

Doc.No.: SOF-TAN-KT-1000.0.02 ✓

Issue No.: 1

Issue Date: 01.10.2002

Title: As Built Ray-Tracing Analysis

As Built Ray-Tracing Analysis

Assembly Identifier: OA

SOF-TAN-KT-1000.0.02


Issue: 1



Rev.: -

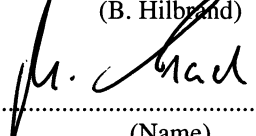
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Document Approval Sheet



Project: SOFIA
Document Title: As Built Ray-Tracing Analysis
Assembly Identifier: OA
Document Number: SOF-TAN-KT-1000.0.02
Issue: 1
Revision: -

Prepared:  Date: 1. 10. 2002
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Released:  Date: 
(M. Erhard)

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Document Change Record

Iss./Rev.	Date	DCN.-No.	Pages Affected
1	1. Oct. 02	First issue of document	all

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1 Scope

This document describes the analysis of the SOFIA as built optical ray-tracing analysis and the results.

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2 Documents

2.1 Applicable Documents

AD1 SOFIA Telescope Assembly Requirements Specification; NASA; SOF-1011 Revision 6

2.2 Reference Documents

RD1: SOFIA M1 Primary Mirror Acceptance Data Package, SOF-ADP-RC-001, Issue 1, 03.07.2002

RD2: Optical Assembly Description; SOF-SPE-KT-1000.0.03

RD3: Secondary Mirror Acceptance Data Package, SOF-ADP-MM-001

RD4: SOFIA M3 Acceptance Data Package, SOF-ADP-RC-002, Issue 1, 03.07.2002

RD5: TA Structure Optical Envelope Interface; SOF-ICD-KT-12; Issue 3, 14.12.1999

RD6: SOFIA PMA Acceptance Data Package; SOF-ADP-RC-001

RD7: Image Quality Budget; SOF-LIS-KT-0000.0.01

RD8: Response to PSR RID HIM-1; Presentation Acceptance Review, Kärcher 13.Sep.2002

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3 Abbreviations

E80 80% Encircled Energy Diameter

PSF Point Spread Function

WFE Wave Front Error

Z_n n th Zernike Coefficient (Fringe Notation)

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4 Introduction

This document describes the ray-tracing model of the SOFIA Telescope Assembly, and the analysis results of this model. The model compiles the results from the individual data packages (see RD1, RD3, and RD4). From each data package the following parameters were extracted and fed into the model:

- Primary Mirror
 - Radius of curvature as derived by Hartmann test
 - Conic constant as derived by Hartmann test
 - WFE of integrated mirror in cell
- Secondary Mirror
 - Dimension of optical surface (aperture stop size)
 - Radius of curvature
 - Conic constant
 - WFE
- Tertiary Mirror
 - WFE of integrated mirror

From these data to the following parameters are derived and reported:

- First order data of the telescope
 - Entrance pupil diameter at nominal focus
 - Entrance pupil diameters at the end of the specified focus range
 - Telescope focal length at nominal focus
 - Telescope focal length at the end of the specified focus range

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- Telescope f# at nominal focus
- Telescope f# at the end of the specified focus range
- WFE map at nominal focus 0°, 15°, 45°, 75° 90° elevation
- PSF of the telescope for 90° elevation and 0° elevation based on Zernike decomposition of all optical components
- Encircled energy performance at worst and best elevation

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5 Description of the Analysis

The data as described above were introduced into a ray-tracing model. WFE data were transferred by Zernike coefficients. The number of coefficients used was limited to describe the aberrations in an adequate way. For the Secondary Mirror for example 36 coefficients were used, as the mirror shows some higher order aberrations. The Dichroic mirror only shows primary aberrations, and therefore less Zernike were used to describe the wave front.

From the WFE measurement of the Primary Mirror the E80 contribution of the item was calculated directly from the wave front map. The SAGEM inhouse tool "Warp" was used for this calculation.

