Visible & Infrared Survey Telescope for Astronomy

Project Office

Tel: +44 (0)131 668 8411
Fax: +44 (0)131 668 8412
Email: vista@roe.ac.uk,
WWW: http://www.roe.ac.uk/atc/vista

Document Title:	**System Image Quality Budget of the VISTA Telescope**
Document Number:	**VIS-TRE-ATC-00002-0001**
Issue:	**3.9**
Date:	**1 September 2003**

Document Prepared By:	**Andy Born Systems Engineer**	**Signature and Date:**	**DRAFT – for review and comment only**
Document Approved By:	**Simon Craig Project Engineer**	**Signature and Date:**	**DRAFT – for review and comment only**
Document Released By:	**Alistair McPherson Project Manager**	**Signature and Date:**	**DRAFT – for review and comment only**

Reviewed By:	**Will Sutherland Project Scientist**	**Signature and Date:**	**DRAFT – for review and comment only**

Change Record

Issue	Date	Section(s) Affected	Description of Change/Change Request Reference/Remarks
1	27/3/01	All, first issue	OCDR status
2	31/5/01	5., 6., 7	Inclusion of Detector contribution, correction of typing errors
3	2/10/01	Major Rework	Inclusion of Detector smearing, Vanes diffraction (as-designed IQ) References Add wavelength bands (r',i',z',J) New as-designed values for Visible Camera Check and update of all values, addition of notes, elimination of matching error Inclusion of effect of on-line wavefront sensing
3.1	11/6/02	Major Rework	SIQ tables reconstructed, document re-worked to allow improved traceability of derivation. (Note that the revised structure of the SIQ Budget was partially generated in-parallel with the Telescope Structure Work Package Technical Specification [RD13] as an iterative process, with the SIQ budget structure being used to define the nature of the Telescope performance/tolerance requirements and *vice-versa*. This new version of the SIQ Budget represents the consolidation, justification and documentation of this process.)
3.2	31/06/02	All	Incorporating changes suggested from circulation of Draft 3.1 Also SIQ tables amended to incorporate CIQ table.
3.3	30/10/02	All	Incorporates further changes recommended from draft circulation of v3.2. Also changes to build-up of SIQ table to incorporate CIQ value.
3.4	02/12/02	All	General "tidying-up" of text and ADs, and inclusion of SIQ tables for Z, H and J bands. Deletion of tables for Visible SIQ performance.
3.5	06/01/03	All	Further cosmetic "tidying-up", and rationalisation of Note references in tables and appendices.
3.6	18/02/03	3, Appendix A	Rationalisation of ADs and RDs to remove redundant references.
3.7	19/08/03	All	Tables updated, with revised top-down allocations
3.8	26/08/03	All	Tidy-up of reference issues and appearance prior to release
3.9	01/09/03	All	Draft release for Systems Review Panel scrutiny.

Table of Contents

1 Introduction and Scope

This document provides the System Image Quality error budget of the VISTA f/1 telescope at the Cassegrain focus for the IR channel[1]. The System Image Quality (SIQ) budget is calculated assuming that the telescope will make use of an active optics system. Therefore a certain number of errors which will affect the wavefront will be partially or totally corrected in the system. The SIQ does not take into account atmospheric seeing. The SIQ is based on the Encircled Energy Diameter (EED) in accordance with that defined by the VISTA Technical Specification (AD01).

2 Acronyms and Abbreviations

ADXX	Applicable Document XX
arcsec	arcseconds
CIQ	Camera Image Quality
EED	Encircled Energy Diameter
PSF	Point Spread Function
r.m.s.	root mean square
RDXX	Referenced Document XX
SIQ	System Image Quality
WFE	Wavefront Error
w.r.t.	with respect to

3 Applicable and Referenced Documents

AD01 VISTA Technical Specification - VIS-SPE-ATC-00000-0003, issue 2.5

AD02 VLT Environmental Specification - VLT-SPE-ESO-10000-004, issue 6.

