0,00	
Telescope internal	t		
	u	3,00	
	b	0,00	
TMS	u		
	b	0,00	
Instrument wrt. CVV			
Measurement error instrument cube	u	0,40	20
Measurement error on CVV cube	u	0,40	20
Telescope wrt. CVV			
Measurement error on Telescope cube	u	0,40	20
Measurement error on CVV cube	u	0,40	20
Optical bench			
Flatness	b	0,00	
Stability	b	0,05	44,8
Adjustment	b	0,00	
Instrument mounting accuracy	b		
Tank Straps	u	0,00	0
Shrinking uncertainty			
OB wrt. CVV	u	0,00	
Telescope wrt. CVV	u	0,40	
Setting effects			
Due to launch	u	0,05	
Due to TB/TV testing	u	0,05	12,4
Remaining adjustment offset	b		20
Offset Instrument	b	0,09	0
Offset Telescope	b	0,50	0
Offset OB	b	1,39	0
In-Orbit effects			
Gravity release	b	0,10	1,1
Pressure release	b	0,14	0,4
Thermoelastic distortion			
LC1-LC2	t	0,010	0,019
Total error CVV			
Uncertainty (rss)	u	0,90	41,9
Bias (rss)	b	1,00	49,1
Total incl. thermoelastic		1,90	91,0
Total error PLM			
Uncertainty (rss)	u	3,29	
Bias (rss)	b	1,00	
Total incl. thermoelasic		**4,39**	
Requirement		**7,00**	
Margin		2,61	
Prediction acc. To [RD 2]		5,10	

PACS		Pupil Mismatch					
						Focus-M2	Mech I/F-M2
	Error class	y[mm]	z[mm]	Ry[arcsec]	Rz[arcsec]	2643,5	1843,5
Instrument internal	t	0,10	0,10				
	u	0,60	0,60				
	b	0,00	0,00				
Telescope internal	t						
	u	0,50	0,50				
	b	-0,45	-0,60				
TMS	u						
	b	0,00	0,00				
Instrument wrt. CVV							
Measurement error instrument cube	u	0,40	0,40	20	20		
Measurement error on CVV cube	u	0,40	0,40	20	20		
Telescope wrt. CVV							
Measurement error on Telescope cube	u	0,40	0,40	20	20		
Measurement error on CVV cube	u	0,40	0,40	20	20		
Optical bench							
Flatness	b			0	0		
Stability	b	0,05	0,05	34	34		
Adjustment	b	0,00	0,00	0	0		
Instrument mounting accuracy	b	0,00	0,00				
Tank Straps	u	0,00	0,00	0	0		
Shrinking uncertainty							
OB wrt. CVV	u	0,00	0,00	0	0		
Telescope wrt. CVV	u	0,10	0,10	0	0		
Setting effects							
Due to launch	u						
Due to TB/TV testing	u	0,05	0,05	12,4	12,4		
Remaining adjustment offset	b						
Offset Instrument	b	-0,81	0,88	-139,2	-202,8		
Offset Telescope	b	0,90	1,50	-47,16	1,08		
Offset OB (cool down, strap retensioning)	b	-0,35	-0,35				
CVVRC4 revised nominal correction	b	0,23	0,00				
In-Orbit effects							
Gravity release	b	0,11	0,11				
Pressure release	b	0,03	0,03				
Thermoelastic distortion							
LC1-LC2	t	0,0021	0,0021				
Total error CVV							
Uncertainty (rss)	u	0,81	0,81	41,88	41,88		
Uncertainty due to Ry,Rz	u	0,54	0,37				
Uncertainty total	u	**0,97**	**0,89**				
Bias (rss)	b	-1,83	-0,98				
Bias due to Ry,Rz	b	-2,65	1,41				
Bias total	b	**-4,48**	**0,44**				
Total incl. thermoelasic		-3,51	1,33				
Pupil Mismatch in M2 plane		-4,97	1,88				
Total error PLM							
Uncertainty (rss)	u	1,25	1,18				
Bias (rss)	b	-4,03	1,02				
Total incl. thermoelastic		-5,38	2,31				
Pupil mismatch in M2 plane		**5,86**					
Requirement		**7,00**					
Margin		1,14					
Prediction acc. To [RD 2]		3,70					

SPIRE		Focus	
	Error class	x [mm]	Rx[arcsec]
Instrument internal	t	0,10	
	u	2,30	
	b	0,00	
Telescope internal	t		
	u	3,00	
	b	0,00	
TMS	u		
	b	0,00	
Instrument wrt. CVV			
Measurement error instrument cube	u	0,40	20
Measurement error on CVV cube	u	0,40	20
Telescope wrt. CVV			
Measurement error on Telescope cube	u	0,40	20
Measurement error on CVV cube	u	0,40	20
Optical bench			
Flatness	b	0,00	
Stability	b	0,05	44,8
Adjustment	b		
Instrument mounting accuracy	b		
Tank Straps	u	0,00	0
Shrinking uncertainty			
OB wrt. CVV	u	0,00	
Telescope wrt. CVV	u	0,40	
Setting effects			
Due to launch	u	0,05	
Due to TB/TV testing	u	0,05	12,4
Remaining adjustment offset	b	0,00	20
Offset Instrument	b	-0,06	0
Offset Telescope	b	0,50	0
Offset OB	b	1,39	0
In-Orbit effects			
Gravity release	b	0,10	1,1
Pressure release	b	0,14	0,4
Thermoelastic distortion			
LC1-LC2	t	0,010	0,021
Total error CVV			
Uncertainty (rss)	u	0,90	41,9
Bias (rss)	b	0,85	49,1
Total incl. thermoelastic		1,76	91,0
Total error PLM			
Uncertainty (rss)	u	3,89	
Bias (rss)	b	0,85	
Total incl. theroelasic		**4,84**	
Requirement		**7,70**	
Margin		2,86	
Prediction acc. To [RD 2]		5,00	

SPIRE		Pupil Mismatch					
						Focus-M2	Mech I/F-M2
	Error class	y[mm]	z[mm]	Ry[arcsec]	Rz[arcsec]	2643,5	1843,5
Instrument internal	t	0,10	0,10				
	u	0,50	0,50				
	b	-1,70	-0,70				
Telescope internal	t						
	u	0,50	0,50				
	b	-0,45	-0,60				
TMS	u						
	b	0,00	0,00				
Instrument wrt. CVV							
Measurement error instrument cube	u	0,40	0,40	20	20		
Measurement error on CVV cube	u	0,40	0,40	20	20		
Telescope wrt. CVV							
Measurement error on Telescope cube	u	0,40	0,40	20	20		
Measurement error on CVV cube	u	0,40	0,40	20	20		
Optical bench							
Flatness	b			0	0		
Stability	b	0,05	0,05	34	34		
Adjustment	b	0,00	0,00	0	0		
Instrument mounting accuracy	b	0,00	0,00				
Tank Straps	u	0,00	0,00	0	0		
Shrinking uncertainty							
OB wrt. CVV	u	0,00	0,00				
Telescope wrt. CVV	u	0,10	0,10				
Setting effects							
Due to launch	u						
Due to TB/TV testing	u	0,05	0,05	12,4	12,4		
Remaining adjustment offset	b						
Offset Instrument	b	-1,21	0,26	-334,2	-170,4		
Offset Telescope	b	0,90	1,50	-47,16	1,08		
Offset OB (cool down, strap retensioning)	b	-0,35	-0,35				
CVVRC4 revised nominal correction	b	0,23	0,00				
In-Orbit effects							
Gravity release	b	0,11	0,11				
Pressure release	b	0,03	0,03				
Thermoelastic distortion							
LC1-LC2	t	0,0028	0,0028				
Total error CVV							
Uncertainty (rss)	u	0,81	0,81	41,88	41,88		
Uncertainty due to Ry,Rz	u	0,54	0,37				
Uncertainty total	u	**0,97**	**0,89**				
Bias (rss)	b	-2,23	-1,59				
Bias due to Ry,Rz	b	-2,24	3,88				
Bias total	b	**-4,47**	**2,29**				
Total incl. thermoelasic		-3,50	3,18				
Pupil Mismatch in M2 plane		-4,95	4,50				
Total error PLM							
Uncertainty (rss)	u	1,20	1,14				
Bias (rss)	b	-5,72	2,19				
Total incl. thermoelastic		-7,03	3,43				
Pupil mismatch in M2 plane		**7,82**					
Requirement		**9,50**					
Margin		1,68					
Prediction acc. To [RD 2]		4,1					

HIFI				Focus	
			Error class	x [mm]	Rx[arcsec]
Instrument internal			t	0,10	
			u	2,70	
			b	0,00	
Telescope internal			t		
			u	3,00	
			b	0,00	
TMS			u		
			b	0,00	
Instrument wrt. CVV					
Measurement error instrument cube			u	0,40	20
Measurement error on CVV cube			u	0,40	20
Telescope wrt. CVV					
Measurement error on Telescope cube			u	0,40	20
Measurement error on CVV cube			u	0,40	20
Optical bench					
Flatness			b	0,00	
Stability			b	0,05	44,8
Adjustment			b		
Instrument mounting accuracy			b		
Tank Straps			u	0,00	0
Shrinking uncertainty					
OB wrt. CVV			u	0,00	
Telescope wrt. CVV			u	0,40	
Setting effects					
Due to launch			u	0,05	
Due to TB/TV testing			u	0,05	12,4
Remaining adjustment offset			b	0,00	20
Offset Instrument			b	-0,65	0
Offset Telescope			b	0,50	0
Offset OB			b	1,39	0
In-Orbit effects					
Gravity release			b	0,10	1,1
Pressure release			b	0,14	0,4
Thermoelastic distortion					
LC1-LC2			t	0,010	0,02
Total error CVV					
Uncertainty (rss)			u	0,90	41,9
Bias (rss)			b	0,30	49,1
Total incl. thermoelastic				1,21	91,0
Total error PLM					
Uncertainty (rss)			u	4,13	
Bias (rss)			b	0,30	
Total incl. theroelasic				**4,54**	
Requirement				**8,50**	
Margin				3,96	
Prediction acc. To [RD 2]				7,40	

