Optical Assembly Design Definition

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CONTENT:

1 Scope

This document describes the design of the Optical Assembly of the SOFIA Telescope Assembly. Due to the long manufacturing time of the TA optical elements (especially the Primary Mirror) the optical design had to be fixed at a very early project phase. On the other hand the dynamic volumetric envelope given by the aircraft and cavity design limits the size of the TA and thus the optical configuration. The optical design drives now the TA development. Thus this document shall serve as a baseline reference for the ongoing development work.

The herein given data details the Optical System Layout OS01-697 from June 24th 1997 which was agreed by all parties.

2 Documents

2.1 Applicable Documents

AD1: SOFIA TA Development Statement of Work
SOW (DARA); REV. 2, 16.12.96

AD2: SOFIA TA Requirements
SOF-1011 (NASA); Rev. 6, May 1996

AD3: SOFIA Interface Requirements
SOF-1030 (NASA); Rev. 6, March 1996

AD4: NASA Doc. SOF-DCR-0023; Rewording of Clear Opical Path

AD5: NASA Doc. SOF-DCR-0033; System Effective Aperture

2.2 Reference Documents

RD1: Primary Mirror Design Definition
SOF-SPE-KT-1110.0.01; Issue 3; 19.09.97

RD2: Secondary Mirror Design Definition
SOF-SPE-KT-1210.0.01; Issue 1; 19.09.1997

RD3: Tertiary Mirrors Design Definition
SOF-SPE-KT-1300.0.01; Issue 2; 03.09.1997

RD4: ZEMAX Optical Design Program User's Manual; Version 5.0

RD5: GLOBAL_05 Interface Control Docment; Draft Version from 23. April 1997

3 Optics Overview

The SOFIA Telescope is a based on a Cassegrain-type design with Nasmyth focus. It is a 2.5 m class telescope and works in the spectral range from 0.3 µm to 1.6 mm. The dynamic pointing stability of the system shall be < 0.2 arcsec RMS. The dichroic tertiary mirror divides the incoming radiation in the (reflected) IR beam and the (transmitted) visible beam. There are a number of various instruments envisaged to be adapted to the IR focal plane. The visible beam is folded into the Focal Plane Imager and is used for tracking purposes only. The mechanical and optical configuration is depicted in figure 3-1 and 3-2 respectively.

The major TA optical elements are:

- Primary Mirror M1 (concave parabolic shape)
- Secondary Mirror M2 (convex hyperbolic shape)
- Dichroic IR-Mirror (Tertiary) M3-1 (flat dichroic beamsplitter plate)
- Visible Mirror M3-2 (flat mirror)

A detailed description of these optical elements are given in section 5.

There are additional optical elements within the tracker cameras (WFI, FFI, FPI) which are not described within this document.

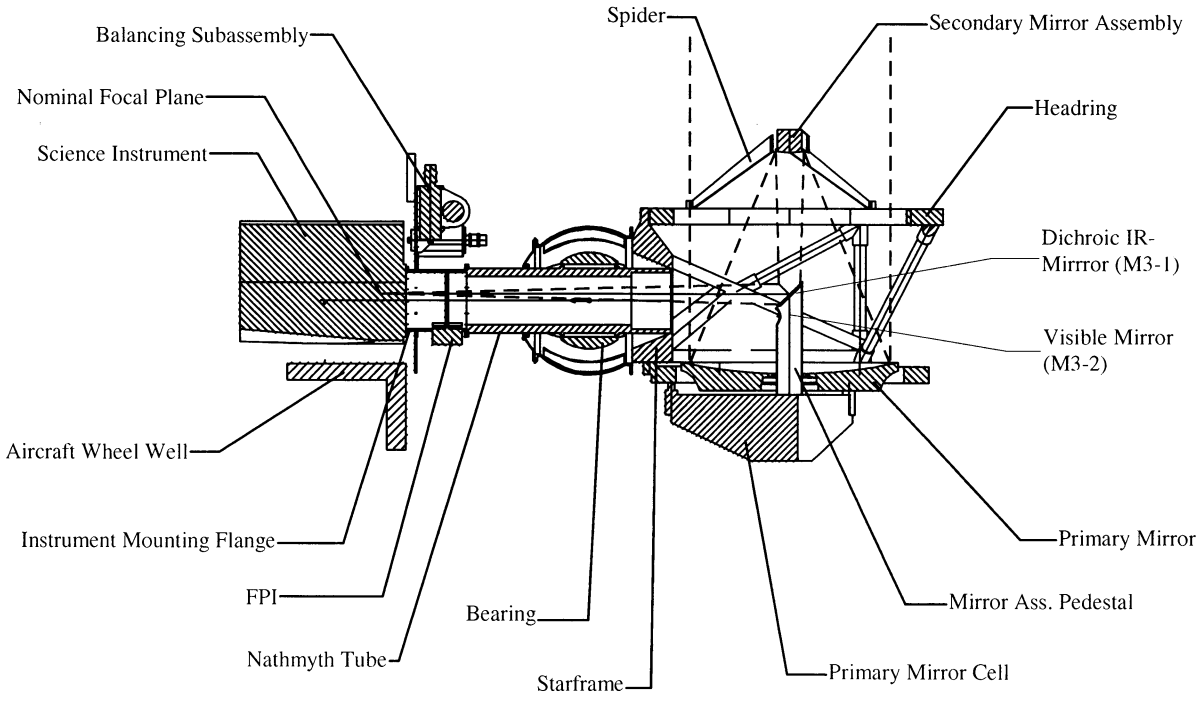


Figure 3-1: Mechanical TA System Configuration

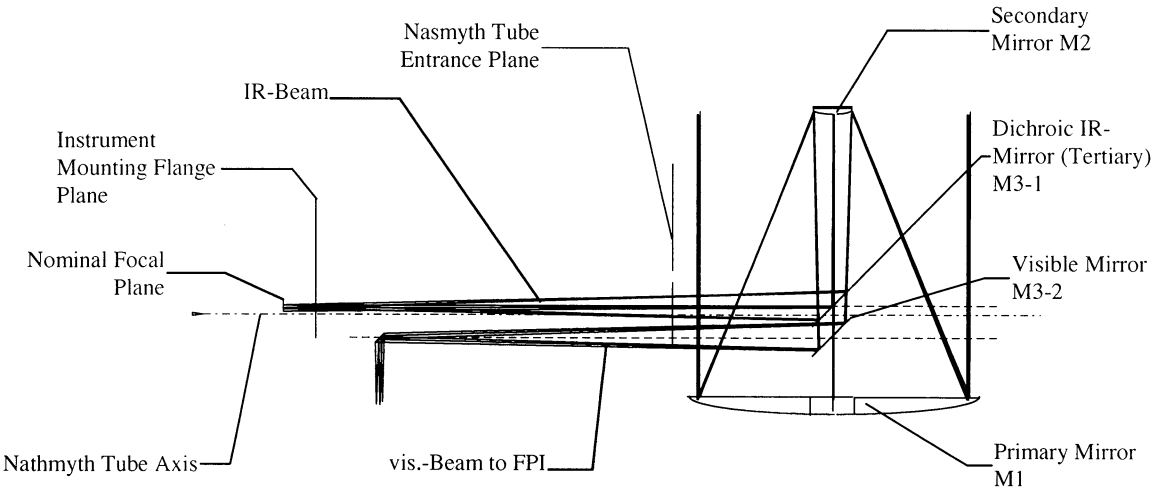


Figure 3-2: Optical System Configuration

4 Optical System Data

The optical system data (table 4-1) describe the optical system layout OS01-697.

Table 4-1: Optical System Data

parameter	**value**
nominal focal length	49140.9 mm
Primary Mirror focal length	3200 mm
Primary Mirror optical diameter	2690 mm
Secondary Mirror focal length	477.065 mm
paraxial image height	± 57.2 mm
back focal length (secondary vertex to focal plane)	6849.0 mm
exit pupil position (= system aperture stop)	secondary mirror plane
entrance pupil position	22514 mm from secondary mirror vertex (= 19760 mm behind primary mirror vertex)
decenter of IR beam to Nasmyth Tube axis	+84 mm in *w*-direction

The relevant optical dimensions for the mechanical design of the TA structure are shown in figure 4-1. For additional information a CAD drawing of the mechanical TA system layout is given in the appendix.

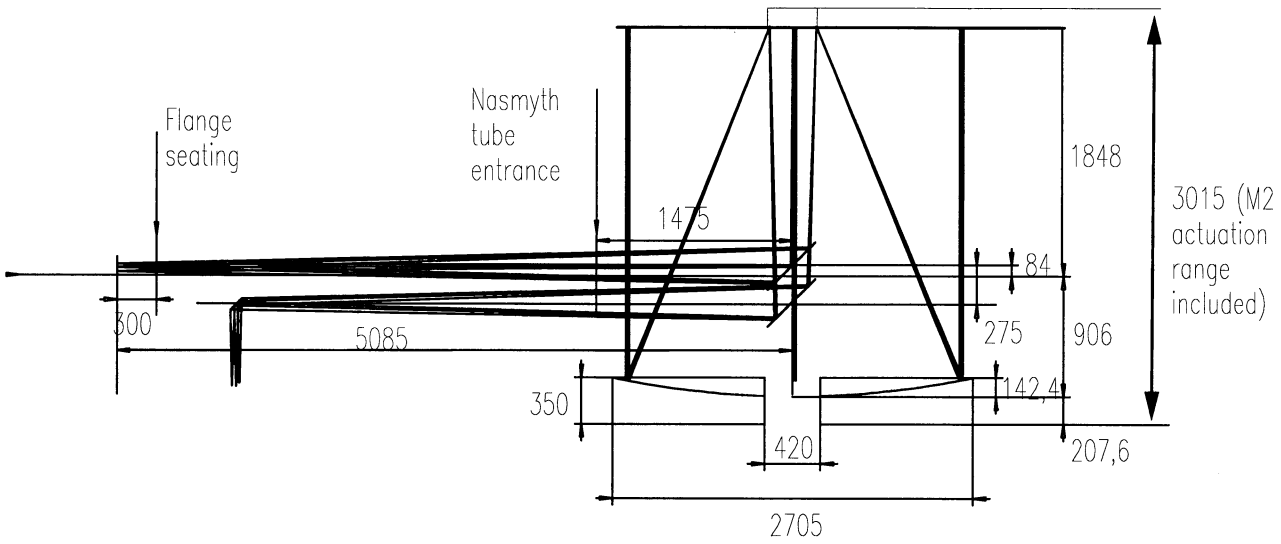


Figure 4-1: Optomechanical dimension derived from optical layout

An overview of the nominal coordinate and orientation of all optical surfaces is given in Table 4-2. The letters *u, v, w* are the local Telescope Assembly coordinate points in mm and *l, m, n* are the direction cosine of each nominal surface normal. The SOFIA Telescope Assembly coordinate system is described in RD5.

Table 4-2: Global coordinates of all optical elements

Component	*u*	*v*	*w*	*l*	*m*	*n*
M1	-2500.0	0.0	-906.0	0.00000	0.00000	1.00000
M2	-2500.0	0.0	1848.0	0.00000	0.00000	-1.00000
M3-1	-2502.4	0.0	86.4	0.70711	0.00000	0.70711
M3-2	-2485.8	0.0	-191.0	0.70681	0.00000	0.70740
IR-focus	2585.0	0.0	84.0	-1.00000	0.00000	0.00000
vis.- focus	TBD	TBD	TBD	TBD	TBD	TBD

5 Description of Optical Elements

Within this section the main data and parameters of the SOFIA TA optical elements are given. For a more detailed description refer to the respective element design definitions (RD1, RD2, RD3).

5.1 Primary Mirror (M1)

The SOFIA Primary Mirror is a monolithic lightweighted Zerodur mirror of parabolic concave shape. Its parameters are given in table 5-1.

Table 5-1: Primary Mirror Desing Data

parameter	**value**
mechanical diameter	2705 mm
free optical diameter	2690 mm
focal length	3200 mm
conic constant	-1 (parabola)
edge thickness	≈ 350 mm
surface roughness	≤ 2 nm RMS
wave front error	≈ 300 nm RMS
center hole diameter	420 mm
material	Zerodur (Schott)
coating	bare Al
mass	850 kg

5.2 Secondary Mirror (M2)

The SOFIA Secondary Mirror is a monolithic lightweighted mirror of hyperbolic convex shape. Its parameters are given in table 5-2.

Table 5-2: Secondary Mirror Design Data

parameter	**value**
mechanical diameter	355 mm
free optical diameter	352 mm
focal length	477.065 mm (convex)
conic constant	-1.2980
center thickness	≈ 40 mm
surface roughness	≤ 2 nm RMS (tbd)
wave front error	< 80 nm RMS
center hole diameter	< 40 mm
material	Zerodur, Beryllium or Silicon Carbide (tbd)
coating	bare Al
mass	tbd

The Secondary Mirror is suspended in an articulating mechanism which allows axial and lateral movements and tilts of the element for chopping and image adjustment.

The axial travel range is ± 10 mm (tbc) and the lateral travel range is ± 5 mm.

5.3 Dichroic IR-Mirror (M3-1)

The tertiary mirror of the SOFIA TA is called Dichroic IR-Mirror (M3-1) since it is a beamsplitter which splits the incoming radiation in an IR part which is reflected in direction of the Nasmyth tube and a visible part which is transmitted to the Visible Mirror (M3-2).

Its shape is an elliptical wedge with plane surfaces. Its parameters are given in table 5-3.