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6 Analysis Results

6.1 SOFIA Telescope First Order Data

Parameter	Value
Focal Length	
Nominal focus position	49084.5 mm
Back focal length +600 mm (longer)	53310.5 mm
Back focal length -600 mm (shorter)	44894.7 mm
Entrance Pupil Diameter	
Nominal focus position	2524.7 mm
Back focal length +600 mm	2510.8 mm
Back focal length -600 mm	2541.2 mm
F#	
Nominal focus position	19.4
Back focal length +600 mm	21.2
Back focal length -600 mm	17.7
Field of View (largest FoV without vignetting)	
(Max. FoV as limited by the Primary Mirror clear aperture)	
Nominal focus position	± 14.49 arcminutes
Back focal length +600 mm	± 15.68 arcminutes
Back focal length -600 mm	± 13.08 arcminutes

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First order data of TA are so close to the nominal design. Compliance with the clear optical path requirement based on this analysis is obvious (see also RD5 for the nominal clear optical path envelope).

6.2 SOFIA Telescope Image Performance at Nominal Focus Location

The WFE maps shown here are the maps of the integrated primary mirror. Compared to the WFE of the Primary Mirror, the contributors of the other optical elements are negligible. Their contribution is shown in the table in section 6.2.10.

6.2.1 WFE at 90° Elevation



WaRPP v 3.02 PRO

90° elevation

Date : 18/07/02

Heure : 13:28:44

Surface

L = 632,80 nm

R = 1350,000 nm

Résol. : 200x200

Echelle Lin. :

-836,521 nm à

841,789 nm

29204 points

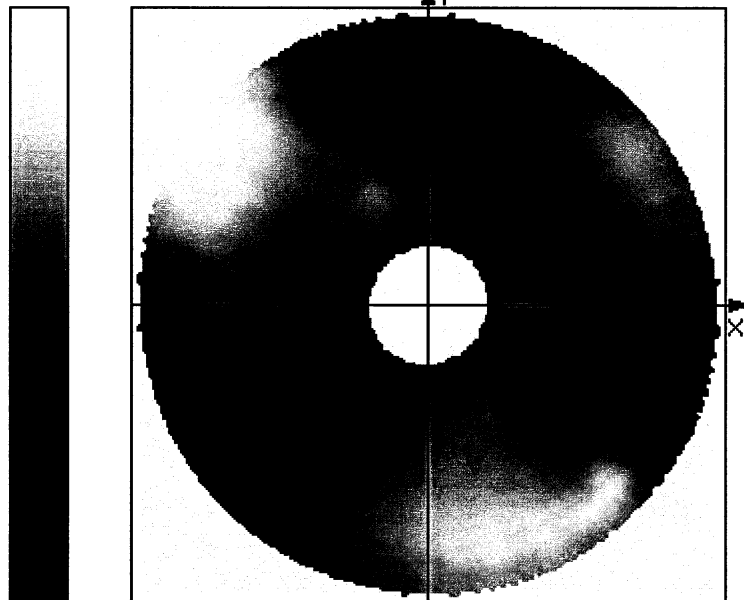
Min = -836,521 nm

Max = 841,789 nm

Moy = 6,152 nm

P-V = 1678,310 nm

RMS = 278,600 nm



X = -0.2938 Y = 0.1824 R = 0.3374 Z = 76.6524 nm

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6.2.2 WFE at 75° Elevation

REOSC
SAGEM

WaRPP v 3.02 PRO

75° elevation

Date : 18/07/02

Heure : 13:39:47

Surface

L = 632,80 nm

R = 1350,000 nm

Résol. : 200x200

Echelle Lin. :