HIFI		Pupil Mismatch					
						Focus-M2	Mech I/F-M2
	Error class	y[mm]	z[mm]	Ry[arcsec]	Rz[arcsec]	2643,5	1843,5
Instrument internal	t	0,10	0,10				
	u	2,00	2,00				
	b	0,00	0,00				
Telescope internal	t						
	u	0,50	0,50				
	b	-0,45	-0,60				
TMS	u						
	b	0,00	0,00				
Instrument wrt. CVV							
Measurement error instrument cube	u	0,40	0,40	20	20		
Measurement error on CVV cube	u	0,40	0,40	20	20		
Telescope wrt. CVV							
Measurement error on Telescope cube	u	0,40	0,40	20	20		
Measurement error on CVV cube	u	0,40	0,40	20	20		
Optical bench							
Flatness	b			0	0		
Stability	b	0,05	0,05	34	34		
Adjustment	b	0,00	0,00	0	0		
Instrument mounting accuracy	b	0,00	0,00				
Tank Straps	u	0,00	0,00	0	0		
Shrinking uncertainty							
OB wrt. CVV	u	0,00	0,00				
Telescope wrt. CVV	u	0,10	0,10				
Setting effects							
Due to launch	u						
Due to TB/TV testing	u	0,05	0,05	12,4	12,4		
Remaining adjustment offset	b						
Offset Instrument	b	-1,03	0,01	7,8	81,0		
Offset Telescope	b	0,90	1,50	-47,16	1,08		
Offset OB (cool down, strap retensioning)	b	-0,35	-0,35				
CVVRC4 revised nominal correction	b	0,23	0,00				
In-Orbit effects							
Gravity release	b	0,11	0,11				
Pressure release	b	0,03	0,03				
Thermoelastic distortion							
LC1-LC2	t	0,0027	0,0027				
Total error CVV							
Uncertainty (rss)	u	0,81	0,81	41,88	41,88		
Uncertainty due to Ry,Rz	u	0,54	0,37				
Uncertainty total	u	**0,97**	**0,89**				
Bias (rss)	b	-2,05	-1,84				
Bias due to Ry,Rz	b	1,11	-0,87				
Bias total	b	**-0,94**	**-2,71**				
Total incl. thermoelasic		0,03	-1,82				
Pupil Mismatch in M2 plane		0,05	-2,57				
Total error PLM							
Uncertainty (rss)	u	2,28	2,25				
Bias (rss)	b	-0,49	-2,11				
Total incl. thermoelastic		-2,87	-4,26				
Pupil mismatch in M2 plane		**5,14**					
Requirement		**24,00**					
Margin		18,86					
Prediction acc. To [RD 2]		16,3	Due to very big internal uncertainty as given by SRON				

Attachment to HP-2-ASED-TR-0260

EADS astrium

Procedure for Herschel Telescope Alignment wrt. CVV

Herschel

1. Alignment Telescope 24.4.2008

Title: **Procedure for Herschel Telescope Alignment wrt. CVV**

CI-No: 125 400

Prepared by:	Dr. E. Hölzle	E. Hölzle	Date:	22.04.2008
Checked by:	D. Schink	D. Schink		22.04.2008
AIT	R. Hohn	H		23.04.08
Engineering	J. Kroeker	J. Kroeker		22.04.2008
Product Assurance:	R. Stritter	St		23.04.08
Configuration Control:	W. Wietbrock	W. Wietbrock		22.04.2008
Project Management:	Dr. W. Fricke	Fricke		22/04/2008

Distribution: See Distribution List (last page)

Issue	Date	Sheet	Description of Change	Release
1	15.04.08	All	First formal issue, comments of TAS-F implemented.	
2	22.04.08	All	Implementation of laser tracker for all distance measurements as requested in telescope alignment TRR. Change of telescope ref. cube orientation from LOS to theodolite readings. All changes marked by vertical bar.	

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1 INTRODUCTION

1.1 Scope

This document describes the telescope alignment measurement which will be performed after telescope integration, in order to verify the correct position of the telescope wrt. PLM. The detailed step-by-step procedure for performing these activities is reflected in chapter 9 of this document.

In addition to specific telescope related measurements, measurements of the CVV reference cubes will be made, in order to have a full overview on stabilities in the S/C area.

This procedure is valid only for the PFM S/C. Lessons learned with the STM programmes have been implemented into this PFM related procedure.

1.2 Objective

The alignment requirements as specified in [AD 1] are applicable only for in-orbit conditions if not stated otherwise. The final verification of these requirements is a combination of on-ground alignment measurements and a calculation taking into account in-orbit effects and launch loads. This analysis is performed in [RD 1] whereas this procedure covers the alignment activities for on-ground verification measurements.

This means, that the measurements as defined in this document are specifically supporting the final analytical verification of requirements concerning the relation between experiments CVV and telescope as defined in AD 1 (HERS). The alignment measurements of this procedure are related to the following requirements of HERS: HERS-640, -1220, -1230.

A test plan and sequence for the PFM is given in [RD 1] and [RD 3].

2 Applicable Documents

2.1 Applicable Documents

[AD 1]	H-EPLM Requirements Specification (HERS) H-P-2-ASPI-SP-0250, issue 3.3, dated 20.10.2004
[AD 2]	Instrument Interface Document IID Part A SCI-PT-IIDA-04624, issue 4.0, dated 30.04.2006
[AD 3]	Herschel Telescope User Manual HER.NT.1034.T.ASTR, Issue 1
[AD 4]	Mechanical Interface Control Report HER.RPT.1036.T.ASTR, Issue 1

2.2 Reference Documents

[RD 1]	Alignment Method, Plan & Results HP-2-ASED-TN-0097
[RD 2]	Herschel System Alignment Plan H-P-2-ASPI-PL-0276
[RD 3]	Satellite AIT Plan Part 2: S/C and S/C-PFM Acceptance Phase, HP-2-ASED-PL-0026
[RD 4]	H-EPLM-Thermal Distortion Analysis CDR Status, HP-2-ASED-TN-0046, issue 2
[RD 5]	Amendment of Thermal Distortion Analysis HP-2-ASED-TN-0169, issue 1
[RD 6]	TMS Shim Definition and Manufacturing HP-2-ASED-RP-0237, Issue 1
[RD 7]	Herschel Instrument Alignment wrt. CVV Test Report, HP-2-ASED-TR-0219., Issue 1
[RD 8]	Distance Measurements Validity Check HP-2-ASED-TR-0174, Issue 1
[RD 9]	Mechanical Integration and 3D Measurement Results of the FM Telescope Mounting Structure (TMS) HP-2-ASED-TR-0201- Issue 1

3 Alignment Activities Description

3.1 Alignment Process Overview

The alignment activities for the telescope described here comprise the alignment measurements of the telescope wrt CVV.

This procedure covers the following alignment tasks:

- Orientation measurements of reference cubes of CVV (CVVRC2, -3 and -4), of telescope reference cubes TRC1. -2, -3 and -4 and TMS reference TMS-RC wrt. CVVRC1 as prime reference.
- Position measurements .of the telescope references (TRC 1 – 4) wrt. CVVRC1 as prime reference.

The above alignment measurements will be later repeated in the context of more extended alignment checks, e. g, before and after satellite environment testing. This means that the measurements as presented in detail in this procedure will serve also as reference for later alignment and stability checks.

All measurements will be carried out at ambient conditions.

3.2 Angle Measurements

The angle measurements between different alignment references are based on the principle of auto-collimation. A theodolite with illuminated cross hair is used as autocollimator. The cross hair image is projected on a flat mirror (surface of alignment cube) on which the angle orientation has to be determined. When the line of sight of the theodolite is parallel to the flat mirror normal, the reflected image of the cross hair is refocused in the cross hair plane and coincides with the theodolite cross hair. The corresponding azimuth and elevation angle from the flat mirror normal can than be read from the theodolite scales.

In the vertical plane this reading is related to the theodolite-internal plumb line (i. e. earth's gravity field). The horizontal reading has to be related to a reference direction, for which an Angle Transfer Prism (ATP) will be used.

3.2.1 *Theodolite Readings*

The theodolite defines the reference frame for the elevation angles (internal levelling of the theodolite). For the azimuth the reference frame will be determined by an Angle Transfer Prism (ATP). This ATP defines the zero for the azimuth reading.

The elevation can vary between 0 and 180.0000 deg and the azimuth is between 0 and 360.0000 deg. The definition for elevation and azimuth is given in the following figures.

Each normal to a reference cube surface is defined by the elevation and the azimuth angle as shown in Figure 3-1 and 3-2. These are the raw measurement data that will be provided with the filled in Test Procedure.