Table 5-3: Dichroic IR-Mirror Design Data

parameter	**value**
mechanical dimensions	elliptical 500 mm x 354 mm
dimensiones of main optical area (dichroic)	elliptical 440 mm x 310 mm
dimensiones of radiometric optitcal area (dichroic)	elliptical 498 mm x 352 mm
dimensiones of refractive side optical area	elliptical 390 mm x 290 mm
thickness	45 mm
wedge angle	3.5 arcmin
surface roughness	≤ 2 nm RMS (tbd)
wave front error on reflective side	≤ 80 nm RMS
surface error on refractive side	≤ 300 nm RMS
reflected wavelength band	2 µm to 1600 µm
refracted wavelength band	0.4 µm to 1.1 µm
material	fused silica (Suprasil) (tbc)
coating	bare gold
mass	tbd

5.4 Visible Mirror (M3-2)

The Tertiary Mirror for the visible beam M3-2 of the SOFIA TA is called Visible Mirror it reflects the visible beam in the direction of the Nasmyth tube. It is a plane mirror with elliptical shape. The Visible Mirror parameters are given in table 5-4.

Table 5-4: Visible Mirror Data

parameter	**value**
mechanical dimensions	410 mm x 290 mm
free optical diameter	410 mm x 290 mm
thickness	35 mm
surface roughness	≤ 2 nm RMS (tbd)
wave front error	≤ 80 nm RMS
reflected wavelength band	0.4 µm to 1.1 µm
material	Zerodur (tbd)
coating	Al + protective coating (tbd)
mass	tbd

6 Optical Design Description

6.1 Customer Specifications

The customer requirements document AD2 (SOF-1011, Rev. 6) specifies the SOFIA telescope to be a generic Cassegrain design with a Nasmyth focal plane providing two Nasmyth foci (§3.3.1). An entrance pupil size of ≥ 2.5 m is specified (§3.3.11) for any specified focus location in the range of ±60 cm (§3.3.7) from the nominal focus position. Focusing is accomplished by axial actuation of the Secondary Mirror (§3.3.14.1).

Two Tertiary Mirror elements are specified, one of which shall be dichroic (§1.3.1). An operating spectral range from 300 nm to 1.6 mm is specified, however, any image performance, which shall be compliant with a generic Cassegrain design, is referenced to a wavelength of 633 nm (§3.3.4). The unvignetted field of view of the telescope is specified with ≥ 8 arcminutes at the nominal Nasmyth focus (§3.3.5) plus an additional chop angle of 5 arcminutes. Both angles are measured in object space. It is required to provide the nominal IR focus with an allowable system focal ratio between f/10 an f/24 inclusively (§3.3.6).

The Primary Mirror clear optical diameter must be sufficiently large for the unvignetted field of view plus chop offset and a diffraction offset (§3.3.12.1). The center hole shall be sufficiently small, to be unobservable from any point of the field of view in the image plane (§3.3.12.1). A focal ratio of < f/1.1 is required for the Primary Mirror element (§3.3.12.2).

The Secondary Mirror must be the optical system aperture stop (§3.3.13.1) and a maximum obscuration of 4% caused by the tertiary mirror is allowed (§3.3.13.2). The telescope must be capable of chopping the field of view (§3.3.14.3). There is no requirement on the pivot location of the Secondary Mirror chopper mechanism.

For the optical design, various sequential ray tracing models have been established to design the telescope according to the specification, and to analyze various parameters coming from the design. These sequential ray tracing models are:

1. Ray tracing model of the nominal IR system including focus and specified focus locations. This model is traced forwards (from infinity to the focal plane)

2. Ray tracing model of the nominal vis. system including focus and refractive optical path through the dichroic mirror. This model is traced forwards (from infinity to the focal plane)

3. Ray tracing model of the chopping system. This model is traced forwards (from infinity to the focal plane)

4. Ray tracing model for the obscuration. This model is traced forwards (from infinity to the focal plane)

5. Ray tracing model of the obscured telescope beams for the central button design. This model is traced backwards (from the image plane to the Tertiary Mirror)

6. Ray tracing model to analyze the vis. obscuration caused by the dichroic. This model is traced backwards (from the image plane to a simulated exit pupil of the telescope located at the Secondary Mirror position)

All sequential ray tracing analysis have been performed with the ZEMAX optical design program from Focu Software Inc. Version 5.0 and 6.0 was used for most of the models, however, no advanced features from version 6.0 have been used. All analysis and models described can be traced and analyzed with version 5.0. This optical design program uses a different coordinat system than the telescope (positive z-coordinate points along the optical axis into the telescope entrance pupil). **Any coordinate value given in the listings of the sequential models is referenced to the local Zemax coordinate system and has nothing to do with the *x, y, z* coordinate system of the aircraft or with the *u, v, w* coordinate system of the TA!** Details on the Zemax coordinate system are described in RD4.

The following table is a summary of all requirements for the optical design and describes which model must be reviewed to verify the conformity with the respective requirement. There is no reference to the model #6 because the visible path of the telescope has no direct requirement in AD2.

Requirement	Ray Tracing Model	Comment
Cassegrain design (§3.3.1)	1	Conic constants of surfaces 3 and 5
Nasmyth focus (§3.3.1)	1	Obvious from the design
Two Nasmyth foci (§3.3.1)	1, 2	One model per focus
Entrance pupil size ≥2.5 m (§3.3.14.1)	1	First order data in the system listing ('Entr. Pup. Dia.')
Focus range ±60cm (§3.3.7)	1	Surface 16 shifts back focal length

Focusing by actuated Secondary Mirror (§3.3.14.2)	1	Surface 4 actuates Secondary Mirror for refocus
Dichroic Tertiary (§1.3.1)	(1), 2	Obvious from the design
Spectral range and reference wavelength (§3.3.4 + §3.3.3)	1	System listing ('Wavelength...')
Image performance compliant with generic Cassegrain (§3.3.4)	1	Obvious from design and analysis in chapter 6.2.2
Unvignetted field of view (§3.3.5)	1	System listing ('Fields...')
Chop angle (§3.3.5)	3	System listing ('Fields...')
Angle measured in object space (§3.3.5)	1, 3	Obvious because of forward ray trace parameter (object field angle specification)
IR focus system focal ratio (§3.3.6)	1	First order data in the system listing ('Image Space F/#')
Primary Mirror clear optical diameter (§3.3.12.1)	1	See analysis results in chapter 6.3.2
Center hole diameter (§3.3.12.1)	5	See analysis results in chapter 6.6.2
Primary Mirror focal ratio (§3.3.12.1)	1	Obvious from surface 3 specification and analysis results of the required Primary Mirror optical diameter
Secondary Mirror is aperture stop (§3.3.13.1)	1	Surface 5 is aperture stop ('STO')
Maximum obscuration < 4% (§3.3.13.2)	4	See analysis results in chapter 6.5.2
Chopping angle (§3.3.14.3)	3	System listing ('Fields'...) and ('Param 3....') of surface 6 in ('Configuration 1....')

Tab. 6-1 Primary System Requirements for the Optical Design

6.2 Nominal IR Optical System

The nominal system consists of 17 sequential surfaces as given in the next chapter. It is a classical Cassegrain telescope configuration consisting of two active optical surfaces. Surface 3 is a conic surface with a conic constant of -1 (parabolic primary mirror) and surface 5 is a conic surface with a conic constant of approximately -1.2 (hyperbolic secondary mirror). Refer to RD4 for a description of the conic constant definition. Surface 5 is the secondary mirror and aperture stop of the system which is compliant with the requirement specified in §3.3.13.1.

Surface 4 is used for focusing the system on any axial image location, which can be chosen by offset of surface 16.

From the first order data of the model listing a nominal focal length of 49140.9 mm can be derived. Design is performed at 633 nm wavelength.

6.2.1 Sequential Ray Trace Model Listing

The corresponding data can be found under Annex B, chapter 1.

6.2.2 Analysis Results

Three analyis results are presented graphically. The first plot shows the diffraction encircled energy of the design at 633 nm wavelength. Geometric optical corrections can be derived from the rim ray curves and the field aberration plot. Both graphs show aberrations typical for Cassegrain designs e.g. field curvature is the dominant aberration.

6.2.2.1 Diffraction Encircled Energy

A value of 178.7 µm corresponds to 1.5 arcsec in object space.

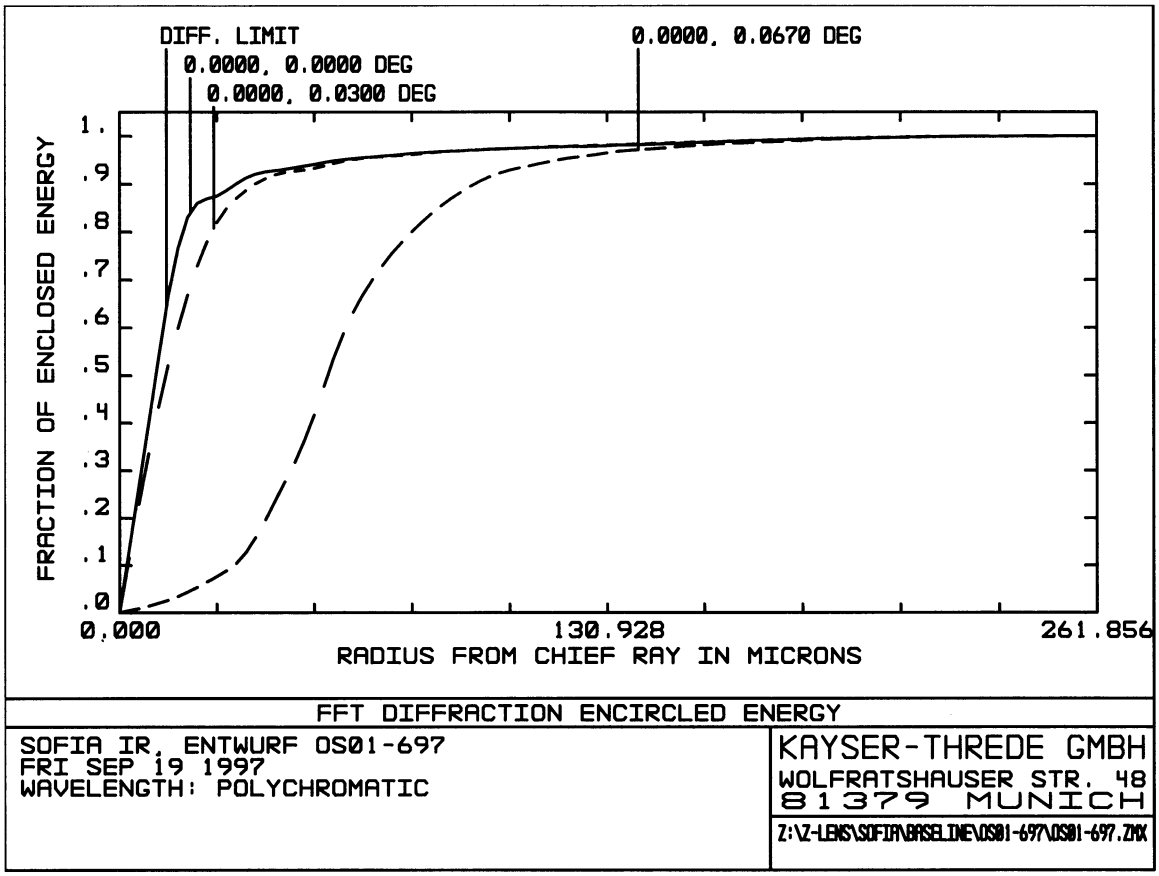


Fig. 6-1 Diffraction Encircled Energy of the Nominal Design (IR)

6.2.2.2 Rim Ray Curves

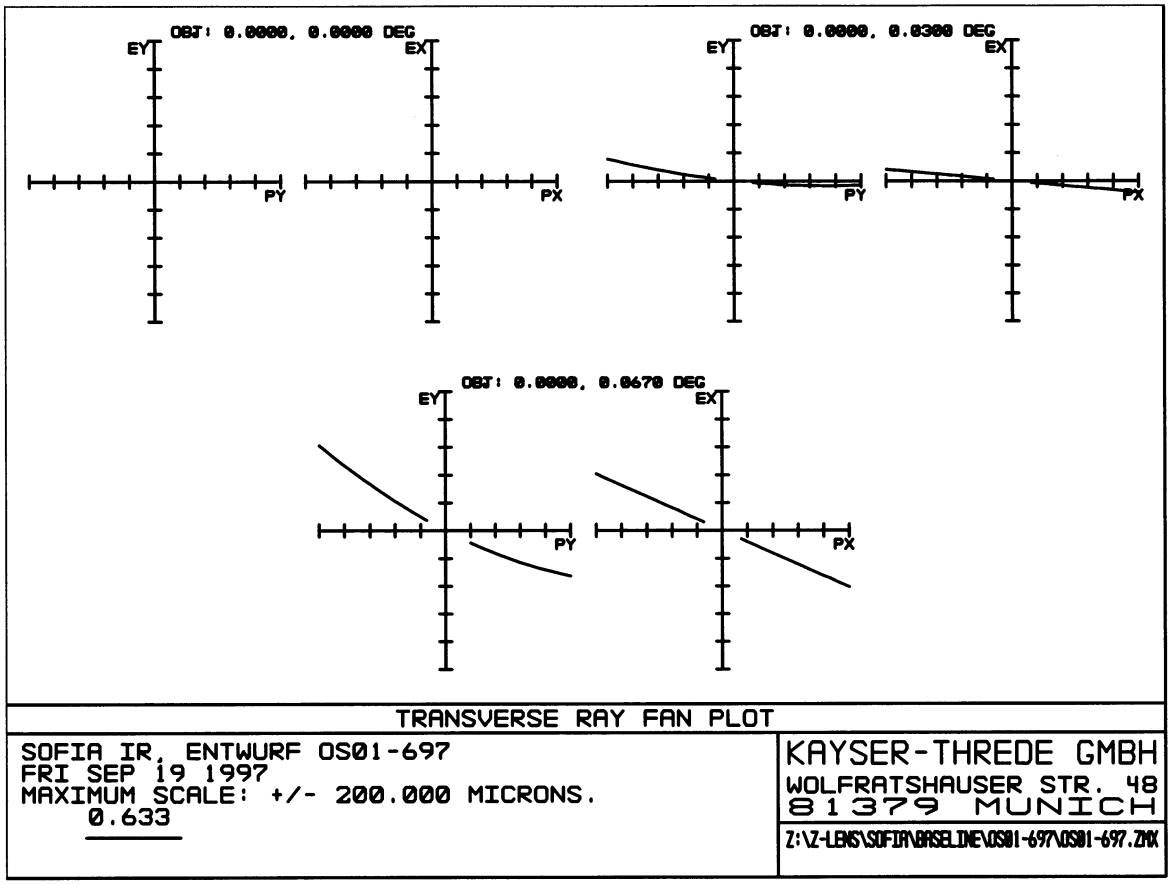


Fig. 6-2 Rim Ray Cuves Nominal Design (IR)

6.2.2.3 Field Curves

The field curves show the typical image curvature, which can already be seen in the rim ray curves.