AD03 VISTA Infra-Red Camera Technical Specification – VIS-SPE-ATC-06000-0004 Issue 1.0

RD01 Optical Models for VISTA IR Camera - VIS-DES-ATC-06021-0002 Issue 1 – “FLATWINDOW#4” design case.

RD02 Overview of Primary Mirror Support - VIS-TRE-ATC-03000-0001, issue 1

RD03 Calculations for the support of the primary mirror of VISTA, L. Noethe, 8/2/2000 – appended to RD02.

[1] At present this document only details the SIQ build-up for the IR channel; the visible SIQ requirements are included for completeness.

RD04 Pixel Scale and Effects on SIQ Error Budget – VIS-TRE-00002-0022 Issue 1.0

RD05 Sensitivity Analysis in the Visible and IR Cameras - VIS-TRE-ATC-00112-0010, issue 1

RD06 Pointing and Tracking Budget of the VISTA Telescope VIS-TRE-ATC-00002-0007, issue 3.

RD07 Contributions to the SIQ from Mechanical Stability, Alignment and Positioning Errors VIS-TRE-ATC-00002-0020 Issue 1.0.

RD08 Wavefront Errors due to Axial Support Force Errors VIS-TRE-ATC-02020-0012 Issue 1.0

RD09 Technical Specification for the Telescope Structure Work Package VIS-SPE-ATC-01000-0006 Issue 2.0

RD10 Technical Specification for the Figuring and Polishing of the VISTA 4m Primary Mirror VIS-SPE-ATC-02020-0001 Issue 5.0

RD11 Technical Specification for the Design and Manufacture of the Secondary Mirror (M2) Work Package VIS-SPE-ATC-05010-0002 Issue 3.0

RD12 Camera Image Quality Budget VIS-BDG-RAL-06013-1001 Issue 1.1

4 Definitions and Conventions

4.1 System Image Quality

The image quality of the telescope is the image quality obtained after all the correction capabilities of the telescope have been put into operation. Some of the corrections are of a non-continuous nature and therefore it is assumed that corrections are put in place at regular intervals in order for the image quality not to degrade beyond the specified value, *e.g.* movement of M2, variation of M1 support forces.

The image quality is defined in terms of image size and is specified in the Vista Technical Specification (AD01) as System Image Quality (SIQ). It includes all the contributions to the image size which are dependent from the telescope, its optics, the guiding and tracking system and the local conditions generated by the dome. It includes field aberrations but does not include the contribution of the free atmospheric seeing. The contribution to the SIQ from the IR Camera is included as a separate term, the scope and maximum permissible value of which is described in AD03.

The SIQ is defined in terms of Encircled Energy Diameter (EED). It applies:

$$SIQ = \max(50\%\ EED,\ 80\%\ EED/1.54)$$

The two quantities in brackets are equal to the Full Width Half Maximum in case of a Gaussian PSF. The basic global requirements Technical Specification demands that the SIQ for the VISTA telescope shall be better than *0.4 arcsec* in the visible and *0.51 arcsec* in the infrared. Degradation is permitted for increasing windspeed, zenith distance and angular distance from the optical axis (as defined in AD01). The calculation of the SIQ is done supposing that the single error sources are uncorrelated and therefore they add quadratically to obtain the overall value.

4.2 Telescope Operating Conditions

The operating conditions of the telescope are those specified in the Environmental Specification (AD02).

5 Error Budget Structure

5.1 General

The Vista telescope is based on an active optics system. This system corrects wavefront aberrations by using elastic deformation of the active primary mirror and a five-axis control of the secondary mirror for focussing, centring (coma correction) and tilt. The system is able to correct low order optical aberration in the telescope. This not only has an impact on the specification for the optical surfaces, but it also allows the correction to a certain extent of errors of permanent and variable nature occurring during observation. In order for the error to be correctable they must be:

a) Measurable. A detection system must be in place and the frequency variation of the measuring system must be compatible with that of the error. Error varying during the read-out time of the measuring system cannot be correctly measured.

b) Fall within the dynamic range of the correcting active optics system, both in terms of frequency and amplitude. That means the elastic deformations related to the error to be corrected must be within the force and the speed of the actuators used in the deformation of the primary mirror and in the focusing and centring of the secondary mirror.