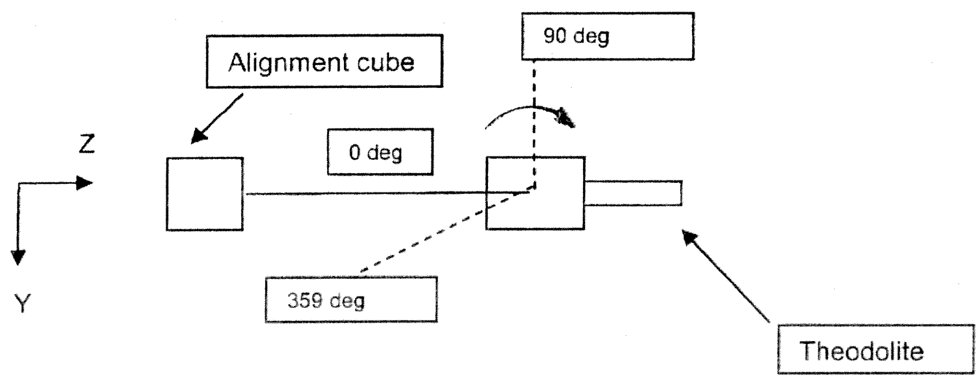


Figure 3-1: Azimuth Reading

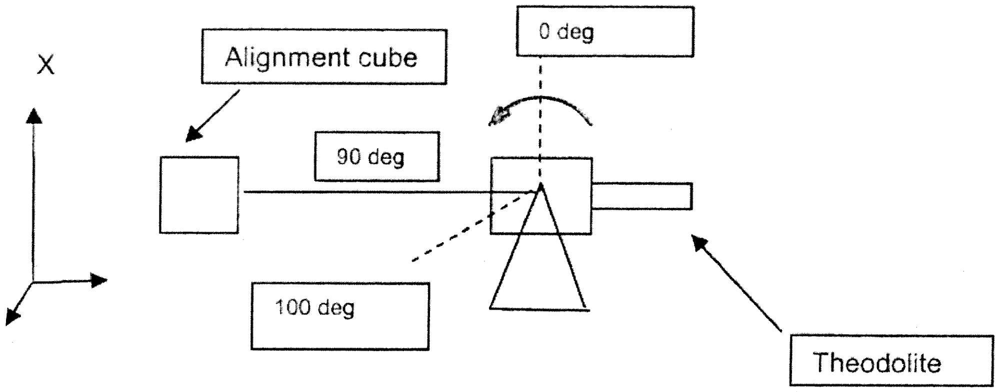


Figure 3-2: Elevation Reading

3.3 Distance Measurements

The distance measurements are based on measurements using the ESA laser tracker.

4 Test Article Description

Figure 4-1 shows the complete Herschel FM Satellite. However, for the measurements as described in this procedure, only the S/C is concerned.

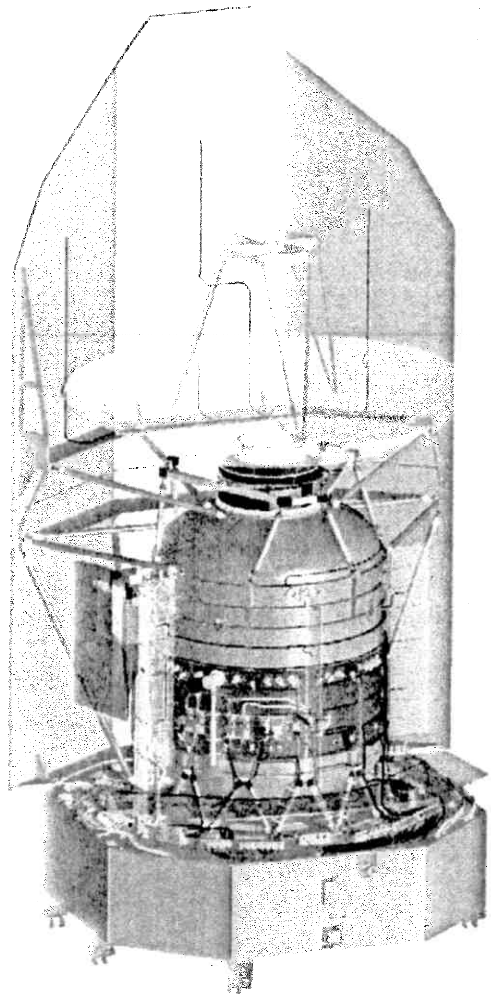


Figure 4-1: Herschel PFM

The Herschel FM Satellite configuration, as applicable for the telescope alignment measurements.

5 Test Set-Up Configuration

The configuration of the test set-up for the PPM is shown in Figure 5-1. As already mentioned for the alignment measurement described here, only the upper part (E-PLM) is concerned.

The theodolite is located at a distance of appr. 1 - 5 m from the satellite (as close as possible to maximize intensity and contrast of theodolite image)

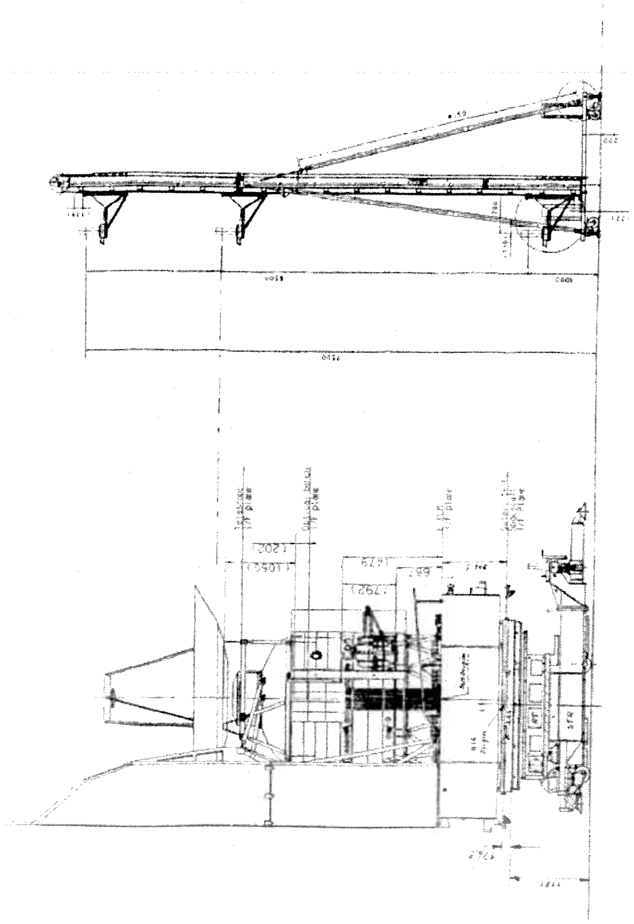


Figure 5-1: Principle Alignment Measurement Test Set-Up

As already mentioned in Figure 4.1, for the purpose of this procedure only the upper part of the satellite is concerned.
The ATP is set-up at 90.0 deg to the line theodolite E-PLM and not shown in this figure.

6 Test Equipment

In the following table the main equipment needed for PFM alignment activities is shown.

Nr.	Qty	Equipment	Description
1	1	Theodolite	Wild T2000 S
2	2	Angle Transfer Prism	Reference for azimuth
3	1	Alignment Tripod	For theodolite
4	2	Alignment Tripod	For Angle Transfer Prism
5	1	ESA Laser Tracker	For distance measurements

Table 6-1: Alignment Equipment List

The units to be aligned for the (CVV and telescope) will be delivered equipped with alignment references.

7 Test Conditions

7.1 Environmental Conditions

Environmental	Nominal	Remark
Clean Room Class	100000	
Temperature	22°C ± 3°C	
Rel. Humidity	40% - 60%	
Pressure	Ambient	

Table 7-1: Environmental Conditions

7.2 Other conditions

The alignment shall be performed on a stable, vibration free floor.

7.3 Personnel

The following personnel is required to perform the alignment measurements.

Responsibility	Name
Test Manager	D. Schink
Handling and Integration Engineer	R. Suess
Alignment Engineers (2 Persons)	D. Schink / A. Tavares (ESA)
PA Responsible	R. Langenstein

Table 7-2: Personnel

7.4 General and Special Precautions/Safety

The following shall be considered:

The handling of the test set-up shall be in accordance with controlled procedure only.

Handling, mechanical and electrical, has to be done only by qualified personnel.

- The test personnel shall make sure that the complete test is carried out following the procedure steps exactly. This will be confirmed by a signature on the corresponding procedure sheet.
- Correct set-up of the test equipment has to be checked carefully prior to the test.
- Any changes to the alignment sequence have to be recorded in the procedure variation sheet.
- Wherever nominal values and dedicated tolerances are defined, actual measured values shall be recorded to document that the test step was successful. If any actual measured value is out-of-limits or if any step cannot be completed correctly, a Non-Conformance-Report (NCR) shall be written. All deviations during the integration have to be handled with NCR's and have to be noted in the NCR summary table.

8 Specific Conditions for PFM Alignment

All angle measurements will be performed with a theodolite if not mentioned otherwise. Linear measurements are made with the ESA Laser Tracker.

The individual alignment steps to perform the alignment with the PFM are described in chapter 9.

The requirements specified in AD 1 are only valid for in-orbit conditions. I.e. during on-ground tests (outside the TV chamber) the alignment will deviate from the in-orbit alignment due to thermal shrinkage of the CVV, which has to be taken into account by a pre-compensation at integration.

8.1 Measurement Accuracy

Concerning the measurement described in Chapter 9, the following accuracies (2 σ-values) shall apply:

Rotation: ± 20 arcsec for single measurement

Translation: ± 0.4 mm

8.2 Measurement Logic

Among the accessible reference cubes, CVVRC1 is the only cube which is accessible from three sides (+Y, -Y and –Z). Therefore, all measurements of this procedure are made wrt. the CVVRC1 as prime reference and all measurements (positions and orientations) will be reported in the CVVRC1 system.

Furthermore, the telescope orientations will be also reported in the UB-flange system: Earlier measurements of the instruments, when the CVV was still open and CVVRC1 not available (since mounted on upper bulkhead) were made wrt. the CVV flange as reference. Also the Telescope Mounting Structure (TMS) - mounted nominally to the TMS - was measured wrt. the UB-flange plane. In the same way, the telescope will be mounted nominally to the TMS. For these reasons, the telescope angle measurements will be transferred to the UB-system, to derive the telescope alignment wrt. the instruments. The transfer will be made according to the figures reported in RD 7. The way to derive the necessary corrections is indicated in the following Sect. 8.3.