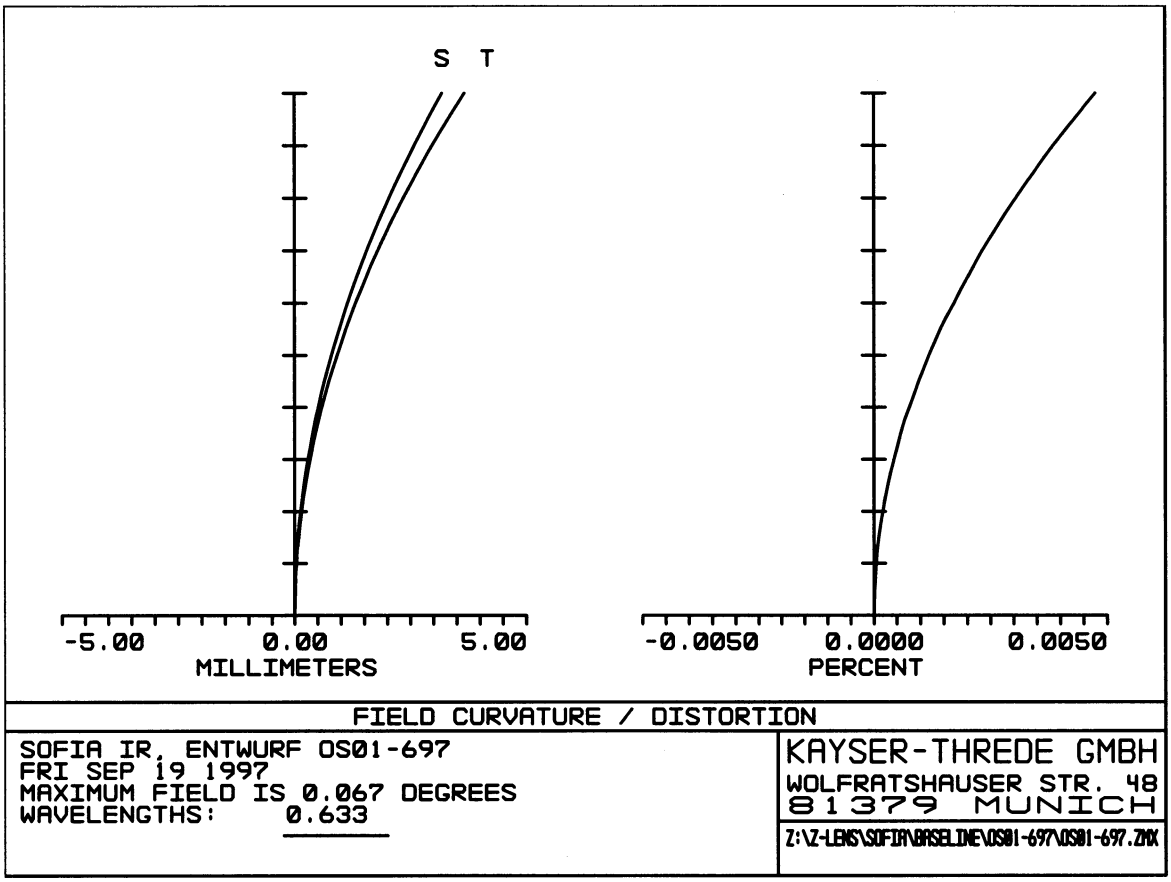


Fig. 6-3 Field Curvature Nominal Design (IR)

6.2.3 Tolerances

A tolerance analysis shows, that typical tolerance values for the mirrors curvature (7 mm for the primary and 1 mm for the secondary) result in an axial range of ±12 mm of the best system focus location. For the conic constant of the secondary mirror a value of ±0.05 provides the ability to form a perfect focus within the same range.

An analysis has been performed to derive how the curvature tolerances of the Primary and Secondary Mirror effect the final entrance pupil diameter. If the Primary Mirror Radius tolerance is -7 mm and the Secondary Mirror Tolerance is -1 mm, and the system is perfectly focused, the telescope has the smallest entrance pupil diameter. In order to meet

the entrance pupil requirement, the secondary mirror diameter has been increased by 0.4 mm. The opposite configuration defines the required margin of the Primary Mirror diameter margin. If the Primary Mirror has +7 mm tolerance, and the Secondary Mirror has +1 mm tolerance, the maximum entrance pupil diameter requires an Primary Mirror optical diameter increase of 5 mm. Resulting from analysing the ray tracing model, the required free diameters for the Primary Mirror are as follows:

- Diameter required for the center field: < 2506 mm
- Diameter required for the field: < 2555 mm
- Diameter required for the chop: < 2630 mm
- Diameter increase due to curvature tolerances: + 5 mm
- Diffraction margin according to (§3.3.12.1): + 22.7 mm
- Sum: < 2660 mm

The finally specified maximum optical diameter of the Primary Mirror is 2690 mm. The additional margin is needed for achieving the required polishing quality at the outer edge of the effectively used optical diameter.

6.3 Nominal vis. Optical System

The listing in the next chapter describes the visible optical path through the SOFIA telescope. A wedge of 0.05833° (3.5 arcminutes) has been put on the refractive side of the dichroic (surface 7 and 8) to correct coma and lateral color. A wavelength set consisting of 480 nm, 633 nm and 900 nm, each one equally weighted has been used for optimization. The longer wavelength is equally weighted for optimization because some CCD cameras have their sensitivity maximum at that wavelength.

6.3.1 Sequential Ray Trace Model Listing

The corresponding data can be found in Annex B, chapter 2.

6.3.2 Analysis Results

In the following, two analysis results are graphically presented. A diffraction encircled energy curve shows, that the optical correction by the wedged dichroic tertiary mirror results in a very good image performance, which is compliant with the requirement for the IR focus. The rim ray curves show that there is a rest of lateral chromatic aberration at all field points which amounts about the same as the field curvature aberrations.

6.3.2.1 Diffraction Encircled Energy

A value of 178.7 µm corresponds to 1.5 arcsec in object space.

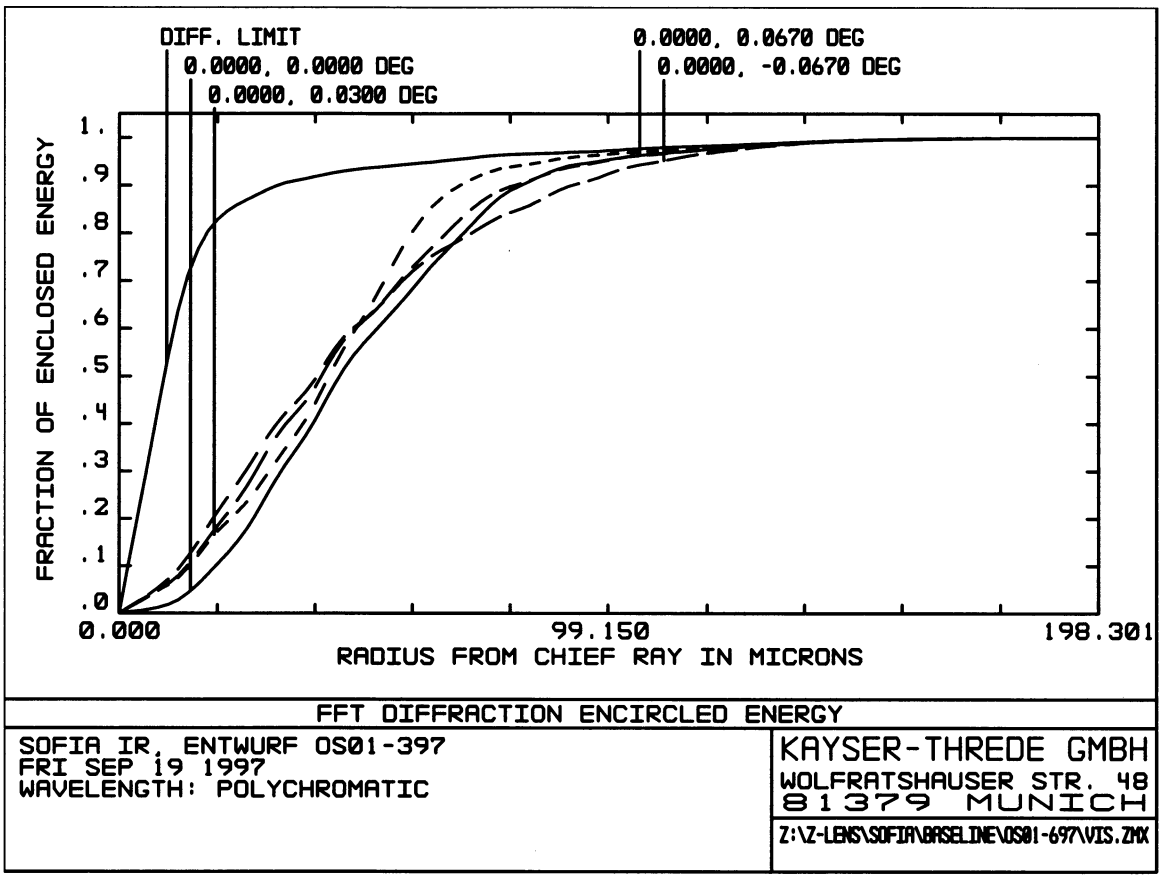


Fig. 6-4 Diffraction Encircled Energy Nomial Design (vis.)

6.3.2.2 Rim Ray Curves

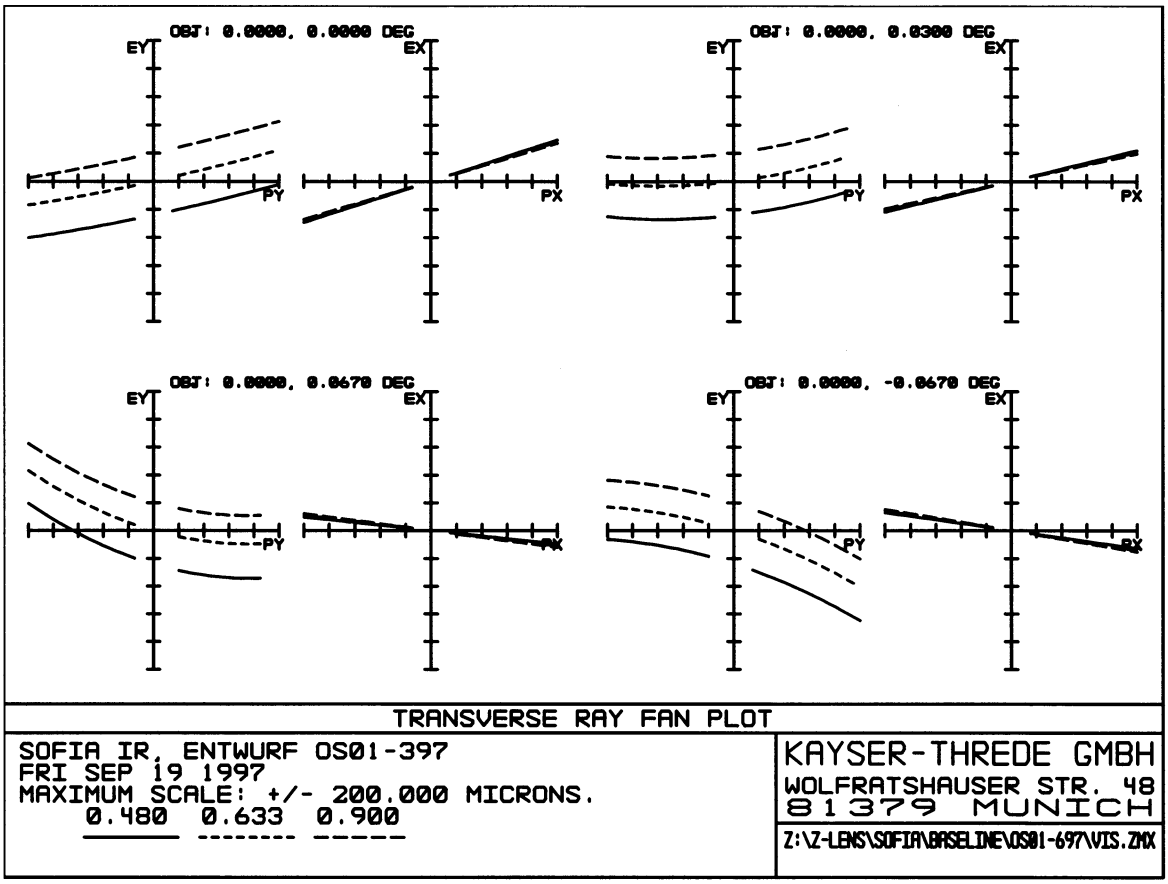


Fig. 6-5 Rim Ray Curves Nominal Design (VIS)

6.3.3 Tolerances

For the beam splitter wedge a tolerance of ±20 arcsec has been derived as acceptable and therefore has been specified.