In addition, repeatable (non-random) errors (for example defocusing caused by flexure under gravity, or thermal expansion of the telescope tube) can be corrected by open-loop adjustment of the active control system. Even if the errors are of a measurable and correctable nature, a perfect correction is not possible. There will be both measuring and implementation inaccuracies which will result in residual error of the wavefront and produce an image blur in the focal plane. Therefore in the cases where the errors are corrected the error budget will include the residual error, if these residuals are expected not to be of negligible magnitude.

The errors are classified in 6 different types:

1) As-designed optical aberrations including geometrical aberrations and diffraction effects (RD01)
2) Surface errors
3) Alignment errors (assembly, and flexure/thermal)
4) Control errors
5) Environmental effects
6) Detector effects (pixel size and smearing)

5.2 As-designed Optical Aberrations

The designed values of the blur due to geometrical aberrations and diffraction are shown in document RD01. The effect of diffraction by the baffles and the vanes[2] in the secondary mirror has been taken into account in the "as designed" image quality. Therefore the value of the diffraction patch is not reported as a separate entity in the tables providing the systems image quality budget.

5.3 Surface Errors

The surface errors are deviations from the nominal surface shape of the optical elements which are remaining after active optics correction. In general they are the high spatial frequency errors beyond the first natural modes of the primary mirror. Typical example are the print-through of the axial support system, the non-correctable effect of the axial and lateral support system (*e.g.* differential thermal deformation between the primary mirror and mirror cell) and the residual matching errors between primary and secondary mirror.

Note that the matching error between the conic constant of the primary and the secondary, producing 3rd order spherical aberration is not included in the surface errors because it is correctable by the active primary[3].

5.4 Alignment and Stability Errors

Alignment and stability errors are errors in the positioning and tilt of the optical surfaces considered as rigid bodies. They are generated by manufacturing and assembly errors in the opto-mechanical systems, alignment error of the telescope, flexures, bulk temperature changes, and thermal gradients and expansion.

One part of the error is quasi-static and it can be considered as non varying ("alignment"), while another part is varying with time or with telescope inclination or Cassegrain rotator angle ("stability"). The first part is the residual which can be achieved at the time of the telescope alignment and it is limited by friction, accuracy of measurement and adjustment capability. The second part is stability (thermal and flexure) and it is partially corrected in the system through realignment.

5.5 Control Errors

Control errors are the residual effects of the active optics detection and actuation system, as well as the tracking error resulting in an undesired image motion on the focal plane.

They may also include offset errors during mosaicing in the Infrared.

---

[2] The thickness of the vanes (or "spider") used in the computation of the diffraction effect is approximately 32mm. The diameter of the baffle used is 1.625m.

[3] The active force used in correcting the spherical aberration from matching error is +-30 N allowing for correcting approximately 400 nm rms.

The tracking error introduces also an image motion which results in an image blur. The blur effect on the 50% EED is approximately 1.67 times the r.m.s. tracking error (based on a Gaussian distribution).

The results assume that fast tip-tilt (frequency greater than 1 Hz) correction will not be implemented.

5.6 Environmental Effects

The environmental effects are local air conditions in the dome or at the proximity of the primary mirror. For the purpose of this budget wind shake is included within the tracking guiding error. An estimate of the effect of local (dome) seeing is also included[4].

5.7 Detector Effects

According to the Technical Specification (AD01) the effect of detector in terms of finite pixel size and smearing shall be included in the SIQ. For the finite pixel size the contribution to the error budget should be computed by convolving the telescope PSF with a boxcar equal to the pixel scale. However for the purpose of this error budget a simplification is introduced as detailed in RD04, which is to add in quadrature a factor of (0.7 * pixel size) if the figure of merit used is 50% EED, which is a realistic approximation for pixel size between 1/3 and 1*FWHM. The pixel size used in the analysis is 0.342" in the IR.

[4] Although no formal analysis is available, the value for dome seeing is based on "intuitive" experience from VLT.