-858,701 nm à

839,461 nm

28805 points

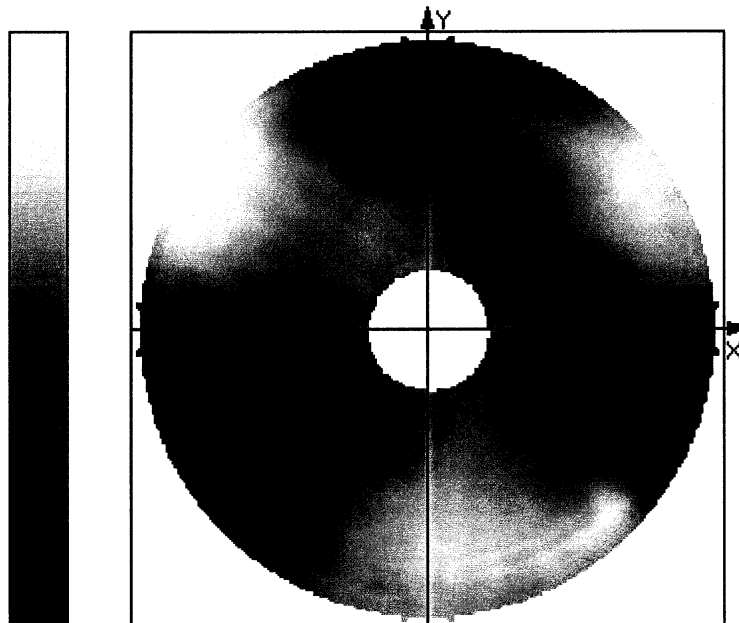
Min = -858,701 nm

Max = 839,461 nm

Moy = 0,746 nm

P-V = 1698,161 nm

RMS = 269,705 nm



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6.2.3 WFE at 45° Elevation

REOSC



WaRPP v 3.02 PRO

45° elevation

Date : 18/07/02

Heure : 13:33:26

Surface

L = 632,80 mm

R = 1350,000 mm

Résol. : 200x200

Echelle Lin. :

-806,530 nm à

809,470 nm

28805 points

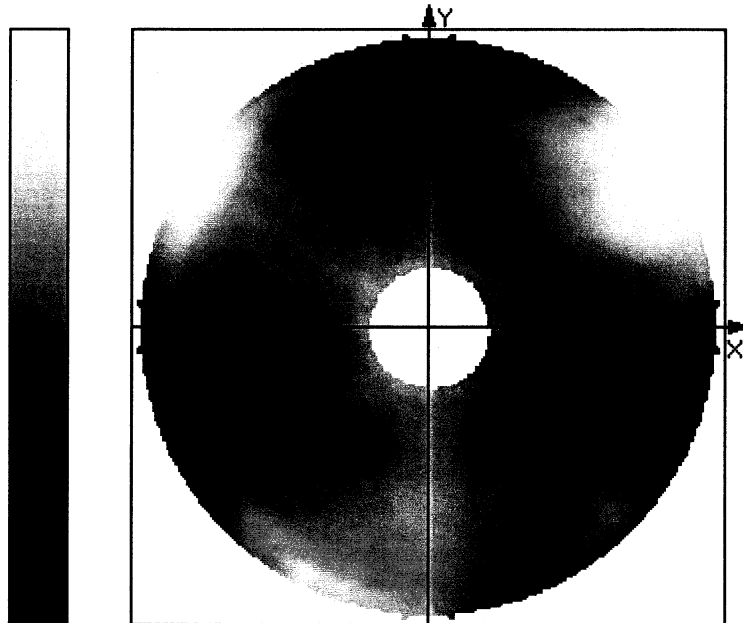
Min = -806,530 nm

Max = 809,470 nm

Moy = -6,752 nm

P-V = 1616,000 nm

RMS = 264,560 nm



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6.2.4 WFE at 15° Elevation

REOSC
 **SAGEM**

WaRPP v 3.02 PRO

15° elevation

Date : 18/07/02

Heure : 13:37:29

Surface

L = 632,80 nm

R = 1350,000 nm

Résol. : 200x200

Echelle Lin. :

-684,342 nm à

909,246 nm

28805 points

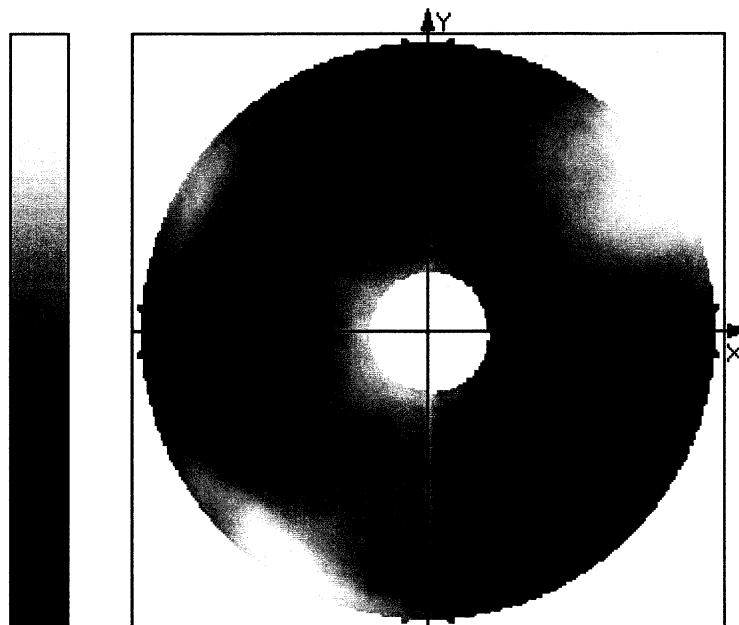
Min = -684,342 nm

Max = 909,246 nm

Moy = -12,435 nm

P-V = 1593,588 nm

RMS = 271,809 nm



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6.2.5 WFE at 0° Elevation

REOSC


WaRPP v 3.02 PRO

0° elevation

Date : 18/07/02

Heure : 13:21:13

Surface

L = 632,80 nm

R = 1350,000 nm

Résol. : 200x200

Echelle Lin. :