8.3 UB Flange as Telescope Alignment Reference: Success Criteria

All deviations between nominal values and measured values of Sect 9 shall be met within the following limits:

Linear measurements: ± 1.0 mm

Angle measurements: ± 90 arcsec (Elevation)

Above angular limits are valid wrt. CVV flange as reference, whereas the linear measurements are valid wrt. CVVRC1. The flange plane is no longer accessible to measurements, since the upper bulkhead is closed. However, the inclination of the CVV flange plane can be derived wrt. the now accessible prime reference CVVRC1. Therefore, the telescope orientation can also be given wrt. the flange plane, i. e., success criteria for the alignment of the telescope wrt. the experiments can be derived (see Sect. 9.6).

From previous measurements we have (from RD 7):

V(CVVRC4) from +Z:	$V(RC4_{+Z}) = 90.0054°$
V(CVVRC4) from +Y:	$V(RC4_{+Y}) = 90.3331°$
V(CVVRC2) from –Z:	$V(RC2_{-Z}) = 90.0300°$
CVV-Flange from +Y:	$V(F_{+Y}) = 90.0044°$
CVV-Flange from +Z:	$V(F_{+Z}) = 90.0060°$

From these values we find:

Inclination of flange wrt. CVVRC4 on +Y side:

$\Delta V(+Y) = V(F_{+Y}) - V(RC4_{+Y}) = 90.0044 - 90.3331 = -0.3287°$.

This implies inclination of flange wrt. CVVRC4 on –Y side:

$\mathbf{\Delta V(-Y) = V(F_{-Y}) - V(RC4_{-Y}) = +0.3287°}$ **(1a)**

With the new measurements of V (CVVRC4 +Y) and V(CVVRC1 -Y), the flange plane from –Y side can then be given by:

$$\mathbf{V(F_{-Y}) = V(CVVRC1_{-Y}) - [V(CVVRC1_{-Y}) - (180° - VCVVRC4_{+Y})] + \Delta V(-Y)}$$

$$\mathbf{V(F_{-Y}) = V(CVVRC1_{-Y}) - [V(CVVRC1_{-Y}) - (180° - VCVVRC4_{+Y})] + 0.3287° \quad (1b)}$$

The inclination of the telescope cube on –Y side can then be directly referenced to this flange inclination on –Y side, thus providing a direct comparison with the alignment of the instrument wrt. the flange plane.

The relation between the involved quantities V(CVVRC1); V(CVVRC4) and V(Flange) are shown in Fig. 8-1. Fig. 8-2 shows the mathematical relation.

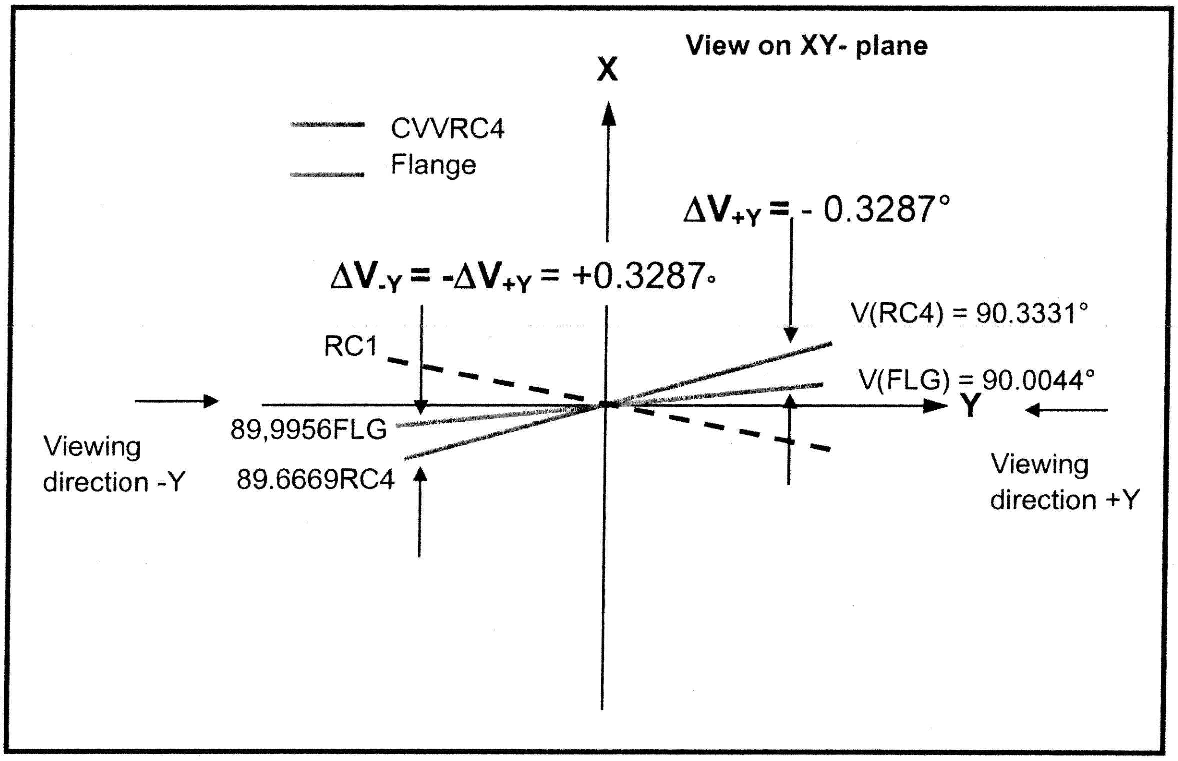
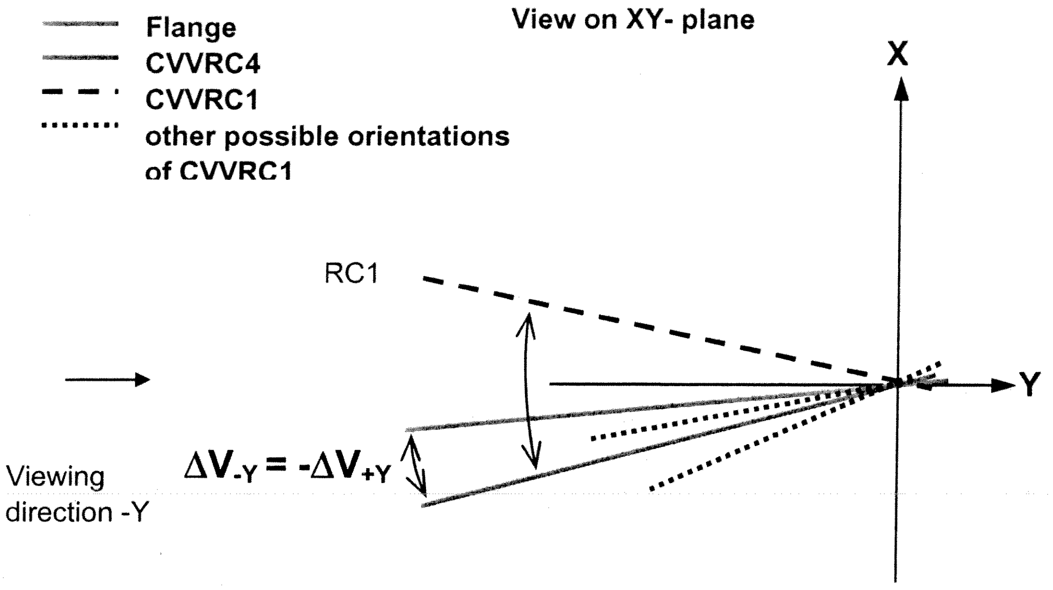


Figure 8-1: Deriving the orientation of the UB flange plane on –Y side:

a) Relation between V measurements of CVVRC4 on +Y side, of CVVRC1 on –Y side and Flange UB plane. ΔV is derived from measurements compiled in RD 9.

This figure is analogously valid for the relations on –Z side.



$$V(FLG_{-Y}) = V(RC1_{-Y}) - [V(RC1_{-Y}) - V(RC4_{-Y})] + \Delta V_{-Y}$$

Figure 8-2: Computation of the orientation of the UB flange plane on –Y side:

b) Computation of the orientation of the UB flange plane from measurements of CVVRC4 on +Y side and CVVRC1 on –Y side. ΔV_{-Y} is derived from measurements compiled in RD 9.

This figure is analogously valid for the relations on –Z side.

Analogous to the above, we find the inclination of the flange wrt. CVVRC2 on -Z side:

Flange inclination on +Z side $V(F_{+Z})$ = 90.0060° implies
$V(F_{-Z})$ = 180° - 90.0060° = 89.9940°.

With V(CVVRC2 –Z) = 90.0300° the inclination to the flange then becomes

$$\Delta V(-Z) = V(F_{-Z}) - V(VCCRC2_{-Z}) = 89.9940° - 90.0300° = -0.0360° \quad (2a)$$

With the new measurements of V ($CVVRC2_{-Z}$) and V($CVVRC1_{-Z}$), the flange plane from –Z side can then be given by:

$$V(F_{-Z}) = V(CVVRC1_{-Z}) - [V(CVVRC1_{-Z}) - VCVVRC2_{-Z})] + \Delta V(-Z)$$

$$V(F_{-Z}) = V(CVVRC1_{-Z}) - [V(CVVRC1_{-Z}) - VCVVRC2_{-Z})] - 0.0360° \quad (2b)$$

The inclination of the telescope cube on –Z side can then be directly referenced to this flange inclination on –Z side, thus providing a direct comparison with the alignment of the instrument wrt. the flange plane.

The above Figures 8-1 and 8-2 are analogously valid for the relations in the XZ plane. Here, the involved quantities are V(CVVRC1$_{-Z}$); V(CVVRC2$_{-Z}$) and V(Flange$_{-Z}$).). Again, the quantity ΔV(-Z) is derived from RD 9.

NOTE:

Upon calculating the above values for the CVV-flange inclinations V(F$_{-Y}$) and V(F $_{-Z}$) it has to made sure, that the sequences as given in relations (1a, b) and (2a, b) above are maintained and that the signs are appropriately considered.