5.8 Summary Tables of Results

Table 1 below compares the results of the analysis reported in Appendix A below with the requirements of the Technical Specification (AD01).

Band	**Z(IR)**			**J**			**H**			**K_s**		
FOV	0	1.0	1.65	0	1.0	1.65	0	1.0	1.65	0	1.0	1.65
50% EED	.4423	.4699	.4600	.4423	.4699	.4751	.4310	.4649	.4916	.4465	.4804	.5411
80% EED/1.54	.4724	.4724	.4918	.4579	.4724	.5000	.4510	.4800	.5213	.4839	.5021	.5863
SIQ	.4724	.4724	.4918	.4579	.4724	.5000	.4510	.4800	.5213	.4839	.5021	.5863
SPEC. (AD01)	.5100	.5100	.6314	0.510	0.510	0.631	0.510	0.510	0.631	0.510	0.510	0.631

Table 1 - Infra-red SIQ summary

<u>Note</u>

- Field of View (FoV): Diameter in degrees
- All Image Quality in arcsec.

6 Conclusion and Recommendations

6.1 Specification Compliance

The SIQ is compliant at all wavebands and points on the FoV.

When looking at the detail of the numbers in the tables one can note that apart from the as-designed image quality, the SIQ is mainly influenced by three items:

a) <u>Surface errors</u>
These are now fixed due to the advanced state of the M1 and M2 contracts[5].

b) <u>Camera Image Quality</u>
The CIQ is the single biggest constituent of the SIQ budget, and is dominated by the large (20µm) pixel size of the Raytheon detectors.

c) <u>Control errors, focussing and coma correction</u>
These items are important and therefore it is vital that the extreme care and all reasonable effort is made to ensure that the presently specified performance of the M2 Unit is met.

[5] (Current information from LZOS suggests that they may comfortably meet their specifications releasing SIQ "contingency" elsewhere in the budget, however this must not be assumed at this stage.)

Appendix A: Tables for System Image Quality Error Budget

The system image quality error budget tables are presented below. For each table the error budget provides the value of image quality obtained on axis and off-axis, based on the optical design presented in RD01 and the sensitivity analysis presented in RD05.

Some of the values in the tables are equivalent either to specification for the optical manufacturer or corresponds to an internal specification for some VISTA subsystems. In other cases the values are estimated and provisions are taken based on experience. Where appropriate, details are given in the notes.

Effects which are known or estimated to be below 0.005 at 50% EED are not counted in the image quality budget.

(blank page)

Doc Number:	VIS-TRE-ATC-00002-0001
Date:	1 September 2003
Issue:	3.9
Page:	13 of 18
Author:	A Born

Z(IR) band 80%EED — 1.625m nested baffle, fixed M2(H), variable filter thickness

Mirror Figuring, Polishing and Support			(*Alloc'd*)	**Calc'd**			
Primary Mirror			(*0.1600*)	**0.1578**			
	Support System				0.0212		
		Axial				0.0200	See Note 1
		Lateral				0.0070	See Note 2
	Polishing Residuals				0.1490		See Note 3
	Axial Support Force Resolution				0.0270		See Note 12
	M1 Support Accuracy				0.0390		See Note 13
Secondary Mirror			(*0.1400*)	**0.1358**			
	Support System				0.0555		See Note 4
		Axial				0.0460	See Note 4
		Lateral				0.0310	See Note 4
	Polishing Residuals				0.1240		See Note 7
M2 Unit			(*0.1200*)	**0.1135**			See Note 15
Assembly Alignment			(*0.0900*)	**0.0800**			
	Focus				0.0140		See Note 5
	Tilt				0.0533		See Note 5
	Decenter				0.0580		See Note 5
Stability			(*0.1400*)	**0.1330**			
	Focus				0.0630		See Note 6
	Tilt				0.0066		See Note 7
	Decenter				0.0069		See Note 8
	Windbuffeting				0.0847		See Note 9
	Local Air				0.0770		See Note 10
	Thermal				0.0230		See Note 11
CIQ							See Note 17
	On axis		(*0.4900*)	**0.4870**			
	Off-axis 1.00 deg		(*0.4900*)	**0.4870**			
	Off-axis 1.65 deg		(*0.4900*)	**0.4870**			
Control			(*0.0400*)	**0.0340**			
	Open loop operation				0.0340		See Note 14
Tracking							
	Tracking Error		(*0.1900*)	**0.1848**			See Note 16
As designed on-axis			(*0.4500*)	**0.4200**			
As designed off-axis 1.00 deg			(*0.5000*)	**0.4200**			
As designed off-axis 1.65 deg			(*0.6800*)	**0.4700**			
						over 1.54:	
Total on-axis				**0.7275**		*0.4724*	
Total off-axis 1.00 deg				**0.7275**		*0.4724*	
Total off-axis 1.65 deg				**0.7574**		*0.4918*	