6.4 Chopping Optical System

The chopping model has been built to analyze the optical diameter requirements of the Primary Mirror, chop angles at the Secondary Mirror element and chopped image quality. A multi configuration system, similar to those used to design and analyze zoom systems is used for this analysis. The model consists of two configurations. Configuration 1 is the system in the full amplitude chop state, configuration 2 represents the unchopped system.

From the model listing it can be derived that the chop pivot for this analysis has been 40 mm behind the Secondary Mirror vertex. This pivot location can be modified easily by just changing the thickness of surface 5.

For a full chop angle of 5 arcmin in object space, the Secondary Mirror has to be tilted by 0.312°.

6.4.1 Sequential Ray Trace Model Listing

The corresponding data can be found in Annex B, chapter 3.

6.4.2 Analysis Results

A significant amount of coma is introduced by chopping. This is due to the relatively long distance of the chop pivot to the coma free chopping point.

There is no requirement for the chopped image quality. The analysis results are only presented here for information. The design is compliant with the requirements.

6.4.2.1 Geometric Encircled Energy

Since the chopped image performance at 633 nm wavelength is limited by geometric aberrations, a diffraction analysis makes no sense. Therefore the analysis is performed on geometric level. A value of 178.7 µm corresponds to 1.5 arcsec in object space. The encircled energy is referenced to the image controid, not to the chief ray.

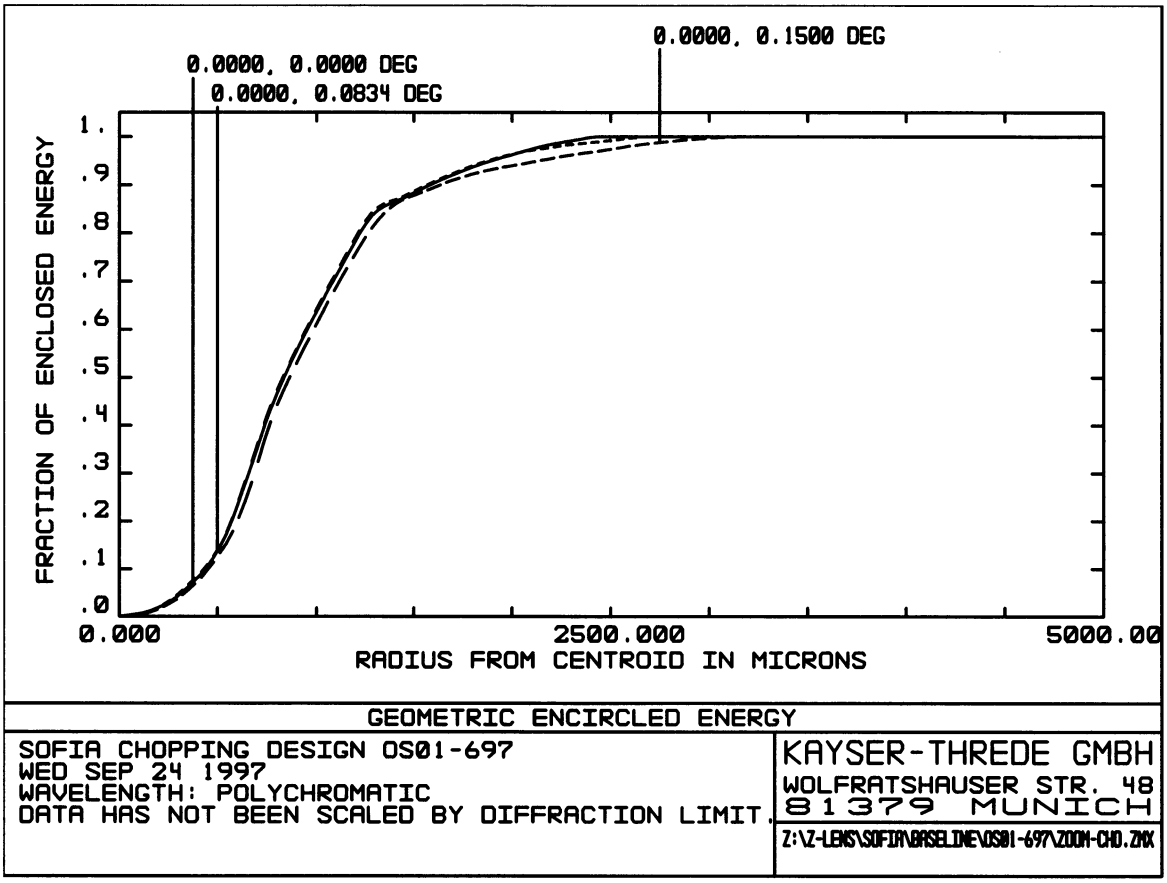


Fig. 6-6 Geometric Encircled Energy at max. Chop Angle

6.4.2.2 Rim Ray Curves

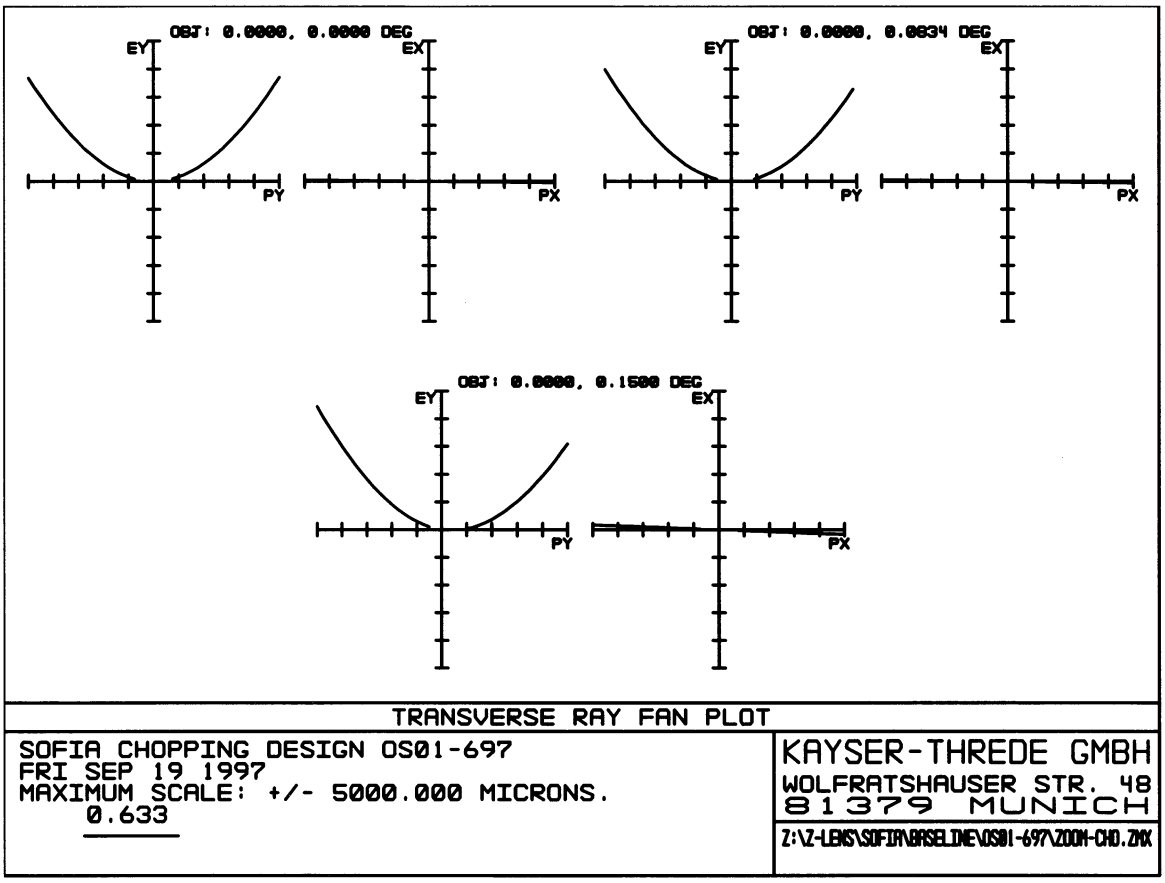


Fig. 6-7 Rim Ray Curves at max. Chop Angle

6.5 Central Obscuration System

To analyze the influence of the telescope design on the central obscuration, an extra sequential ray tracing model is established. This model consists of an extra surface at the position of the Dichroic Tertiary Mirror in the path between Primary and Secondary Mirror.

6.5.1 Sequential Ray Trace Model Listing

The corresponding data can be found under Annex B, chapter 4.

6.5.2 Analysis Results

By analyzing the marginal ray height on a surface precisely located at the dichroic tertiary mirror plane, the effective aperture size at this area can be derived. This surface in the presented model has the number 11. The effective aperture diameter at that surface is 1809.9 mm and the effective Tertiary Mirror diameter is 354 mm. Therefore the obscuration is 3.8%, which is compliant with the requirement (<4%).

This model contains some spider elements, which are not used for the obscuration analysis.

6.6 Obscured Beam Optical System

The central button size at the Secondary Mirror has been analyzed. Therefore the first backwards model of the telescope from the image plane to the nominal Tertiary Mirror plane (dichroic) has been established. The image size at the focus is specified in ±57.6 mm object height.

Design goal was to find a button, just sufficiently large in diameter, that the Tertiary Mirror cannot be seen from any point of the image plane.

6.6.1 Sequential Ray Trace Model Listing

The corresponding data can be found under Annex B, chapter 5.

6.6.2 Analysis Results

If the central button has a diameter of 80 mm, the Tertiary Mirror Assembly cannot be seen from any point at the focal plane.

A ray trace to the primary mirror plane shows that the maximum central hole diameter can be 516 mm (diameter of image surface of this model is equivalent with the primary mirror plane). Since the hole specified is smaller, it cannot be seen from any point in the image plane, which is compliant with the requirements.

6.7 vis. Obscuration System

It was necessary to implement an additional model for the analysis of the obscuration of the vis. ray path to the Focal Plane Imager. The analysis of the SOFIA vis. obscuration requires a backwards (from image plane to object space) tracing model.

6.7.1 Sequential Ray Trace Model Listing

The corresponding data can be found under Annex B, chapter 6.

6.7.2 Analysis Results

The result of the analysis is the size and shape definition for fully visible Tertiary Mirror as specified in RD3, and a vignetting analysis. Fig. 6-8 shows the vignetting of the Focal Plane Imager as a function of image heigth for two dichroic mirror element sizes. Sample 1 corresponds to -57.6 mm, sample 41 to +57.6 mm image height. It can be seen, that the larger mirror causes less vignetting, therefore it has been established as baseline design.