9 Alignment Procedures Step by Step

This chapter describes the necessary steps to perform the measurements as described in chapter

All measured values will be recorded in dedicated tables of the subsequent sections. If not stated otherwise, each measurement shall be performed three times and the related mean value will be calculated.

9.1 Alignment Reference Table

The angle and distance measurements as described in this Section shall be performed for each alignment reference as listed in Table 9-1.

	Alignment Reference	Required Measurements		Measured from
		Rotations	Translations	
1	**CVVRC1**	**Rx, Ry** **Rx, Rz** **Rx, Rz**	**TX, Ty** **TX, Tz** **Tx, Tz**	**-z** **+y** **-y**
2	**CVVRC2**	**Rx, Ry**	**Tx, Ty**	**-z**
3	CVVRC3	Rx, Rz	Tx, Tz	+y
4	**CVVRC4**	**Rx, Rz**	**Tx, Tz**	**+Y**
5	TMS	Rx, Ry Rx, Rz	Tx, Ty Tx, Tz	-z +y
6	**TelescRC1(-y/+z)**	**Rx, Rz**	**Tx, Tz**	**-y**
7	TelescRC2(-y/-z)	Rx, Rz	Tx, Tz	-y
8	**TelescRC3(-z/-y)**	**Rx, Ry**	**Tx, Ty**	**-z**
9	TelescRC4(-z/+y)	Rx, Ry	Tx, Ty	-z

Table 9-1: Alignment Reference Identification

See also schematic in Fig. 9-1.

Rx, Ry, Rz = Rotations about x, y, z

Tx, Ty, Tz = Translations along x, y, z.

Note. Not all of the above listed measurements of reference cubes are really mandatory. Therefore, the following references shall be nominally measured: CVVRC1, CVVRC2, CVVRC4, Telescope RC1, Telescope RC3 (typed bold in Fig. 9-1).

Other cubes CVVRC3, TMS-RC, and Telescope RC2 and Telescope RC 4 shall only be measured in case of anomaly (to be decided during the measurement).

9.2 Alignment Measurements Configuration

The following Figure 9-1 shows the principle arrangement of the measurement set up. The ATP required for measurements of orientations has to be placed at specific points, accessible from the necessary theodolite positions. The ATP positions are denominated ATP1, ATP2 and ATP3 and only mean the ATP positions, not the number of used ATPs. Usually, one ATP will always be installed as primary reference ATP1 (for easy access at all times, e.g. for quick checks of other positions). Auxiliary references ATP2 and ATP3 will only be used temporarily.

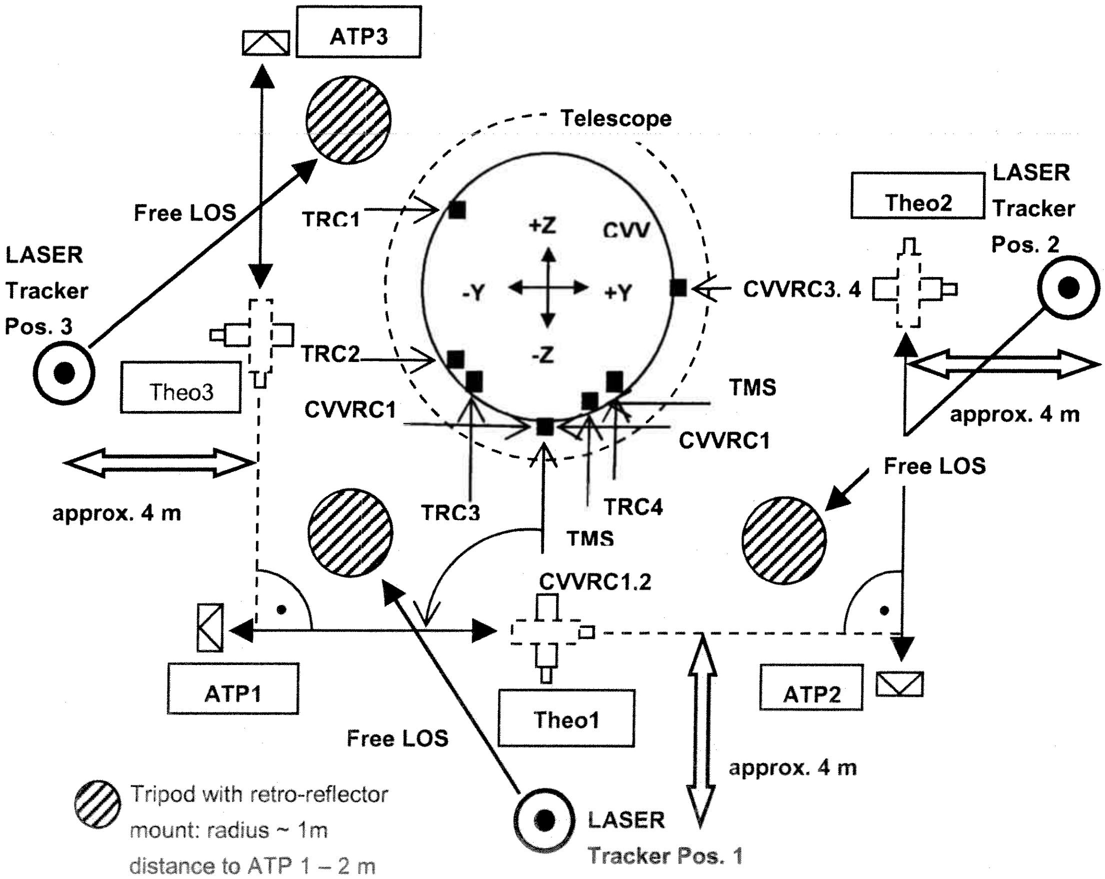


Figure 9-1: Alignment Measurement Configuration

ATP1 is primary reference, defined by the normal of CVVRC 1.
Auxiliary references ATP2 and ATP3 are defined by orthogonality to the line Theo1 – ATP1.
The retro-reflectors in combination with the ATP serve for azimuth reference of laser tracker Rot X measurements. The reference for elevation measurements (Rot Y, Rot Z) is the internal gravity direction of the laser tracker.

9.3 Orientation Measurement of CVV and Telescope Reference Cubes

The following section gives a detailed description of all steps to be performed.

Note: The distance measurements are made with the ESA laser tracker. This means that these measurements could be made together with the orientation measurements (same set-up). However, the measured values shall be recorded in the foreseen tables of Section 9.4.

Steps marked as "**Measurement not mandatory! Continue . . . .** " shall be omitted, except anomalies require otherwise. Necessity of measurement then to be decided from case to case.

Step No.	Activity — Legend: P, N: step performed, not performed	P	N
1.	Install the theodolite in front of CVVRC1 –Z side and perform horizontal adjustment according to instrument manual.	✓	
2.	Set theodolite in autocollimation with CVVRC1 and set Hz = 0.0000 deg.	✓	
3.	Rotate theodolite 90. 0000 de to the left such that Hz = 270.0000 deg is reached.	✓	
4.	Set up ATP as ATP1 such that theodolite at Hz = 270.0000 deg reaches autocollimation with ATP1.	✓	
5.	Rotate theodolite back to autocollimation with CVVRC1 – z side and check that Hz = 0.0000 ± 0.0028 deg. If this is not the case, repeat steps 2 – 5.	✓	
6.	Record the following values:	✓	

CVVRC1 –Z side				Mean
Hz =	359.9997 deg	0.0000 deg	359.9998 deg	359.9998 deg
V =	89.9268 deg	89.9269 deg	89.9267 deg	89.9268 deg

Operator: D. Schink	Product Assurance: [signature]	Date: 24.04.08

Step No.	Activity — Legend: P, N: step performed, not performed	P	N
7.	Install the theodolite in front of CVVRC2 –Z side and perform horizontal adjustment according to instrument user manual.	✓	
8.	Set theodolite in autocollimation with ATP1 and set Hz = 270.0000 deg.	✓	
9.	Rotate theodolite to CVVRC2 –z side, achieve autocollimation and record the following values:	✓	

CVVRC2 -Z side				Mean
Hz =	359.7522 deg	359.7521 deg	359.7523 deg	359.7522 deg
V =	89.9273 deg	89.9267 deg	89.9268 deg	89.9269 deg

10.	**Measurement not mandatory! Continue with step 14.** Install the theodolite in front of TMS-RC –Z side and perform horizontal adjustment according to instrument manual.		✓
11.	Set theodolite in autocollimation with ATP1 and set Hz = 270.0000 deg.		✓
12.	Rotate theodolite to TMS-RC –z side, achieve autocollimation and record the following values:		✓

TMS-RC –Z side **Measurement not mandatory!**				Mean
Hz =	deg	deg	deg	deg
V =	deg	deg	deg	deg

13.	Check ATP1 position: Hz(ATP1) = 269.9999 deg Time: 24.04.08 18.20	✓	

Operator: D. Schick	Product Assurance: [signature]	Date: 24.04.08

Step No.	Activity — Legend: P, N: step performed, not performed	P	N
14.	Install the theodolite in front of TRC3 –Z side and perform horizontal adjustment according to instrument user manual.	✓	
15.	Set theodolite in autocollimation with ATP1 and set Hz = 270.0000 deg.	✓	
16.	Rotate theodolite to TRC3 –z side, achieve autocollimation and record the following values:	✓	

TRC3 -Z side				Mean
Hz =	359.6506 deg	359.6510 deg	359.6522 deg	359.6513 deg
V =	90.1895 deg	90.1897 deg	90.1896 deg	90.1896 deg

17.	**Measurement not mandatory! Continue with step 21.** Install the theodolite in front of TRC4 –Z side and perform horizontal adjustment according to instrument user manual.		✓
18.	Set theodolite in autocollimation with ATP1 and set Hz = 270.0000 deg.		✓
19.	Rotate theodolite to TRC4 –z side, achieve autocollimation and record the following values:		✓