	Calc.:	Spec.:
SIQ on-axis	0.4724	0.5100
SIQ off-axis 1.0 deg	0.4724	0.5100
SIQ off-axis 1.65 deg	0.4918	0.6314

Z(IR) band 50%EED — 1.625m nested baffle, fixed M2(H), variable filter thickness

Mirror Figuring, Polishing and Support			(*Alloc'd*)	**Calc'd**		
Primary Mirror			(*0.1500*)	**0.1337**		
	Support System				0.0716	
		Axial				0.0150
		Lateral				0.0700
	Polishing Residuals				0.1100	
	Axial Support Force Resolution				0.0200	
	M1 Support Accuracy				0.0160	
Secondary Mirror			(*0.1100*)	**0.0970**		
	Support System				0.0361	
		Axial				0.0300
		Lateral				0.0200
	Polishing Residuals				0.0900	
M2 Unit			(*0.0600*)	**0.0500**		
Assembly Alignment			(*0.0600*)	**0.0524**		
	Focus				0.0100	
	Tilt				0.0410	
	Decenter				0.0310	
Stability			(*0.1000*)	**0.0884**		
	Focus				0.0450	
	Tilt				0.0051	
	Decenter				0.0039	
	Windbuffeting				0.0550	
	Local Air				0.0500	
	Thermal				0.0150	
CIQ						
	On axis		(*0.3350*)	**0.3170**		
	Off-axis 1.00 deg		(*0.3350*)	**0.3170**		
	Off-axis 1.65 deg		(*0.3350*)	**0.3170**		
Control			(*0.0200*)	**0.0140**		
	Open loop operation				0.0140	
Tracking						
	Tracking Error		(*0.1500*)	**0.1490**		
As designed on-axis			(*0.2100*)	**0.1800**		
As designed off-axis 1.00 deg			(*0.2800*)	**0.2400**		
As designed off-axis 1.65 deg			(*0.3800*)	**0.2200**		
Total on-axis				**0.4423**		
Total off-axis 1.00 deg				**0.4699**		
Total off-axis 1.65 deg				**0.4600**		