-704,074 nm à

910,284 nm

29221 points

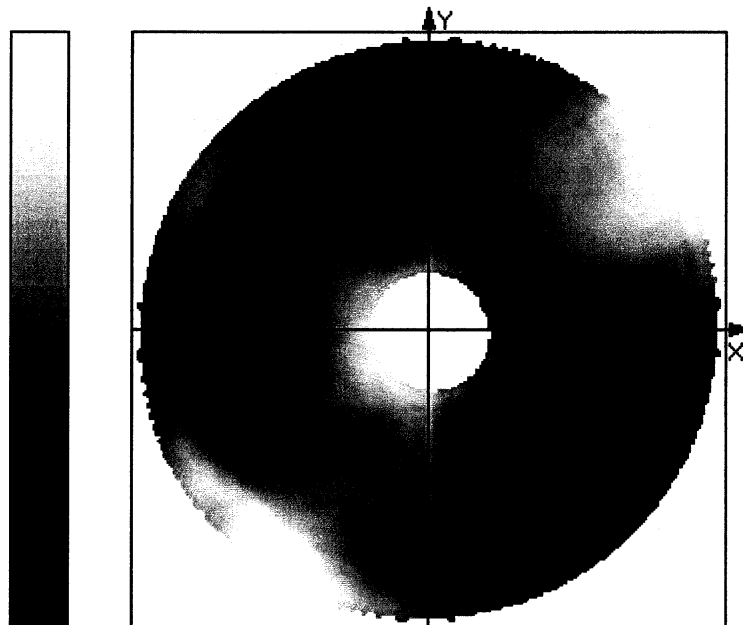
Min = -704,074 nm

Max = 910,284 nm

Moy = -8,285 nm

P-V = 1614,358 nm

RMS = 283,065 nm



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6.2.6 High Order WFE (Z1 to Z36 removed) in 90° Elevation

REOSC



WaRPP v 3.02 PRO

90° elevation

Date : 31/07/02

Heure : 19:28:54

Surface

L = 632,80 nm

R = 1350,000 mm

Résol. : 200x200

Echelle Lin. :

-287,624 nm à

335,019 nm

29204 points

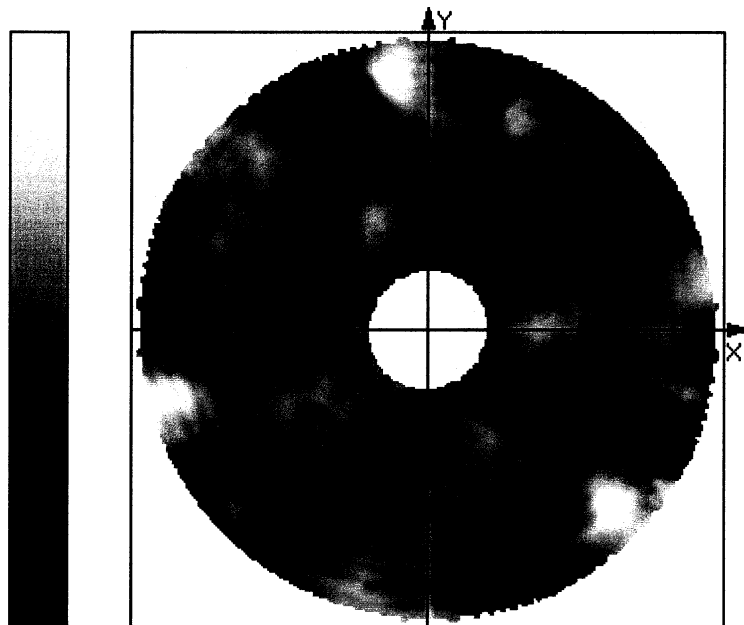
Min = -287,624 nm

Max = 335,019 nm

Moy = 0,000 nm

P-V = 622,643 nm

RMS = 72,287 nm



X = -0,2838 Y = 0,3649 R = 0,4622 Z = 9,8839 nm

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6.2.7 High Order WFE (Z1 to Z36 Removed) in 0° Elevation