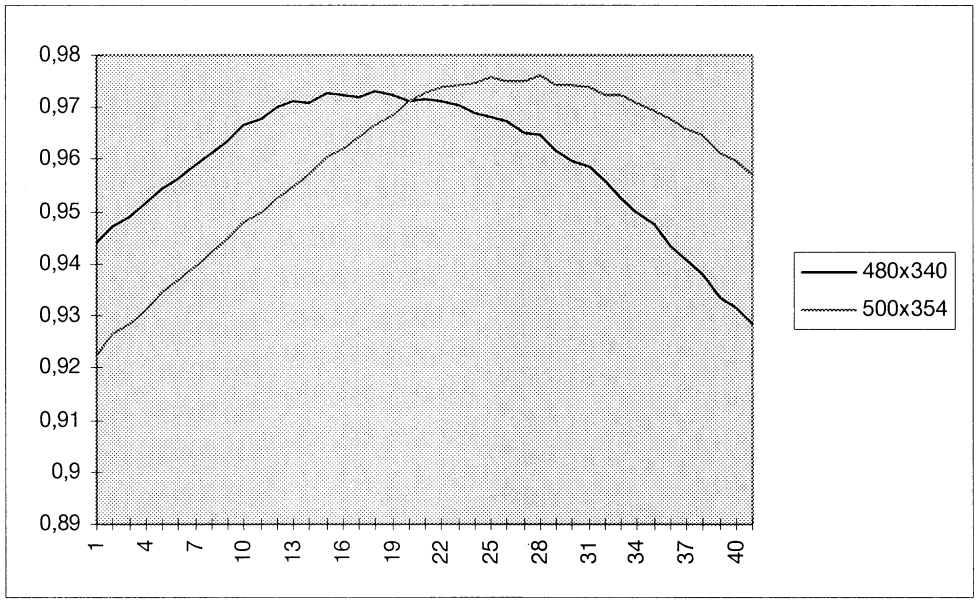
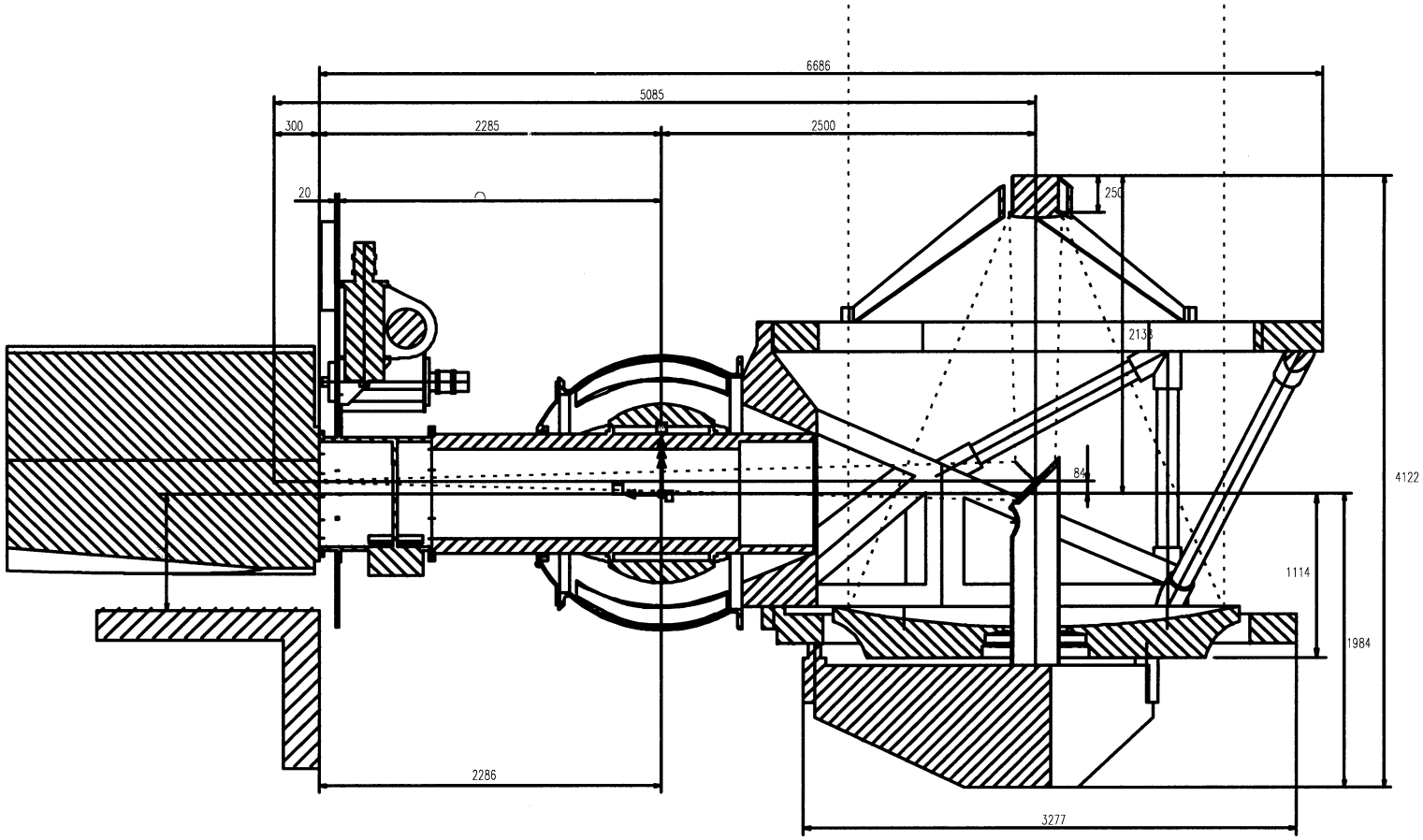


Fig. 6-8 Transmission to Focal Plane Imager (only vignetting)

Annex A


6686
5085
300
2285
2500
20
250
2136
84
4122
1114
1984
2286
3277

Annex B

1. Sequential Ray Trace Model Listing of the Nominal IR Optical System

System/Prescription Data

File : Z:\Z-LENS\SOFIA\BASELINE\OS01-697\Os01-697.zmx
Title: Sofia IR, Entwurf OS01-697
Date : FRI SEP 12 1997

GENERAL LENS DATA:

Surfaces	17
Stop	5
System Aperture	Float By Stop Size = 176
Ray aiming	Real Reference, cache on
X Pupil shift	0.0000000E+000
Y Pupil shift	0.0000000E+000
Z Pupil shift	0.0000000E+000
Apodization	Uniform, factor = 0.00000E+000
Eff. Focal Len.	4.91409E+004 (in air)
Eff. Focal Len.	4.91409E+004 (in image space)
Total Track	6.07500E+003
Image Space F/#	1.94574E+001
Para. Wrkng F/#	1.94574E+001
Working F/#	1.95098E+001
Obj. Space N.A.	1.26278E-007
Stop Radius	1.76000E+002
Parax. Ima. Hgt.	5.74640E+001
Parax. Mag.	0.00000E+000
Entr. Pup. Dia.	2.52557E+003
Entr. Pup. Pos.	2.25137E+004
Exit Pupil Dia.	3.52000E+002
Exit Pupil Pos.	6.84900E+003
Field Type	Angle in degrees
Maximum Field	6.70000E-002
Primary Wave	6.33000E-001
Lens Units	Millimeters
Angular Mag.	-7.17490E+000

Fields : 3
Field Type: Angle in degrees

#	X-Value	Y-Value	Weight
1	0.000000	0.000000	1.000000
2	0.000000	0.030000	1.000000
3	0.000000	0.067000	1.000000

Vignetting Factors

#	VDX	VDY	VCX	VCY
1	0.000000	0.000000	0.000000	0.000000
2	0.000000	0.000000	0.000000	0.000000

3 0.000000 0.000000 0.000000 0.000000

Wavelengths : 1
Units: Microns

#	Value	Weight
1	0.633000	1.000000

SURFACE DATA SUMMARY:

Surf	Type	Comment	Radius	Thickness	Glass	Diameter	Conic
OBJ	STANDARD		Infinity	Infinity		0.0000000E+000	0
1	STANDARD		Infinity	0		2.5733120E+003	0
2	STANDARD		Infinity	2.7540000E+003		2.5733120E+003	0
3	STANDARD	PRIMAERSPIEGEL	-6.4000000E+003	-2.7540000E+003	MIRROR	2.7000000E+003	-1.0000000E+000
4	STANDARD	FOKALTRIEB	Infinity	-9.2495298E-004		3.6557928E+002	0
STO	STANDARD	SEKUNDAERSPIEGEL	-9.5413000E+002	9.2495298E-004	MIRROR	3.5200000E+002	-1.2980258E+000
6	STANDARD		Infinity	1.7640000E+003		3.5144054E+002	0
7	COORDBRK		-	0	-	-	-
8	COORDBRK	M3-1 ZENTRIERUNG	-	0	-	-	-
9	STANDARD	TERTIAERSPIEGEL	Infinity	0	MIRROR	4.1074280E+002	0
10	COORDBRK		-	0	-	-	-
11	COORDBRK		-	0	-	-	-
12	COORDBRK		-	-1.4750000E+003	-	-	-
13	COORDBRK	IR +84MM DEZENT.	-	0	-	-	-
14	STANDARD	EINGANG ROHR	Infinity	0		6.0000000E+002	0
15	COORDBRK		-	-3.6100000E+003	-	-	-
16	STANDARD	'+/- 600MM SHIFT	Infinity	0		1.1517817E+002	0
IMA	STANDARD		Infinity			1.1517817E+002	0

SURFACE DATA DETAIL:

Surface OBJ : STANDARD
Surface 1 : STANDARD
Surface 2 : STANDARD
Aperture : Circular Obscuration
Minimum Radius : 0
Maximum Radius : 176
Surface 3 : STANDARD
Comment : PRIMAERSPIEGEL
Surface 4 : STANDARD
Comment : FOKALTRIEB
Surface STO : STANDARD
Comment : SEKUNDAERSPIEGEL
Surface 6 : STANDARD
Surface 7 : COORDBRK
Decenter X : 0.00000000E+000
Decenter Y : 0.00000000E+000
Tilt About X : 4.50000000E+001
Tilt About Y : 0.00000000E+000
Tilt About Z : 0.00000000E+000
Order : Decenter then tilt
Surface 8 : COORDBRK

```
 Comment        : M3-1 ZENTRIERUNG
 Decenter X     :  0.00000000E+000
 Decenter Y     : -3.45000000E+000
 Tilt About X   :  0.00000000E+000
 Tilt About Y   :  0.00000000E+000
 Tilt About Z   :  0.00000000E+000
 Order          : Decenter then tilt
Surface   9     : STANDARD
 Comment        : TERTIAERSPIEGEL
 Aperture       : Elliptical Aperture
 X Half Width   :           177
 Y Half Width   :           250
Surface  10     : COORDBRK
 Decenter X     :  0.00000000E+000
 Decenter Y     :  3.45000000E+000
 Tilt About X   :  0.00000000E+000
 Tilt About Y   :  0.00000000E+000
 Tilt About Z   :  0.00000000E+000
 Order          : Decenter then tilt
Surface  11     : COORDBRK
 Decenter X     :  0.00000000E+000
 Decenter Y     :  0.00000000E+000
 Tilt About X   :  4.50000000E+001
 Tilt About Y   :  0.00000000E+000
 Tilt About Z   :  0.00000000E+000
 Order          : Decenter then tilt
Surface  12     : COORDBRK
 Decenter X     :  0.00000000E+000
 Decenter Y     :  0.00000000E+000
 Tilt About X   :  0.00000000E+000
 Tilt About Y   :  0.00000000E+000
 Tilt About Z   :  0.00000000E+000
 Order          : Decenter then tilt
Surface  13     : COORDBRK
 Comment        : IR +84MM DEZENT.
 Decenter X     :  0.00000000E+000
 Decenter Y     :  8.40000000E+001
 Tilt About X   :  0.00000000E+000
 Tilt About Y   :  0.00000000E+000
 Tilt About Z   :  0.00000000E+000
 Order          : Decenter then tilt
Surface  14     : STANDARD
 Comment        : EINGANG ROHR
Surface  15     : COORDBRK
 Decenter X     :  0.00000000E+000
 Decenter Y     : -8.40000000E+001
 Tilt About X   :  0.00000000E+000
 Tilt About Y   :  0.00000000E+000
 Tilt About Z   :  0.00000000E+000
 Order          : Decenter then tilt
Surface  16     : STANDARD
 Comment        : '+/- 600MM SHIFT
```

```
Surface IMA      : STANDARD

SOLVE AND VARIABLE DATA:

Thickness of   3        : Solve, pick up value from 2, scaled by -1.00000
Semi Diameter   3       : Fixed
Thickness of   5        : Solve, pick up value from 4, scaled by -1.00000
Semi Diameter   5       : Fixed
Parameter  2 Surf  10   : Pickup from 8 times -1.000000
Parameter  3 Surf  11   : Pickup from 7 times 1.000000
Semi Diameter  14       : Fixed
Parameter  2 Surf  15   : Pickup from 13 times -1.000000
```

2. Sequential Ray Trace Model Listing of Nominal vis. Optical System

System/Prescription Data

File : Z:\Z-LENS\SOFIA\BASELINE\OS01-697\Vis.zmx
Title: Sofia vis. Entwurf OS01-697
Date : FRI SEP 26 1997

GENERAL LENS DATA:

Surfaces : 23
Stop : 5
System Aperture : Float By Stop Size = 176
Ray aiming : Real Reference, cache on
X Pupil shift : 0.0000000E+000
Y Pupil shift : 0.0000000E+000
Z Pupil shift : 0.0000000E+000
Apodization :Uniform, factor = 0.00000E+000
Eff. Focal Len. : 4.91409E+004 (in air)
Eff. Focal Len. : 4.91409E+004 (in image space)
Total Track : 5.52379E+003
Image Space F/# : 1.94574E+001
Para. Wrkng F/# : 1.94574E+001
Working F/# : 1.94974E+001
Obj. Space N.A. : 1.26278E-007
Stop Radius : 1.76000E+002
Parax. Ima. Hgt.: 5.74640E+001
Parax. Mag. : 0.00000E+000
Entr. Pup. Dia. : 2.52557E+003
Entr. Pup. Pos. : 2.25137E+004
Exit Pupil Dia. : 3.52000E+002
Exit Pupil Pos. : 6.86004E+003
Field Type : Angle in degrees
Maximum Field : 6.70000E-002
Primary Wave : 6.33000E-001
Lens Units : Millimeters
Angular Mag. : -7.17490E+000

Fields : 4
Field Type: Angle in degrees

#	X-Value	Y-Value	Weight
1	0.000000	0.000000	1.000000
2	0.000000	0.030000	1.000000
3	0.000000	0.067000	1.000000
4	0.000000	-0.067000	1.000000

Vignetting Factors

#	VDX	VDY	VCX	VCY
1	0.000000	0.000000	0.000000	0.000000
2	0.000000	0.000000	0.000000	0.000000
3	0.000000	0.000000	0.000000	0.000000

4 0.000000 0.000000 0.000000 0.000000

Wavelengths : 3
Units: Microns

#	Value	Weight
1	0.480000	1.000000
2	0.633000	1.000000
3	0.900000	1.000000

SURFACE DATA SUMMARY:

Surf	Type	Comment	Radius	Thickness	Glass	Diameter	Conic
OBJ	STANDARD		Infinity	Infinity		0.0000000E+000	0
1	STANDARD		Infinity	0		2.5733120E+003	0
2	STANDARD		Infinity	2.7540000E+003		2.5733120E+003	0
3	STANDARD	PRIMAERSPIEGEL	-6.4000000E+003	-2.7540000E+003	MIRROR	2.7000000E+003	-1.0000000E+000
4	STANDARD		Infinity	-9.2495298E-004		3.6557928E+002	0
STO	STANDARD	SEKUNDAERSPIEGEL	-9.5413000E+002	9.2495298E-004	MIRROR	3.5200000E+002	-1.2980258E+000
6	STANDARD		Infinity	1.7640000E+003		3.5144054E+002	0
7	COORDBRK		-	0	-	-	-
8	STANDARD	IR-TEILERSCHICHT	Infinity	4.5000000E+001	SILICA	4.1804113E+002	0
9	COORDBRK		-	0	-	-	-
10	STANDARD		Infinity	0		4.5314987E+002	0
11	COORDBRK		-	0	-	-	-
12	COORDBRK		-	0	-	-	-
13	COORDBRK		-	2.4318019E+002	-	-	-
14	COORDBRK		-	0	-	-	-
15	COORDBRK	VIS PARALLEL IR	-	0	-	-	-
16	STANDARD	VIS SPIEGEL	Infinity	0	MIRROR	4.0501852E+002	0
17	COORDBRK		-	0	-	-	-
18	COORDBRK		-	0	-	-	-
19	COORDBRK		-	-1.4891812E+003	-	-	-
20	COORDBRK	VIS -191 ACHSE	-	0	-	-	-
21	STANDARD	EINGANG ROHR	Infinity	0		6.0000000E+002	0
22	COORDBRK	BILD ZENTRIEREN	-	-3.3327918E+003	-	-	-
IMA	STANDARD		Infinity			1.1502348E+002	0

SURFACE DATA DETAIL:

Surface OBJ : STANDARD
Surface 1 : STANDARD
Surface 2 : STANDARD
Aperture : Circular Obscuration
Minimum Radius : 0
Maximum Radius : 175
Surface 3 : STANDARD
Comment : PRIMAERSPIEGEL
Surface 4 : STANDARD
Surface STO : STANDARD
Comment : SEKUNDAERSPIEGEL
Surface 6 : STANDARD
Surface 7 : COORDBRK

```
 Decenter X     :  0.00000000E+000
 Decenter Y     :  0.00000000E+000
 Tilt About X   :  4.50000000E+001
 Tilt About Y   :  0.00000000E+000
 Tilt About Z   :  0.00000000E+000
 Order          : Decenter then tilt
Surface   8     : STANDARD
 Comment        : IR-TEILERSCHICHT
 Aperture       : Elliptical Aperture
 X Half Width   :           177
 Y Half Width   :           250
Surface   9     : COORDBRK
 Decenter X     :  0.00000000E+000
 Decenter Y     :  0.00000000E+000
 Tilt About X   :  5.83300000E-002
 Tilt About Y   :  0.00000000E+000
 Tilt About Z   :  0.00000000E+000
 Order          : Decenter then tilt
Surface  10     : STANDARD
 Aperture       : Elliptical Aperture
 X Half Width   :           177
 Y Half Width   :           205
Surface  11     : COORDBRK
 Decenter X     :  0.00000000E+000
 Decenter Y     :  0.00000000E+000
 Tilt About X   : -5.83300000E-002
 Tilt About Y   :  0.00000000E+000
 Tilt About Z   :  0.00000000E+000
 Order          : Decenter then tilt
Surface  12     : COORDBRK
 Decenter X     :  0.00000000E+000
 Decenter Y     :  0.00000000E+000
 Tilt About X   : -4.50000000E+001
 Tilt About Y   :  0.00000000E+000
 Tilt About Z   :  0.00000000E+000
 Order          : Decenter then tilt
Surface  13     : COORDBRK
 Decenter X     :  0.00000000E+000
 Decenter Y     :  1.76386012E+001
 Tilt About X   :  0.00000000E+000
 Tilt About Y   :  0.00000000E+000
 Tilt About Z   :  0.00000000E+000
 Order          : Decenter then tilt
Surface  14     : COORDBRK
 Decenter X     :  0.00000000E+000
 Decenter Y     :  0.00000000E+000
 Tilt About X   :  4.50000000E+001
 Tilt About Y   :  0.00000000E+000
 Tilt About Z   :  0.00000000E+000
 Order          : Decenter then tilt
Surface  15     : COORDBRK
 Comment        : VIS PARALLEL IR
```

```
 Decenter X     :  0.00000000E+000
 Decenter Y     :  0.00000000E+000
 Tilt About X   : -2.37200000E-002
 Tilt About Y   :  0.00000000E+000
 Tilt About Z   :  0.00000000E+000
 Order          : Decenter then tilt
Surface  16     : STANDARD
 Comment        : VIS SPIEGEL
Surface  17     : COORDBRK
 Decenter X     :  0.00000000E+000
 Decenter Y     :  0.00000000E+000
 Tilt About X   :  2.37200000E-002
 Tilt About Y   :  0.00000000E+000
 Tilt About Z   :  0.00000000E+000
 Order          : Decenter then tilt
Surface  18     : COORDBRK
 Decenter X     :  0.00000000E+000
 Decenter Y     :  0.00000000E+000
 Tilt About X   :  4.50000000E+001
 Tilt About Y   :  0.00000000E+000
 Tilt About Z   :  0.00000000E+000
 Order          : Decenter then tilt
Surface  19     : COORDBRK
 Decenter X     :  0.00000000E+000
 Decenter Y     :  0.00000000E+000
 Tilt About X   :  0.00000000E+000
 Tilt About Y   :  0.00000000E+000
 Tilt About Z   :  0.00000000E+000
 Order          : Decenter then tilt
Surface  20     : COORDBRK
 Comment        : VIS -191 ACHSE
 Decenter X     :  0.00000000E+000
 Decenter Y     : -1.91000000E+002
 Tilt About X   :  0.00000000E+000
 Tilt About Y   :  0.00000000E+000
 Tilt About Z   :  0.00000000E+000
 Order          : Decenter then tilt
Surface  21     : STANDARD
 Comment        : EINGANG ROHR
Surface  22     : COORDBRK
 Comment        : BILD ZENTRIEREN
 Decenter X     :  0.00000000E+000
 Decenter Y     :  1.91147807E+002
 Tilt About X   :  0.00000000E+000
 Tilt About Y   :  0.00000000E+000
 Tilt About Z   :  0.00000000E+000
 Order          : Decenter then tilt
Surface IMA     : STANDARD

SOLVE AND VARIABLE DATA:

Thickness of   3       : Solve, pick up value from 2, scaled by -1.00000
```

```
Semi Diameter   3       : Fixed
Thickness of    5       : Solve, pick up value from 4, scaled by -1.00000
Semi Diameter   5       : Fixed
Parameter  3 Surf  11   : Pickup from 9 times -1.000000
Parameter  3 Surf  12   : Pickup from 7 times -1.000000
Parameter  3 Surf  17   : Pickup from 15 times -1.000000
Parameter  3 Surf  18   : Pickup from 14 times 1.000000
Semi Diameter  21       : Fixed
```

3. Sequential Ray Trace Model Listing for Chopping Optical System

System/Prescription Data

File : Z:\Z-LENS\SOFIA\BASELINE\OS01-697\Zoom-cho.zmx
Title: SOFIA Chopping Design OS01-697
Date : MON SEP 15 1997

GENERAL LENS DATA:

Surfaces : 15
Stop : 7
System Aperture : Float By Stop Size = 176
Ray aiming : Real Reference, cache on
X Pupil shift : 0.0000000E+000
Y Pupil shift : 0.0000000E+000
Z Pupil shift : 0.0000000E+000
Apodization :Uniform, factor = 0.00000E+000
Eff. Focal Len. : 4.91409E+004 (in air)
Eff. Focal Len. : 4.91409E+004 (in image space)
Total Track : 6.07500E+003
Image Space F/# : 1.94574E+001
Para. Wrkng F/# : 1.94578E+001
Working F/# : 1.95071E+001
Obj. Space N.A. : 1.26278E-007
Stop Radius : 1.76000E+002
Parax. Ima. Hgt.: 1.28651E+002
Parax. Mag. : 0.00000E+000
Entr. Pup. Dia. : 2.52557E+003
Entr. Pup. Pos. : 2.25137E+004
Exit Pupil Dia. : 2.53380E+003
Exit Pupil Pos. : 4.93011E+004
Field Type : Angle in degrees
Maximum Field : 1.50000E-001
Primary Wave : 6.33000E-001
Lens Units : Millimeters
Angular Mag. : -7.17490E+000

Fields : 3
Field Type: Angle in degrees

#	X-Value	Y-Value	Weight
1	0.000000	0.000000	1.000000
2	0.000000	0.083400	1.000000
3	0.000000	0.150000	1.000000

Vignetting Factors

#	VDX	VDY	VCX	VCY
1	0.000000	0.000042	0.000000	0.000042
2	0.000000	-0.014845	0.000435	0.014843
3	0.000000	0.000000	0.000000	0.000000

Wavelengths : 1

Units: Microns

#	Value	Weight
1	0.633000	1.000000

SURFACE DATA SUMMARY:

Surf	Type	Comment	Radius	Thickness	Glass	Diameter	Conic
OBJ	STANDARD		Infinity	Infinity		0.0000000E+000	0
1	STANDARD		Infinity	0		2.6478216E+003	0
2	STANDARD		Infinity	2.7540000E+003		2.6478216E+003	0
3	STANDARD		-6.4000000E+003	-2.7540000E+003	MIRROR	2.7500000E+003	-1.0000000E+000
4	STANDARD		Infinity	-9.2496202E-004		3.6710342E+002	0
5	STANDARD		Infinity	-4.0000000E+001		3.6710262E+002	0
6	COORDBRK		-	4.0000000E+001	-	-	-
STO	STANDARD		-9.5413000E+002	-4.0000000E+001	MIRROR	3.5200000E+002	-1.2980258E+000
8	COORDBRK		-	4.0000000E+001	-	-	-
9	STANDARD		Infinity	9.2496202E-004		3.5168362E+002	0
10	STANDARD		Infinity	1.7640000E+003		3.5168359E+002	0
11	COORDBRK		-	0	-	-	-
12	STANDARD		Infinity	0	MIRROR	4.2536176E+002	0
13	COORDBRK		-	-5.0850000E+003	-	-	-
14	STANDARD		Infinity	0		1.3560632E+002	0
IMA	STANDARD		Infinity			1.3560632E+002	0

SURFACE DATA DETAIL:

Surface OBJ : STANDARD
Surface 1 : STANDARD
Surface 2 : STANDARD
Aperture : Circular Obscuration
Minimum Radius : 0
Maximum Radius : 170
Surface 3 : STANDARD
Surface 4 : STANDARD
Surface 5 : STANDARD
Surface 6 : COORDBRK
Decenter X : 0.00000000E+000
Decenter Y : 0.00000000E+000
Tilt About X : 3.12065254E-001
Tilt About Y : 0.00000000E+000
Tilt About Z : 0.00000000E+000
Order : Decenter then tilt
Surface STO : STANDARD
Surface 8 : COORDBRK
Decenter X : 0.00000000E+000
Decenter Y : 0.00000000E+000
Tilt About X : -3.12065254E-001
Tilt About Y : 0.00000000E+000
Tilt About Z : 0.00000000E+000
Order : Decenter then tilt
Surface 9 : STANDARD
Surface 10 : STANDARD

```
Surface  11     : COORDBRK
 Decenter X     :  0.00000000E+000
 Decenter Y     :  0.00000000E+000
 Tilt About X   :  4.50000000E+001
 Tilt About Y   :  0.00000000E+000
 Tilt About Z   :  0.00000000E+000
 Order          : Decenter then tilt
Surface  12     : STANDARD
Surface  13     : COORDBRK
 Decenter X     :  0.00000000E+000
 Decenter Y     :  0.00000000E+000
 Tilt About X   :  4.50000000E+001
 Tilt About Y   :  0.00000000E+000
 Tilt About Z   :  0.00000000E+000
 Order          : Decenter then tilt
Surface  14     : STANDARD
Surface IMA     : STANDARD

MULTI-CONFIGURATION DATA:

 Configuration   1:
 Field wgt   2 :             1
 Field wgt   3 :             1
 Param 3     6 :     0.3120653

 Configuration   2:
 Field wgt   2 :             0
 Field wgt   3 :             0
 Param 3     6 :             0

SOLVE AND VARIABLE DATA:

Thickness of   3       : Solve, pick up value from 2, scaled by -1.00000
Semi Diameter   3      : Fixed
Thickness of   6       : Solve, pick up value from 5, scaled by -1.00000
Thickness of   7       : Solve, pick up value from 5, scaled by 1.00000
Semi Diameter   7      : Fixed
Thickness of   8       : Solve, pick up value from 5, scaled by -1.00000
Parameter  3 Surf   8  : Pickup from 6 times -1.000000
Thickness of   9       : Solve, pick up value from 4, scaled by -1.00000
Parameter  3 Surf  13  : Pickup from 11 times 1.000000
```