TRC4 -Z side **Measurement not mandatory!**				Mean
Hz =	deg	deg	deg	deg
V =	deg	deg	deg	deg

20.	Check ATP1 position: Hz(ATP1) = 269.9999 deg Time: 18.40	✓	

Operator: D. Schink	Product Assurance: [signature]	Date: 24.04.08

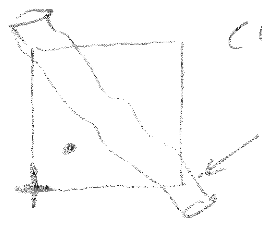
Step No.	Activity Legend: P, N: step performed, not performed	P	N
21.	Set up theodolite close to point ATP2, adjust horizontal according to instrument user manual.	✓	
22.	Achieve autocollimation with ATP1 and set Hz = 0.0000 deg.	✓	
23.	Rotate theodolite to the left through 90.0000 deg such that Hz = 270.0000 deg is reached.	✓	
24.	Set up ATP as ATP 2 such that theodolite is in autocollimation with ATP2.	✓	
25.	Install theodolite at position Theo2 according to fig 9-1 such that ATP2 as well as reference cubes at +y side can be viewed in autocollimation from this side.	✓	
26.	**Measurement not mandatory! Continue with step 29.** Install the theodolite in front of CVVRC3 +Y side and perform horizontal adjustment according to instrument manual.	✓	
27.	Set theodolite in autocollimation with ATP2 and set Hz = 270.0000 deg.	✓	
28.	Rotate theodolite to CVVRC3, achieve autocollimation and record the following values:	✓	

CVVRC3 +Y side **Measurement not mandatory!**				Mean	ATP 2
Hz =	359.4942 deg	359.4937 deg	359.4938 deg	359.4940 deg	270.0004
V =	90.1041 deg	90.1039 deg	90.1038 deg	90.1039 deg	
CVVRC1 +Y side				Mean	ATP 2
Hz =	0.0028	0.0029	0.0029	0.0029	270.0006
V =	90.0542	90.0539	90.0537	90.0539	
CVVRC2 +Y side				Mean	ATP 2
Hz =	359.7512	359.7507	359.7508	359.7509	269.9997
V =	90.0357	90.0358	90.0354	90.0356	

Operator: D. Schulte	Product Assurance: [illegible]	Date: 25.4.08

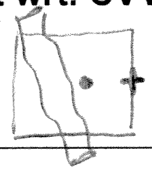
• Autokollimation

+ Distance



CVVRC2 +Y

Harnell



Step No.	Activity Legend: P, N: step performed, not performed	P	N
29.	Install the theodolite in front of CVVRC4 + Y side and perform horizontal adjustment according to instrument manual.	✓	
30.	Set theodolite in autocollimation with ATP2 and set Hz = 270.0000 deg.	✓	
31.	Rotate theodolite to CVVRC4, achieve autocollimation and record the following values:	✓	

CVVRC4 +Y side				Mean
Hz =	359.7425 deg	359.7423 deg	359.7426 deg	359.7425 deg
V =	90.3646 deg	90.3648 deg	90.3650 deg	90.3648 deg

32.	**Measurement not mandatory! Continue with step 36.** Install the theodolite in front of TMSRC +Y side and perform horizontal adjustment according to instrument manual.		✓
33.	Set theodolite in autocollimation with ATP2 and set Hz = 270.0000 deg.		✓
34.	Rotate theodolite to TMSRC + y, achieve autocollimation and record the following values:		✓

TMS-RC +Y side **Measurement not mandatory!**				Mean
Hz =	deg	deg	deg	deg
V =	deg	deg	deg	deg

35.	Check ATP2 position: Hz(ATP2) = 270.0006 deg Time: 17:40	✓	

Operator: D. Schick	Product Assurance: [illegible]	Date: 25.4.08

Step No.	Activity Legend: P, N: step performed, not performed	P	N
36.	Set up theodolite close to point ATP1, adjust horizontal according to instrument user manual.	✓	
37.	Achieve autocollimation with ATP1 and set Hz = 0.0000 deg.	✓	
38.	Rotate theodolite to the right through 90.0000 deg such that Hz = 90.0000 deg is reached.	✓	
39.	Set up ATP as ATP 3 such that theodolite is in autocollimation with ATP3.	✓	
40.	Install theodolite at position Theo3 according to fig 9-1 such that ATP3 as well as reference cubes at -y side (TRC1, TRC2 and CVVRC1) can be viewed in autocollimation from this side.	✓	
41.	Install the theodolite in front of CVVRC1 –Y side and perform horizontal adjustment according to instrument manual.	✓	
42.	Set theodolite in autocollimation with ATP3 and set Hz = 270.0000 deg.	✓	
43.	Rotate theodolite to CVVRC1, achieve autocollimation and record the following values:	✓	

CVVRC1 -Y side				Mean
Hz =	0.0042 deg	0.0043 deg	0.0042 deg	0.0042 deg
V =	89.9446 deg	89.9449 deg	89.9455 deg	89.9450 deg

Check APP3 Hz = 270.0004 deg 25.4.08 / 11:40

Operator: D. Schück	Product Assurance:	Date: 25.4.08

Step No.	Activity — Legend: P, N: step performed, not performed	P	N
44.	Install the theodolite in front of TRC1 –Y side and perform horizontal adjustment according to instrument manual.	✓	
45.	Set theodolite in autocollimation with ATP3 and set Hz = 270.0000 deg.	✓	
46.	Rotate theodolite to TRC1, achieve autocollimation and record the following values:	✓	

TRC1 -Y side				Mean
Hz =	0.3926 deg	0.3925 deg	0.3927 deg	0.3926 deg
V =	90.1792 deg	90.1792 deg	90.1787 deg	90.1790 deg

ATP 3
270.0004

Step No.	Activity	P	N
47.	**Measurement not mandatory! Continue with step 51.** Install the theodolite in front of TRC2 –Y side and perform horizontal adjustment according to instrument manual.		✓
48.	Set theodolite in autocollimation with ATP3 and set Hz = 270.0000 deg.		✓
49.	Rotate theodolite to TRC2, achieve autocollimation and record the following values:		✓

TRC2 -Y side **Measurement not mandatory!**				Mean
Hz =	deg	deg	deg	deg
V =	deg	deg	deg	deg

50.	Check ATP3 position: Hz(ATP3) = 270.0004 deg Time: 25.4.08 / 14.10	✓	

Operator: D. Schick	Product Assurance: D. [signature]	Date: 25.4.08

9.4 Position Measurements of Reference Cubes

For the distance measurements, the ESA laser tracker will be used.

Step No.	Activity — Legend: P, N: step performed, not performed	P	N
51.	Install large tripod on the –Z side of the S/C such that CVVRC1 (-Z), CVVRC2(–Z), TRC3 and TRC4, TMS-RC(-Z) can be viewed from this side.	✓	
52.	Set theodolite horizontal according to user manual, direct theodolite towards ATP1 and achieve autocollimation, set Hz = 270.000 deg.	✓	
53.	Rotate theodolite back to 0.0000 deg, adjust V = 90.0000 deg and adjust theodolite laterally to centre of **CVVRC1** reticle. Perform laser tracker measurement and record the following values:	✓	

CVVRC1 –Z side **Reference value for meas. on –Z side**				Mean
X	mm	mm	mm	mm
Y	mm	mm	mm	mm

Data recorded in separate File
see attachment

Operator: D. Schink	Product Assurance: [signature]	Date: 24.04.08

A. Tavarei

Step No.	Activity Legend: P, N: step performed, not performed	P	N
54.	Shift theodolite to TRC3 –Z side.	✓	
55.	Set theodolite horizontal according to user manual, direct theodolite towards ATP1 and achieve autocollimation, set Hz = 270.000 deg.	✓	
56.	Rotate theodolite back to 0.0000 deg, adjust V = 90.0000 deg and adjust theodolite laterally to centre of **TRC3** reticle. Perform laser tracker measurement and record the following values:	✓	

TRC3 –Z side	CVVRC1-Z is reference			Mean
X	mm	mm	mm	mm
Y	mm	mm	mm	mm

Data recorded in separate file see attachment

57.	**Measurement not mandatory! Continue with step 63.** Shift theodolite to TRC4 –Z side.		✓
58.	Set theodolite horizontal according to user manual, direct theodolite towards ATP1 and achieve autocollimation, set Hz = 270.000 deg.		✓
59.	Rotate theodolite back to 0.0000 deg, adjust V = 90.0000 deg and adjust theodolite laterally to centre of **TRC4** reticle. Perform laser tracker measurement and record the following values:		✓

TRC4 –Z side	CVVRC1-Z is reference			Mean
X	mm	mm	mm	mm
Y	mm	mm	mm	mm

Operator: D. Schink	Product Assurance: [signature]	Date: 24.04.08

A. Tavares

Step No.	Activity — Legend: P, N: step performed, not performed	P	N
60.	**Measurement not mandatory! Continue with step 63** Shift theodolite to TMS-RC –Z side.		✓
61.	Set theodolite horizontal according to user manual, direct theodolite towards ATP1 and achieve autocollimation, set Hz = 270.000 deg.		✓
62.	Rotate theodolite back to 0.0000 deg, adjust V = 90.0000 deg and adjust theodolite laterally to centre of **TMS-RC** reticle. Perform laser tracker measurement and record the following values:		✓

TMS-RC –Z side	CVVRC1-Z is reference			Mean
X	mm	mm	mm	mm
Y	mm	mm	mm	mm

63.	Shift theodolite to CVVRC2 –Z side.	✓	
64.	Set theodolite horizontal according to user manual, direct theodolite towards ATP1 and achieve autocollimation, set Hz = 270.000 deg.	✓	
65.	Rotate theodolite back to 0.0000 deg, adjust V = 90.0000 deg and adjust theodolite laterally to centre of **CVVRC2** reticle. Perform laser tracker measurement and record the following values:	✓	

CVVRC2 –Z side	CVVRC1-Z is reference			Mean
X	mm	mm	mm	mm
Y	mm	mm	mm	mm

Data recorded in separate file, see attachment

66.	Check ATP 1 position:	✓	

Operator: D. Schink	Product Assurance: ? [signature]	Date: 24.04.08

A. Tavares

For the distance measurements, the ESA laser tracker will be used.