REOSC
 **SAGEM**

WaRPP v 3.02 PRO

0° elevation

Date : 31/07/02

Heure : 19:30:27

Surface

L = 632,80 nm

R = 1350,000 nm

Résol. : 200x200

Echelle Lin. :

-401,242 nm à

278,427 nm

29221 points

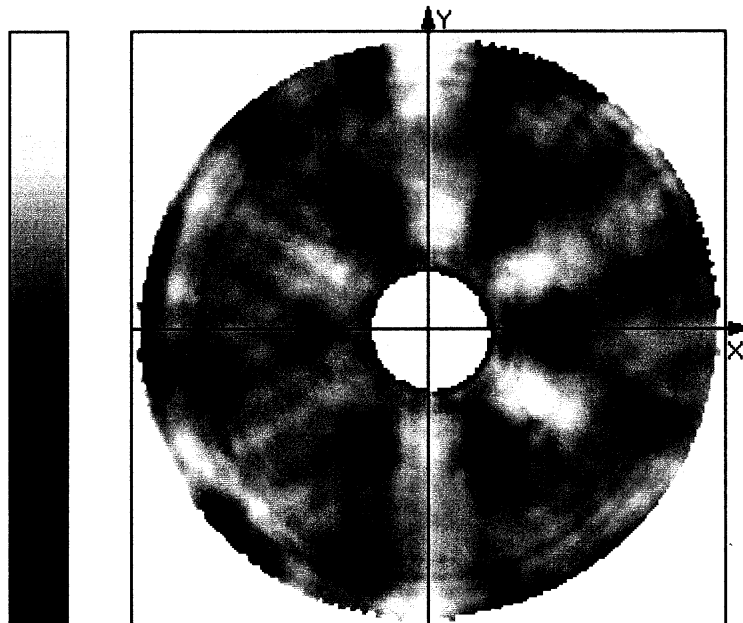
Min = -401,242 nm

Max = 278,427 nm

Moy = 0,000 nm

P-V = 679,669 nm

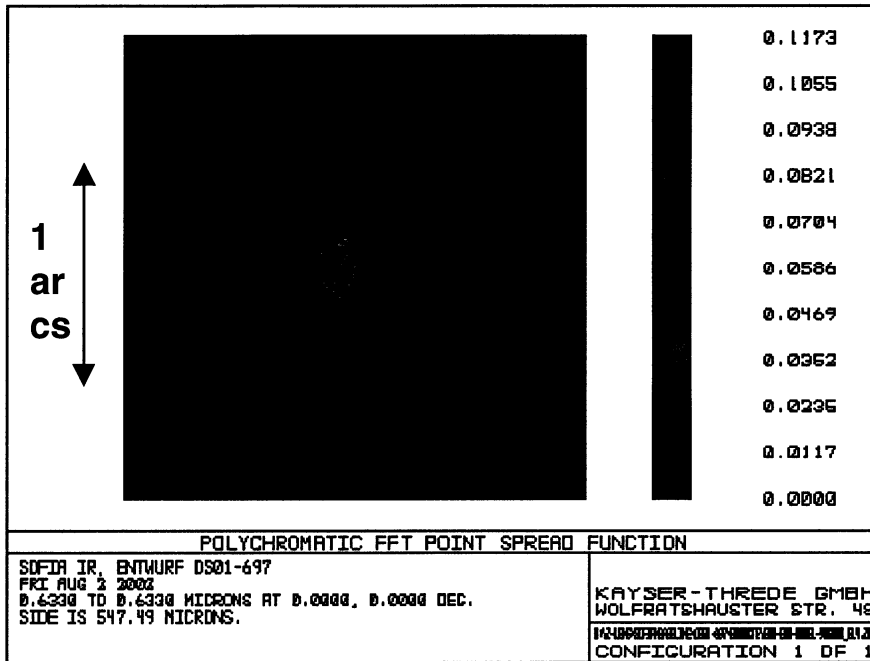
RMS = 72,739 nm



X = -0.8919 Y = 0.9865 R = 1.3299

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6.2.8 PSF at 0° Based on Z1 to Z36 of all Optical Elements