4. Sequential Ray Trace Model Listing of Central Obscuring System

System/Prescription Data

File : Z:\Z-LENS\SOFIA\BASELINE\OS01-697\OBSCURATION.ZMX
Title: Sofia IR OS1-697 Abschattungen
Date : MON SEP 15 1997

GENERAL LENS DATA:

Surfaces	26
Stop	16
System Aperture	Float By Stop Size = 176
Ray aiming	Real Reference, cache on
X Pupil shift	0.0000000E+000
Y Pupil shift	0.0000000E+000
Z Pupil shift	0.0000000E+000
Apodization	Uniform, factor = 0.00000E+000
Eff. Focal Len.	4.91409E+004 (in air)
Eff. Focal Len.	4.91409E+004 (in image space)
Total Track	6.07500E+003
Image Space F/#	1.94574E+001
Para. Wrkng F/#	1.94574E+001
Working F/#	1.95098E+001
Obj. Space N.A.	1.26278E-007
Stop Radius	1.76000E+002
Parax. Ima. Hgt.	0.00000E+000
Parax. Mag.	0.00000E+000
Entr. Pup. Dia.	2.52557E+003
Entr. Pup. Pos.	2.25137E+004
Exit Pupil Dia.	3.52000E+002
Exit Pupil Pos.	6.84900E+003
Field Type	Angle in degrees
Maximum Field	0.00000E+000
Primary Wave	6.33000E-001
Lens Units	Millimeters
Angular Mag.	0.00000E+000

Fields : 1
Field Type: Angle in degrees

#	X-Value	Y-Value	Weight
1	0.000000	0.000000	1.000000

Vignetting Factors

#	VDX	VDY	VCX	VCY
1	0.000000	0.000000	0.000000	0.000000

Wavelengths : 1
Units: Microns

#	Value	Weight
1	0.633000	1.000000

SURFACE DATA SUMMARY:

Surf	Type	Comment	Radius	Thickness	Glass	Diameter	Conic
OBJ	STANDARD		Infinity	Infinity		0.0000000E+000	0
1	STANDARD		Infinity	0		2.5191953E+003	0
2	STANDARD		Infinity	0		2.5191953E+003	0
3	STANDARD		Infinity	0		2.5191953E+003	0
4	STANDARD		Infinity	0		2.5191953E+003	0
5	STANDARD		Infinity	1.7640000E+003		2.5191953E+003	0
6	COORDBRK		-	0	-	-	-
7	COORDBRK		-	0	-	-	-
8	COORDBRK		-	0	-	-	-
9	COORDBRK		-	9.9000000E+002	-	-	-
10	STANDARD		-6.4000000E+003	-9.9000000E+002	MIRROR	2.7000000E+003	-1.0000000E+000
11	STANDARD	EPD @ M3-1-EBENE	Infinity	0		1.8099268E+003	0
12	COORDBRK		-	0	-	-	-
13	STANDARD		Infinity	0		4.3345658E+003	0
14	COORDBRK		-	-1.7640000E+003	-	-	-
15	STANDARD	FOKALTRIEB	Infinity	-9.2496218E-004		3.6526125E+002	0
STO	STANDARD		-9.5413000E+002	9.2496218E-004	MIRROR	3.5200000E+002	-1.2980258E+000
17	STANDARD		Infinity	1.7640000E+003		3.5116976E+002	0
18	COORDBRK		-	0	-	-	-
19	STANDARD		Infinity	0	MIRROR	3.7842073E+002	0
20	COORDBRK		-	0	-	-	-
21	COORDBRK		-	-1.4750000E+003	-	-	-
22	COORDBRK		-	0	-	-	-
23	STANDARD		Infinity	-3.6100000E+003		6.0000000E+002	0
24	COORDBRK		-	0	-	-	-
25	STANDARD	'+/- 600MM SHIFT	Infinity	0		1.4381953E-009	0
IMA	STANDARD		Infinity			1.4381953E-009	0

SURFACE DATA DETAIL:

Surface OBJ : STANDARD
Surface 1 : STANDARD
Aperture : Rectangular Obscuration
X Half Width : 10
Y Half Width : 700
X- Decenter : 160
Y- Decenter : 700
Surface 2 : STANDARD
Aperture : Rectangular Obscuration
X Half Width : 10
Y Half Width : 700
X- Decenter : -160
Y- Decenter : -700
Surface 3 : STANDARD
Aperture : Rectangular Obscuration
X Half Width : 700
Y Half Width : 10
X- Decenter : 700
Y- Decenter : -160

```
Surface   4     : STANDARD
 Aperture       : Rectangular Obscuration
 X Half Width   :            700
 Y Half Width   :             10
 X- Decenter    :           -700
 Y- Decenter    :            160
Surface   5     : STANDARD
Surface   6     : COORDBRK
 Decenter X     :  0.00000000E+000
 Decenter Y     :  0.00000000E+000
 Tilt About X   :  4.50000000E+001
 Tilt About Y   :  0.00000000E+000
 Tilt About Z   :  0.00000000E+000
 Order          : Decenter then tilt
Surface   7     : COORDBRK
 Decenter X     :  0.00000000E+000
 Decenter Y     :  0.00000000E+000
 Tilt About X   :  0.00000000E+000
 Tilt About Y   :  0.00000000E+000
 Tilt About Z   :  0.00000000E+000
 Order          : Decenter then tilt
Surface   8     : COORDBRK
 Decenter X     :  0.00000000E+000
 Decenter Y     :  0.00000000E+000
 Tilt About X   : -4.50000000E+001
 Tilt About Y   :  0.00000000E+000
 Tilt About Z   :  0.00000000E+000
 Order          : Decenter then tilt
Surface   9     : COORDBRK
 Decenter X     :  0.00000000E+000
 Decenter Y     :  0.00000000E+000
 Tilt About X   :  0.00000000E+000
 Tilt About Y   :  0.00000000E+000
 Tilt About Z   :  0.00000000E+000
 Order          : Decenter then tilt
Surface  10     : STANDARD
Surface  11     : STANDARD
 Comment        : EPD @ M3-1-EBENE
Surface  12     : COORDBRK
 Decenter X     :  0.00000000E+000
 Decenter Y     :  0.00000000E+000
 Tilt About X   :  4.50000000E+001
 Tilt About Y   :  0.00000000E+000
 Tilt About Z   :  0.00000000E+000
 Order          : Decenter then tilt
Surface  13     : STANDARD
Surface  14     : COORDBRK
 Decenter X     :  0.00000000E+000
 Decenter Y     :  0.00000000E+000
 Tilt About X   : -4.50000000E+001
 Tilt About Y   :  0.00000000E+000
 Tilt About Z   :  0.00000000E+000
```

```
 Order          : Decenter then tilt
Surface  15     : STANDARD
 Comment        : FOKALTRIEB
Surface STO     : STANDARD
Surface  17     : STANDARD
Surface  18     : COORDBRK
 Decenter X     :  0.00000000E+000
 Decenter Y     :  0.00000000E+000
 Tilt About X   :  4.50000000E+001
 Tilt About Y   :  0.00000000E+000
 Tilt About Z   :  0.00000000E+000
 Order          : Decenter then tilt
Surface  19     : STANDARD
Surface  20     : COORDBRK
 Decenter X     :  0.00000000E+000
 Decenter Y     :  0.00000000E+000
 Tilt About X   :  4.50000000E+001
 Tilt About Y   :  0.00000000E+000
 Tilt About Z   :  0.00000000E+000
 Order          : Decenter then tilt
Surface  21     : COORDBRK
 Decenter X     :  0.00000000E+000
 Decenter Y     :  0.00000000E+000
 Tilt About X   :  0.00000000E+000
 Tilt About Y   :  0.00000000E+000
 Tilt About Z   :  0.00000000E+000
 Order          : Decenter then tilt
Surface  22     : COORDBRK
 Decenter X     :  0.00000000E+000
 Decenter Y     :  8.40000000E+001
 Tilt About X   :  0.00000000E+000
 Tilt About Y   :  0.00000000E+000
 Tilt About Z   :  0.00000000E+000
 Order          : Decenter then tilt
Surface  23     : STANDARD
Surface  24     : COORDBRK
 Decenter X     :  0.00000000E+000
 Decenter Y     : -8.40000000E+001
 Tilt About X   :  0.00000000E+000
 Tilt About Y   :  0.00000000E+000
 Tilt About Z   :  0.00000000E+000
 Order          : Decenter then tilt
Surface  25     : STANDARD
 Comment        : '+/- 600MM SHIFT
Surface IMA     : STANDARD

SOLVE AND VARIABLE DATA:

Parameter  3 Surf   8  : Pickup from 6 times -1.000000
Thickness of  10       : Solve, pick up value from 9, scaled by -1.00000
Semi Diameter  10      : Fixed
Thickness of  14       : Solve, pick up value from 5, scaled by -1.00000
```

```
Parameter  3 Surf  14  : Pickup from 12 times -1.000000
Thickness of  16       : Solve, pick up value from 15, scaled by -1.00000
Semi Diameter  16      : Fixed
Thickness of  17       : Solve, pick up value from 5, scaled by 1.00000
Parameter  3 Surf  20  : Pickup from 18 times 1.000000
Semi Diameter  23      : Fixed
Parameter  2 Surf  24  : Pickup from 22 times -1.000000
```

5. Sequential Ray Trace Model Listing of Obscured Beam Optical System

System/Prescription Data

File : Z:\Z-LENS\SOFIA\BASELINE\OS01-697\Button.zmx
Title: Sofia IR, Central Button M2
Date : MON SEP 15 1997

GENERAL LENS DATA:

Surfaces	17
Stop	15
System Aperture	Float By Stop Size = 177
Ray aiming	Real Reference, cache on
X Pupil shift	0.0000000E+000
Y Pupil shift	0.0000000E+000
Z Pupil shift	0.0000000E+000
Apodization	Uniform, factor = 0.00000E+000
Eff. Focal Len.	4.77065E+002 (in air)
Eff. Focal Len.	4.77065E+002 (in image space)
Total Track	6.07500E+003
Image Space F/#	6.33069E+000
Para. Wrkng F/#	6.24294E+000
Working F/#	6.26293E+000
Obj. Space N.A.	5.21533E-003
Stop Radius	1.77000E+002
Parax. Ima. Hgt.	3.75085E+000
Parax. Mag.	6.51189E-002
Entr. Pup. Dia.	7.53574E+001
Entr. Pup. Pos.	-7.22451E+003
Exit Pupil Dia.	3.54000E+002
Exit Pupil Pos.	9.90000E+002
Field Type	Object height in Millimeters
Maximum Field	5.76000E+001
Primary Wave	6.33000E-001
Lens Units	Millimeters
Angular Mag.	2.12874E-001

Fields : 4
Field Type: Object height in Millimeters

#	X-Value	Y-Value	Weight
1	0.000000	0.000000	1.000000
2	0.000000	57.600000	1.000000
3	0.000000	-57.600000	1.000000
4	57.600000	0.000000	1.000000

Vignetting Factors

#	VDX	VDY	VCX	VCY
1	0.000000	0.000000	0.000000	0.000000
2	0.000000	0.000000	0.000000	0.000000
3	0.000000	0.000000	0.000000	0.000000
4	0.000000	0.000000	0.000000	0.000000

Wavelengths : 1
Units: Microns

#	Value	Weight
1	0.633000	1.000000

SURFACE DATA SUMMARY:

Surf	Type	Comment	Radius	Thickness	Glass	Diameter	Conic
OBJ	STANDARD		Infinity	0		1.1520000E+002	0
1	STANDARD	600MM SHIFT	Infinity	0		1.1520000E+002	0
2	STANDARD		Infinity	-3.6100000E+003		1.1520000E+002	0
3	COORDBRK	IR 84MM DEZENTR.	-	0	-	-	-
4	STANDARD	EINGANG ROHR	Infinity	0		6.0000000E+002	0
5	COORDBRK		-	-1.4750000E+003	-	-	-
6	COORDBRK		-	0	-	-	-
7	COORDBRK		-	0	-	-	-
8	COORDBRK	M3-1 ZENTRIERUNG	-	0	-	-	-
9	STANDARD	TERTIAERSPIEGEL	Infinity	0	MIRROR	1.3040615E+002	0
10	COORDBRK		-	0	-	-	-
11	COORDBRK		-	1.7640000E+003	-	-	-
12	STANDARD	FOKALTRIEB	Infinity	9.2495298E-004		7.7339451E+001	0
13	STANDARD	SEKUNDAERSPIEGEL	9.5413000E+002	-9.2495298E-004	MIRROR	7.7335115E+001	-1.2980258E+000
14	STANDARD		Infinity	-1.7640000E+003		7.7458079E+001	0
STO	STANDARD		Infinity	0		3.5400000E+002	0
16	STANDARD		Infinity	-9.9000000E+002		3.5400000E+002	0
IMA	STANDARD		Infinity			5.1595510E+002	0

SURFACE DATA DETAIL:

Surface OBJ : STANDARD
Surface 1 : STANDARD
Comment : 600MM SHIFT
Surface 2 : STANDARD
Surface 3 : COORDBRK
Comment : IR 84MM DEZENTR.
Decenter X : 0.00000000E+000
Decenter Y : 8.40000000E+001
Tilt About X : 0.00000000E+000
Tilt About Y : 0.00000000E+000
Tilt About Z : 0.00000000E+000
Order : Decenter then tilt
Surface 4 : STANDARD
Comment : EINGANG ROHR
Surface 5 : COORDBRK
Decenter X : 0.00000000E+000
Decenter Y : -8.40000000E+001
Tilt About X : 0.00000000E+000
Tilt About Y : 0.00000000E+000
Tilt About Z : 0.00000000E+000
Order : Decenter then tilt
Surface 6 : COORDBRK

```
 Decenter X      :  0.00000000E+000
 Decenter Y      :  0.00000000E+000
 Tilt About X    :  0.00000000E+000
 Tilt About Y    :  0.00000000E+000
 Tilt About Z    :  0.00000000E+000
 Order           : Decenter then tilt
Surface   7      : COORDBRK
 Decenter X      :  0.00000000E+000
 Decenter Y      :  0.00000000E+000
 Tilt About X    :  4.50000000E+001
 Tilt About Y    :  0.00000000E+000
 Tilt About Z    :  0.00000000E+000
 Order           : Decenter then tilt
Surface   8      : COORDBRK
 Comment         : M3-1 ZENTRIERUNG
 Decenter X      :  0.00000000E+000
 Decenter Y      : -3.45000000E+000
 Tilt About X    :  0.00000000E+000
 Tilt About Y    :  0.00000000E+000
 Tilt About Z    :  0.00000000E+000
 Order           : Decenter then tilt
Surface   9      : STANDARD
 Comment         : TERTIAERSPIEGEL
 Aperture        : Elliptical Aperture
 X Half Width    :            177
 Y Half Width    :            250
Surface  10      : COORDBRK
 Decenter X      :  0.00000000E+000
 Decenter Y      :  3.45000000E+000
 Tilt About X    :  0.00000000E+000
 Tilt About Y    :  0.00000000E+000
 Tilt About Z    :  0.00000000E+000
 Order           : Decenter then tilt
Surface  11      : COORDBRK
 Decenter X      :  0.00000000E+000
 Decenter Y      :  0.00000000E+000
 Tilt About X    :  4.50000000E+001
 Tilt About Y    :  0.00000000E+000
 Tilt About Z    :  0.00000000E+000
 Order           : Decenter then tilt
Surface  12      : STANDARD
 Comment         : FOKALTRIEB
Surface  13      : STANDARD
 Comment         : SEKUNDAERSPIEGEL
Surface  14      : STANDARD
Surface STO      : STANDARD
Surface  16      : STANDARD
Surface IMA      : STANDARD

SOLVE AND VARIABLE DATA:

Semi Diameter   3       : Fixed
```

```
Semi Diameter   4      : Fixed
Semi Diameter   5      : Fixed
Parameter  2 Surf   5  : Pickup from 3 times -1.000000
Parameter  2 Surf  10  : Pickup from 8 times -1.000000
Thickness of  13       : Solve, pick up value from 12, scaled by -1.00000
Thickness of  14       : Solve, pick up value from 11, scaled by -1.00000
Semi Diameter  15      : Fixed
```

6. Sequential Ray Trace Model Listing of vis. Obscuration System

System/Prescription Data

File : Z:\Z-LENS\SOFIA\BASELINE\OS01-697\Vis-vig.zmx
Title: OS01-697: Vignetting of VIS at Tube and M3-1
Date : TUE SEP 23 1997

GENERAL LENS DATA:

Surfaces : 26
Stop : 24
System Aperture : Float By Stop Size = 175
Ray aiming : Paraxial Reference, cache on
X Pupil shift : 0.0000000E+000
Y Pupil shift : 0.0000000E+000
Z Pupil shift : 0.0000000E+000
Apodization :Uniform, factor = 0.00000E+000
Eff. Focal Len. : -1.00000E+010 (in air)
Eff. Focal Len. : -1.00000E+010 (in image space)
Total Track : 2.53454E+003
Image Space F/# : 2.85714E+007
Para. Wrkng F/# : 1.95497E+001
Working F/# : 1.95513E+001
Obj. Space N.A. : 2.55675E-002
Stop Radius : 1.75000E+002
Parax. Ima. Hgt.: 5.72000E+001
Parax. Mag. : 1.00000E+000
Entr. Pup. Dia. : 3.50000E+002
Entr. Pup. Pos. : 3.50961E+003
Exit Pupil Dia. : 3.50000E+002
Exit Pupil Pos. : 5.00000E+002
Field Type : Object height in Millimeters
Maximum Field : 5.72000E+001
Primary Wave : 6.33000E-001
Lens Units : Millimeters
Angular Mag. : -1.00000E+000

Fields : 5
Field Type: Object height in Millimeters

#	X-Value	Y-Value	Weight
1	0.000000	0.000000	1.000000
2	0.000000	57.200000	1.000000
3	0.000000	-57.200000	1.000000
4	57.200000	0.000000	1.000000
5	-57.200000	0.000000	1.000000

Vignetting Factors

#	VDX	VDY	VCX	VCY
1	0.000000	0.000000	0.000000	0.000000
2	0.000000	0.000000	0.000000	0.000000
3	0.000000	0.000000	0.000000	0.000000

4 0.000000 0.000000 0.000000 0.000000
5 0.000000 0.000000 0.000000 0.000000

Wavelengths : 1
Units: Microns

#	Value	Weight
1	0.633000	1.000000

SURFACE DATA SUMMARY:

Surf	Type	Comment	Radius	Thickness	Glass	Diameter	Conic
OBJ	STANDARD		Infinity	3.3327900E+003		1.1440000E+002	0
1	COORDBRK		-	0	-	-	-
2	COORDBRK		-	0	-	-	-
3	STANDARD	NASMYTH EINGANG	Infinity	0		6.1127969E+002	0
4	COORDBRK		-	0	-	-	-
5	STANDARD		Infinity	1.4750000E+003		2.2929358E+002	0
6	COORDBRK		-	0	-	-	-
7	COORDBRK		-	0	-	-	-
8	COORDBRK	SHIFT M3-1	-	0	-	-	-
9	STANDARD	OBS VOM M3-1	Infinity	0		1.1609798E+003	0
10	COORDBRK		-	0	-	-	-
11	COORDBRK		-	0	-	-	-
12	COORDBRK		-	0	-	-	-
13	COORDBRK	LAT. STRAHLVERS.	-	1.4180000E+001	-	-	-
14	COORDBRK		-	0	-	-	-
15	STANDARD	M3-2	Infinity	0	MIRROR	4.0383314E+002	0
16	COORDBRK		-	0	-	-	-
17	COORDBRK		-	-2.2554000E+002	-	-	-
18	COORDBRK		-	0	-	-	-
19	COORDBRK		-	0	-	-	-
20	STANDARD		Infinity	-4.5000000E+001	SILICA	4.5778401E+002	0
21	STANDARD	IR-TEILERSCHICHT	Infinity	0		4.0924723E+002	0
22	COORDBRK		-	0	-	-	-
23	COORDBRK		-	-1.7640000E+003	-	-	-
STO	STANDARD		Infinity	0		3.5000000E+002	0
25	STANDARD		Infinity	-5.0000000E+002		3.5000000E+002	0
IMA	STANDARD		Infinity			3.8397824E+002	0

SURFACE DATA DETAIL:

Surface OBJ : STANDARD
Surface 1 : COORDBRK
Decenter X : 0.00000000E+000
Decenter Y : 0.00000000E+000
Tilt About X : 0.00000000E+000
Tilt About Y : 0.00000000E+000
Tilt About Z : 0.00000000E+000
Order : Decenter then tilt
Surface 2 : COORDBRK
Decenter X : 0.00000000E+000
Decenter Y : 1.91000000E+002

```
 Tilt About X    :  0.00000000E+000
 Tilt About Y    :  0.00000000E+000
 Tilt About Z    :  0.00000000E+000
 Order           : Decenter then tilt
Surface   3      : STANDARD
 Comment         : NASMYTH EINGANG
 Aperture        : Circular Aperture
 Minimum Radius :              0
 Maximum Radius :            300
Surface   4      : COORDBRK
 Decenter X      :  0.00000000E+000
 Decenter Y      : -1.91000000E+002
 Tilt About X    :  0.00000000E+000
 Tilt About Y    :  0.00000000E+000
 Tilt About Z    :  0.00000000E+000
 Order           : Decenter then tilt
Surface   5      : STANDARD
Surface   6      : COORDBRK
 Decenter X      :  0.00000000E+000
 Decenter Y      :  2.75000000E+002
 Tilt About X    :  0.00000000E+000
 Tilt About Y    :  0.00000000E+000
 Tilt About Z    :  0.00000000E+000
 Order           : Decenter then tilt
Surface   7      : COORDBRK
 Decenter X      :  0.00000000E+000
 Decenter Y      :  0.00000000E+000
 Tilt About X    :  4.50000000E+001
 Tilt About Y    :  0.00000000E+000
 Tilt About Z    :  0.00000000E+000
 Order           : Decenter then tilt
Surface   8      : COORDBRK
 Comment         : SHIFT M3-1
 Decenter X      :  0.00000000E+000
 Decenter Y      :  3.45000000E+000
 Tilt About X    :  0.00000000E+000
 Tilt About Y    :  0.00000000E+000
 Tilt About Z    :  0.00000000E+000
 Order           : Decenter then tilt
Surface   9      : STANDARD
 Comment         : OBS VOM M3-1
 Aperture        : Elliptical Obscuration
 X Half Width    :            177
 Y Half Width    :            250
Surface  10      : COORDBRK
 Decenter X      :  0.00000000E+000
 Decenter Y      : -3.45000000E+000
 Tilt About X    :  0.00000000E+000
 Tilt About Y    :  0.00000000E+000
 Tilt About Z    :  0.00000000E+000
 Order           : Decenter then tilt
Surface  11      : COORDBRK
```

```
 Decenter X      :  0.00000000E+000
 Decenter Y      :  0.00000000E+000
 Tilt About X    : -4.50000000E+001
 Tilt About Y    :  0.00000000E+000
 Tilt About Z    :  0.00000000E+000
 Order           : Decenter then tilt
Surface  12      : COORDBRK
 Decenter X      :  0.00000000E+000
 Decenter Y      : -2.75000000E+002
 Tilt About X    :  0.00000000E+000
 Tilt About Y    :  0.00000000E+000
 Tilt About Z    :  0.00000000E+000
 Order           : Decenter then tilt
Surface  13      : COORDBRK
 Comment         : LAT. STRAHLVERS.
 Decenter X      :  0.00000000E+000
 Decenter Y      :  0.00000000E+000
 Tilt About X    :  0.00000000E+000
 Tilt About Y    :  0.00000000E+000
 Tilt About Z    :  0.00000000E+000
 Order           : Decenter then tilt
Surface  14      : COORDBRK
 Decenter X      :  0.00000000E+000
 Decenter Y      :  0.00000000E+000
 Tilt About X    :  4.50000000E+001
 Tilt About Y    :  0.00000000E+000
 Tilt About Z    :  0.00000000E+000
 Order           : Decenter then tilt
Surface  15      : STANDARD
 Comment         : M3-2
Surface  16      : COORDBRK
 Decenter X      :  0.00000000E+000
 Decenter Y      :  0.00000000E+000
 Tilt About X    :  4.50000000E+001
 Tilt About Y    :  0.00000000E+000
 Tilt About Z    :  0.00000000E+000
 Order           : Decenter then tilt
Surface  17      : COORDBRK
 Decenter X      :  0.00000000E+000
 Decenter Y      :  0.00000000E+000
 Tilt About X    :  0.00000000E+000
 Tilt About Y    :  0.00000000E+000
 Tilt About Z    :  0.00000000E+000
 Order           : Decenter then tilt
Surface  18      : COORDBRK
 Decenter X      :  0.00000000E+000
 Decenter Y      :  0.00000000E+000
 Tilt About X    : -4.50000000E+001
 Tilt About Y    :  0.00000000E+000
 Tilt About Z    :  0.00000000E+000
 Order           : Decenter then tilt
Surface  19      : COORDBRK
```

```
 Decenter X      :  0.00000000E+000
 Decenter Y      :  2.84277719E+001
 Tilt About X    :  0.00000000E+000
 Tilt About Y    :  0.00000000E+000
 Tilt About Z    :  0.00000000E+000
 Order           : Decenter then tilt
Surface  20      : STANDARD
 Aperture        : Elliptical Aperture
 X Half Width    :            177
 Y Half Width    :            205
Surface  21      : STANDARD
 Comment         : IR-TEILERSCHICHT
 Aperture        : Elliptical Aperture
 X Half Width    :            177
 Y Half Width    :            250
Surface  22      : COORDBRK
 Decenter X      :  0.00000000E+000
 Decenter Y      : -3.45000000E+000
 Tilt About X    :  4.50000000E+001
 Tilt About Y    :  0.00000000E+000
 Tilt About Z    :  0.00000000E+000
 Order           : Decenter then tilt
Surface  23      : COORDBRK
 Decenter X      :  0.00000000E+000
 Decenter Y      :  0.00000000E+000
 Tilt About X    :  0.00000000E+000
 Tilt About Y    :  0.00000000E+000
 Tilt About Z    :  0.00000000E+000
 Order           : Decenter then tilt
Surface STO      : STANDARD
Surface  25      : STANDARD
Surface IMA      : STANDARD

SOLVE AND VARIABLE DATA:

Parameter  2 Surf   4  : Pickup from 2 times -1.000000
Parameter  2 Surf  10  : Pickup from 8 times -1.000000
Parameter  3 Surf  11  : Pickup from 7 times -1.000000
Parameter  2 Surf  12  : Pickup from 6 times -1.000000
Parameter  3 Surf  16  : Pickup from 14 times 1.000000
Parameter  3 Surf  22  : Pickup from 18 times -1.000000
Semi Diameter  24      : Fixed
```