Step No.	Activity Legend: P, N: step performed, not performed	P	N
67.	Install large tripod on the +Y side of the S/C such that CVVRC1 (+Y), CVVRC3(+Y), CVVRC4(+Y), TMS-RC(+Y) can be viewed from this side.	✓	
68.	Set theodolite horizontal according to user manual, direct theodolite towards ATP2 and achieve autocollimation, set Hz = 270.000 deg.	✓	
69.	Rotate theodolite back to 0.0000 deg, adjust V = 90.0000 deg and adjust theodolite laterally to centre of **CVVRC1** reticle. Perform laser tracker measurement and record the following values:	✓	

CVVRC1 +Y side **Reference value for meas. on +Y side**				Mean
X	mm	mm	mm	mm
Z	mm	mm	mm	mm

Data recorded in separate file, see attachment

70.	**Measurement not mandatory! Continue with step 73.** Shift theodolite to CVVRC3 +Y side.	✓	
71.	Set theodolite horizontal according to user manual, direct theodolite towards ATP2 and achieve autocollimation, set Hz = 270.000 deg.	✓	
72.	Rotate theodolite back to 0.0000 deg, adjust V = 90.0000 deg and adjust theodolite laterally to centre of **CVVRC3** reticle. Perform laser tracker measurement and record the following values:	✓	

CVVRC3 +Y side CVVRC1+Y is reference				Mean
X	mm	mm	mm	mm
Z	mm	mm	mm	mm

Data recorded in separate file, see attachment

Operator: D. Schink	Product Assurance: [signature]	Date: 25.04.08

A. Tavares

Step No.	Activity Legend: P, N: step performed, not performed	P	N
73.	Shift theodolite to CVVRC4 +Y side.	✓	
74.	Set theodolite horizontal according to user manual, direct theodolite towards ATP2 and achieve autocollimation, set Hz = 270.000 deg.	✓	
75.	Rotate theodolite back to 0.0000 deg, adjust V = 90.0000 deg and adjust theodolite laterally to centre of **CVVRC4** reticle. Perform laser tracker measurement and record the following values:	✓	

CVVRC4 +Y side CVVRC1+Y is reference				Mean
X	mm	mm	mm	mm
Z	mm	mm	mm	mm

Data recorded in separate file, see attachment

76.	**Measurement not mandatory! Continue with step 80.** Shift theodolite to TMS-RC +Y side.		✓
77.	Set theodolite horizontal according to user manual, direct theodolite towards ATP2 and achieve autocollimation, set Hz = 270.000 deg.		✓
78.	Rotate theodolite back to 0.0000 deg, adjust V = 90.0000 deg and adjust theodolite laterally to centre of **TMS-RC** reticle. Perform laser tracker measurement and record the following values:		✓

TMS-RC +Y side CVVRC1+Y is reference				Mean
X	mm	mm	mm	mm
Z	mm	mm	mm	mm

79.	Check ATP2 position:	✓	

Operator: D. Schink	Product Assurance: [signature]	Date: 25.04.08

A. Taverer

Step No.	Activity Legend: P, N: step performed, not performed	P	N
80.	Install large tripod on the –Y side of the S/C such that CVVRC1 (-Y), TRC1 and TRC2 can be viewed from this side.	✓	
81.	Set theodolite horizontal according to user manual, direct theodolite towards ATP3 and achieve autocollimation, set Hz = 270.000 deg.	✓	
82.	Rotate theodolite back to 0.0000 deg, adjust V = 90.0000 deg and adjust theodolite laterally to centre of **CVVRC1** reticle. Perform laser tracker measurement and record the following values:	✓	

CVVRC1 –y side **Reference value for meas. on -Y side**				Mean
X	mm	mm	mm	mm
Z	mm	mm	mm	mm

Data recorded in separate file, see attachment

83.	Shift theodolite to TRC1 -Y side.	✓	
84.	Set theodolite horizontal according to user manual, direct theodolite towards ATP3 and achieve autocollimation, set Hz = 270.000 deg.	✓	
85.	Rotate theodolite back to 0.0000 deg, adjust V = 90.0000 deg and adjust theodolite laterally to centre of **TRC1** reticle. Perform laser tracker measurement and record the following values:	✓	

TRC1 -Y side CVVRC1-Y is reference				Mean
X	mm	mm	mm	mm
Z	mm	mm	mm	mm

Data recorded in separate file, see attachment

Operator: D. Schick	Product Assurance: [signature]	Date: 25.04.08

A. Tavarez

Step No.	Activity Legend: P, N: step performed, not performed	P	N
86.	**Measurement not mandatory! End of measurements.** Shift theodolite to TRC2 -Y side.		✓
87.	Set theodolite horizontal according to user manual, direct theodolite towards ATP3 and achieve autocollimation, set Hz = 270.000 deg.		✓
88.	Rotate theodolite back to 0.0000 deg, adjust V = 90.0000 deg and adjust theodolite laterally to centre of **TRC2** reticle. Perform laser tracker measurement and record the following values:		✓

TRC2 -Y side	CVVRC1-Y is reference			Mean
X	mm	mm	mm	mm
Z	mm	mm	mm	mm

89.	Check ATP3 position:	✓	

9.5 Measurement Summary

The following tables contain all essential measurement values collected from previous sections. Measured values are compared to nominal ones and decision on success of measurements is made.

Table 9-2: Angle Measurements of Reference Cubes

Cube		Measured Value * [deg]	Remark
CVVRC1	-y face	Hz = 0.0042 V = 89.9450	
	-z face	Hz = 359.9998 V = 89.9268	
	+y face	Hz = 0.0029 V = 90.0539	
CVVRC2	- z face	Hz = 359.7522 V = 89.9269	+y face Hz = 359.7509 V = 90.0356
CVVRC3	+y face	Hz = 359.4940 V = 90.1039	
CVVRC4	+y face	Hz = 359.7425 V = 90.3648	
TRC1	-y face	Hz = 0.3926 V = 90.1790	
TRC2	-y face	Hz = V =	Not mandatory
TRC3	-z face	Hz = 359.6513 V = 90.1896	
TRC4	-z face	Hz = V =	Not mandatory
TMS-RC	–z face	Hz = V =	Not mandatory
	+ y face	Hz = V =	

* Theodolite readings

Table 9-3: CVV-Flange Orientations as per Sect. 8.3

	[deg]	remark
V(F–Y) wrt. CVVRC4		As per (1b) sect. 8.3
V(F-Z) wrt. CVVRC2		As per (2b) sect. 8.3

Table 9-4: Comparison Telescope and Flange Inclinations

Comparison of Corrected Angle Measurements and Nominal Orientations			
Cube	Nominal Value* V (Telescope) [deg]	V(Telesc.) – V(F) = Diff 1 [arcsec]	Success Criterion: [arcsec] / [deg]
TRC1 -y	**90.2175**		**Diff 1 < 90 / 0.0250**
TRC2 -y	**90.1481**		**Diff 1 < 90 / 0.0250**
TRC3 -z	**90.2856**		**Diff 1 < 90 / 0.0250**
TRC4 -z	**90.2581**		**Diff 1 < 90 / 0.0250**

* as per AD 4 theodolite readings

Table 9-5: Nominal values for cube linear separations from CVVRC1.
For comparison with measurements.

Nominal Separations of CVV and TMS Reference Cubes from CVVRC1				
	ΔX [mm]	ΔY [mm]	ΔZ [mm]	Remark
CVVRC2	-578.5	-5.5	---	ΔZ not measured
CVVRC3	0.00	---	973.5	ΔY not measured
CVVRC4	-578.5	---	1045.5	ΔY not measured
TMS RC -z face +y face	 974.6 974.6	 170.2 ---	 --- 25.0	 ΔZ not measured ΔY not measured
TRC1	1536.8	---	1323.3	ΔY not measured
TRC2	1536.7	---	621.1	ΔY not measured
TRC3	1536.9	-429.8	--	ΔZ not measured
TRC4	1536.9	274.5	---	ΔZ not measured

Nominal positions: see Tab. 13-1.

Table 9-6: Measured values for cube linear separations from CVVRC1

	Measured Values [mm]	Measured – Nominal Val. [mm]	Success Criterion
CVVRC2	Δx Δy		N.A.
CVVRC3	Δx Δz		N.A.
CVVRC4	Δx Δz		N.A.
TMS RC -z face -z face +y face	 Δx Δy Δz		N.A.
TRC1	Δx Δz		< 1 mm < 1 mm
TRC2	Δx Δz		< 1 mm < 1 mm
TRC3	Δx Δy		< 1 mm < 1 mm
TRC4	Δx Δy		< 1 mm < 1 mm

Data recorded in separate file, see attachment

10 Procedure Variation/NCR Summary

10.1 Procedure Variation Summary

No.	Page	Variation Description	Action required
		None	

10.2 Non-Conformance Report (NCR) Summary

NCR No.	Non Conformance Description	Date generated	Originator	Date closed
HP-125400-ASED-NC-4214	During the telescope alignment measurement it was recognized that the results gained are doubtful at the first glance	28.04.05	Str: Hep	

10.3 Test Configuration Record

1. Facility: ESTEC Clean room 100 000
2. Model: Herschel PFM
3. Temperature: 20,6 °C
4. Humidity: 48.6 %
5. Test Start Date: 24.04.08 8.30
6. Test End Date: 25.04.08 17.55
7. Remarks:

Equipment used:

- Theodolite #4 F. Nr. 310455 for actual measurement
- Theodolite #2 F. Nr. 310471 for some ATP checks
- ATP Pos. 1 S. Nr. 47958
- APP Pos. 2+3 S. Nr. 69967

11 Alignment Sign-off Sheet

The alignment has been performed according to this procedure. Deviations from the procedure and/or from the sequence are noted in the procedure variation sheets. Non conformances are listed in the NCR-Summary sheets.