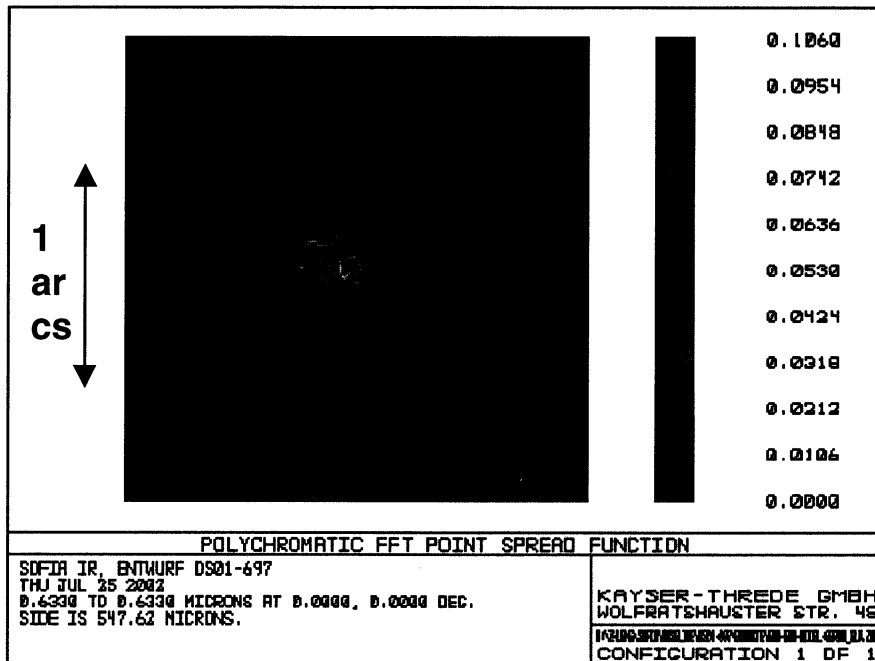
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6.2.9 PSF at 90° Elevation Based on Z1 to Z36 of all Optical Elements



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6.2.10 Performance Summary Telescope

This summary takes into account all contributors according to RD7.

Component	E80
Primary Mirror	0.92 arcsec
Secondary Mirror	0.13 arcsec
Tertiary Mirror	0.05 arcsec
Cooling	0.40 arcsec
Sum optics only (RSS'd)	1.01 arcsec
Pointing contribution above 70 Hz (see RD8 for details)	0.53 arcsec
Sum optics with pointing contribution (RSS'd)	1.14 arcsec
For info: optics only, „at best“ elevation (about 70°)	0.73 arcsec

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7 Conclusion

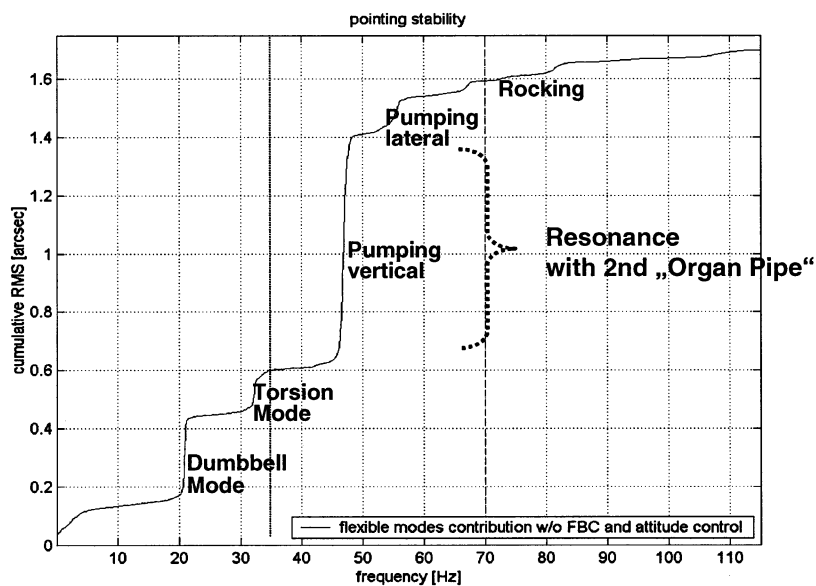
The telescope optical assembly is fully compliant with all optical requirements. This includes image performance values as well as pointing contributions above 70 Hz (see RD8).



RID HIM-1



End-to-end Simulation w/o FBC and Attitude Control



01.10.02

Kärcher

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(Excerpt from RD8)