	Date	Signature
Alignment Engineer	25.04.08	D. Sch[illegible]
PA Responsible	25.04.08	[illegible]

12 Open Work Summary

No.	Page	Open Work Description	Closure Date
		No open work	

13 Annex 1: Position of Alignment Cubes (References)

This chapter gives an overview on the nominal positions of the PFM alignment references mounted at the HIFI FPU and the LOU.
From these nominal positions, we derive the nominal separations to be measured in the frame of this procedure. The nominal separations arte compiled in Table 9-5.

Table 13-1: Positions of Alignment References for CVV and Telescope

CVV and TMS Reference Cubes				
	X [mm]	Y [mm]	Z [mm]	Remark
CVVRC1				
-z face	2000.0	+77.5	---	Z not measured
+y face	2000.0	---	-973.5	Y not measured
-y face	2000.0	---	-973.5	Y not measured
CVVRC2 (z-face)	1421.5	+72.0	---	Z not measured
CVVRC3 (y-face)	2000.0	---	+0.0	Y not measured
CVVRC4 (y-face)	1421.5	---	+72.0	Y not measured
TMS RC				
-z face	2974.6	+247.0	---	Z not measured
+y face	2974.6	---	-948.4	Y not measured
Telescope Reference Cubes				
	X [mm]	Y [mm]	Z [mm]	Remark
TRC1 (-y face)	3536.8	---	+350.1	Y not measured
TRC2 (-y face)	3536.7	---	-352.1	Y not measured
TRC3 (-z face)	3536.9	-352.3	--	Z not measured
TRC4 (-z face)	3536.9	+352.0	--	Z not measured

Telescope bipod - I/f plane: X = 2974.6 mm

END OF DOCUMENT

	Name	Dep./Comp.		Name	Dep./Comp.
	Baldock Richard	FAE12	x	Schweickert Gunn	ASG23
	Barlage Bernhard	AED13	x	Sonn Nico	ASG51
x	Bayer Thomas	ASA42		Steininger Eric	AED32
	Brune Holger	ASA45	x	Stritter Rene	AED11
	Chen Bing	HE Space		Suess Rudi	OTN/ASA44
	Edelhoff Dirk	AED2		Theunissen Martijn	DSSA
	Fehringer Alexander	ASG13		Vascotto Riccardo	HE Space
x	Fricke Wolfgang Dr.	AED 65		Wagner Klaus	ASG23
	Geiger Hermann	ASA42	x	Wietbrock Walter	AET12
	Grasl Andreas	OTN/ASA44		Wöhler Hans	ASG23
	Grasshoff Brigitte	AET12		Wössner Ulrich	ASE252
	Hamer Simon	Terma		Zumstein Armin	ASQ42
	Hanka, Erhard	FI552	x	Hölzle	AED32
	Hendrikse Jeffrey	HE Space			
	Hendry David	Terma			
	Hengstler Reinhold	ASA42			
	Hinger Jürgen	ASG23			
x	Hohn Rüdiger	AED65			
	Hofmann Rolf	ASE252			
	Hopfgarten Michael	AED32			
	Huber Johann	ASA42			
	Hund Walter	ASE252			
	Idler Siegmund	AED312			
	Ivády von András	FAE12			
	Jahn Gerd Dr.	ASG23			
	Jolk Matthias	AET1	x	ESA/ESTEC	ESA
	Kalde Clemens	ASM2	x	Thales Alenia Space Cannes	TAS-F
	Klenke Uwe	ASG72		Thales Alenia Space Torino	TAS-I
	Koelle Markus	ASA43			
	Koppe Axel	AED312		**Instruments:**	
x	Kroeker Jürgen	AED65		MPE (PACS)	MPE
	La Gioia Valentina	Terma		RAL (SPIRE)	RAL
	Lang Jürgen	ASE252		SRON (HIFI)	SRON
X	Langenstein Rolf	AED15			
	Langfermann Michael	ASA41			
	Liberatore Danilo	Rhea		**Subcontractors:**	
	Martin Olivier	ASA43		Austrian Aerospace	AAE
	Maukisch Jan	ASA43		Austrian Aerospace	AAEM
	Much Christoph	ASA43		BOC Edwards	BOCE
	Müller Martin	ASA43		Dutch Space Solar Arrays	DSSA
	Pietroboni Karin	AED65		EADS Astrium Sub-Subsyst. & Equipment	ASSE
	Platzer Wilhelm	AED2		EADS CASA Espacio	CASA
	Reichle Konrad	ASA42		EADS CASA Espacio	ECAS
	Runge Axel	OTN/ASA44		European Test Services	ETS
	Sauer Maximilian Dr.	AED65		Patria New Technologies Oy	PANT
x	Schink Dietmar	AED32		SENER Ingenieria SA	SEN
	Schmidt Thomas	AED15		Thales Alenia Space, Antwerp	TAS-ETCA

Attachment to HP-2-ASED-TP-0113

Telescope position measurement with Laser Tracker and Theodolite

	Reference	Meeasured	Correction	Final	Expected	Delta
	from -z side					
	CVVRC1 CVVRC2					
Tx		-578,3			-578,5	0,2
Ty		-4,6			-5,5	0,9
Tz						
	CVVRC1 TRC3					
Tx		1536,3			1536,9	-0,6
Ty		-426,5			-429,8	3,3
Tz						
	CVVRC1 CVVRC4					
Tx						
Ty		919	25,1	893,9	894,3	-0,4
Tz						
	CVVRC2 TRC3					
Tx		2114,5			2115,4	-0,9
Ty		-421,9			-424,3	2,4
Tz						
	from -y side					
	CVVRC1 TRC1					
Tx		1536,9			1536,8	0,1
Ty						
Tz		1314,8			1323,9	-9,1
	from +y side					
	CVVRC1 CVVRC2					
Tx		-591,2	-12,5	-578,7	-578,5	-0,2
Ty						
Tz		-10,0	12,5	2,5	2,0	0,5
	CVVRC1 CVVRC3					
Tx		1,15			0	1,15
Ty						
Tz		979,4			973,8	5,6
	CVVRC1 CVVRC4					
Tx		-577,1			-578,5	1,4
Ty						
Tz		1060,0	-12,5	1047,5	1045,8	1,7
	CVVRC2 CVVRC4					
Tx		1,6			0	1,6
Ty						
Tz		1048,5			1043,8	4,7

These data do not reflect the final Telescope positional measurements. Please refer to NC-4214. The final positional measurements are given in: Herschel Telescope Alignment at S/C Level Measurement Evaluation Report HP-2-ASP-RP-1599 and is reflected in TR-0260

END OF DOCUMENT

	Name	Dep./Comp.		Name	Dep./Comp.
	Alberti von Mathias Dr.	ASG23		Schmidt Thomas	AED15
	Baldock Richard	FAE12		Schweickert Gunn	ASG23
	Barlage Bernhard	AED13	X	Sonn Nico	ASG51
X	Bayer Thomas	ASA42		Steininger Eric	AED32
	Brune Holger	ASA45	X	Stritter Rene	AED11
	Edelhoff Dirk	AED2		Suess Rudi	OTN/ASA44
	Fehringer Alexander	ASG13		Theunissen Martijn	DSSA
X	Fricke Wolfgang Dr.	AED 65		Vascotto Riccardo	HE Space
	Geiger Hermann	ASA42		Wagner Klaus	ASG23
	Grasl Andreas	OTN/ASA44	X	Wietbrock Walter	AET12
	Grasshoff Brigitte	AET12		Wöhler Hans	ASG23
	Hamer Simon	Terma		Wössner Ulrich	ASE252
	Hanka, Erhard	FI552		Zumstein Armin	ASQ42
	Hendrikse Jeffrey	HE Space			
	Hendry David	Terma			
	Hengstler Reinhold	ASA42			
	Hinger Jürgen	ASG23			
X	Hohn Rüdiger	AED65			
X	Hölzle Edgar Dr.	AED32			
	Hopfgarten Michael	AED32			
	Huber Johann	ASA42			
	Hund Walter	ASE252			
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X	Kettner Bernhard	AET42	X	Thales Alenia Space Cannes	TAS-F
	Klenke Uwe	ASG72		Thales Alenia Space Torino	TAS-I
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	La Gioia Valentina	Terma	X	SRON (HIFI)	SRON
	Lang Jürgen	ASE252			
X	Langenstein Rolf	AED15		**Subcontractors:**	
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	Martin Olivier	ASA43		Austrian Aerospace	AAE
	Maukisch Jan	ASA43		Austrian Aerospace	AAEM
	Much Christoph	ASA43		BOC Edwards	BOCE
	Müller Jörg	ASA42		Dutch Space Solar Arrays	DSSA
X	Müller Martin	ASA43		EADS Astrium Sub-Subsyst. & Equipment	ASSE
	Pietroboni Karin	AED65		EADS CASA Espacio	CASA
	Platzer Wilhelm	AED2		EADS CASA Espacio	ECAS
x	Reichle Konrad	ASA42		European Test Services	ETS
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	Sauer Maximilian Dr.	AED65		SENER Ingenieria SA	SEN
X	Schink Dietmar	AED32		Thales Alenia Space, Antwerp	TAS-ETCA