Table 2 - Z_{IR} SIQ @ 80% & 50% EED

J band 80%EED 1.625m nested baffle, fixed M2(H), variable filter thickness

			Alloc'd	Calc'd			
Mirror Figuring, Polishing and Support			(*Alloc'd*)	**Calc'd**			
	Primary Mirror		(*0.1600*)	**0.1578**			
		Support System			0.0212		
		Axial				0.0200	See Note 1
		Lateral				0.0070	See Note 2
		Polishing Residuals			0.1490		See Note 3
		Axial Support Force Resolution			0.0270		See Note 12
		M1 Support Accuracy			0.0390		See Note 13
	Secondary Mirror		(*0.1400*)	**0.1358**			
		Support System			0.0555		See Note 4
		Axial				0.0460	See Note 4
		Lateral				0.0310	See Note 4
		Polishing Residuals			0.1240		See Note 7
	M2 Unit		(*0.1200*)	**0.1135**			See Note 15
Assembly Alignment			(*0.0900*)	**0.0800**			
		Focus			0.0140		See Note 5
		Tilt			0.0533		See Note 5
		Decenter			0.0580		See Note 5
Stability			(*0.1400*)	**0.1330**			
		Focus			0.0630		See Note 6
		Tilt			0.0066		See Note 7
		Decenter			0.0069		See Note 8
		Windbuffeting			0.0847		See Note 9
		Local Air			0.0770		See Note 10
		Thermal			0.0230		See Note 11
CIQ							See Note 17
		On axis	(*0.4900*)	**0.4870**			
		Off-axis 1.00 deg	(*0.4900*)	**0.4870**			
		Off-axis 1.65 deg	(*0.4900*)	**0.4870**			
Control			(*0.0400*)	**0.0340**			
		Open loop operation			0.0340		See Note 14
Tracking							
		Tracking Error	(*0.1900*)	**0.1848**			See Note 16
As designed on-axis			(*0.4500*)	**0.3800**			
As designed off-axis 1.00 deg			(*0.5000*)	**0.4200**			
As designed off-axis 1.65 deg			(*0.6800*)	**0.4900**			
						over 1.54:	
Total on-axis				**0.7051**		*0.4579*	
Total off-axis 1.00 deg				**0.7275**		*0.4724*	
Total off-axis 1.65 deg				**0.7700**		*0.5000*	

	Calc.:	Spec.:
SIQ on-axis	0.4579	0.5100
SIQ off-axis 1.0 deg	0.4724	0.5100
SIQ off-axis 1.65 deg	0.5000	0.6314

J band 50%EED 1.625m nested baffle, fixed M2(H), variable filter thickness

			Alloc'd	Calc'd		
Mirror Figuring, Polishing and Support			(*Alloc'd*)	**Calc'd**		
	Primary Mirror		(*0.1500*)	**0.1337**		
		Support System			0.0716	
		Axial				0.0150
		Lateral				0.0700
		Polishing Residuals			0.1100	
		Axial Support Force Resolution			0.0200	
		M1 Support Accuracy			0.0160	
	Secondary Mirror		(*0.1100*)	**0.0970**		
		Support System			0.0361	
		Axial				0.0300
		Lateral				0.0200
		Polishing Residuals			0.0900	
	M2 Unit		(*0.0600*)	**0.0500**		
Assembly Alignment			(*0.0600*)	**0.0524**		
		Focus			0.0100	
		Tilt			0.0410	
		Decenter			0.0310	
Stability			(*0.1000*)	**0.0884**		
		Focus			0.0450	
		Tilt			0.0051	
		Decenter			0.0039	
		Windbuffeting			0.0550	
		Local Air			0.0500	
		Thermal			0.0150	
CIQ						
		On axis	(*0.3350*)	**0.3170**		
		Off-axis 1.00 deg	(*0.3350*)	**0.3170**		
		Off-axis 1.65 deg	(*0.3350*)	**0.3170**		
Control			(*0.0200*)	**0.0140**		
		Open loop operation			0.0140	
Tracking						
		Tracking Error	(*0.1500*)	**0.1490**		
As designed on-axis			(*0.2100*)	**0.1800**		
As designed off-axis 1.00 deg			(*0.2800*)	**0.2400**		
As designed off-axis 1.65 deg			(*0.3800*)	**0.2500**		
Total on-axis				**0.4423**		
Total off-axis 1.00 deg				**0.4699**		
Total off-axis 1.65 deg				**0.4751**		

Table 3 - J SIQ @ 80% & 50% EED

H band 80%EED 1.625m nested baffle, fixed M2(H), variable filter thickness

Item				Alloc'd	Calc'd			Note
Mirror Figuring, Polishing and Support				(*Alloc'd*)	**Calc'd**			
	Primary Mirror			(*0.1600*)	**0.1578**			
		Support System				0.0212		
			Axial				0.0200	See Note 1
			Lateral				0.0070	See Note 2
		Polishing Residuals				0.1490		See Note 3
		Axial Support Force Resolution				0.0270		See Note 12
		M1 Support Accuracy				0.0390		See Note 13
	Secondary Mirror			(*0.1400*)	**0.1358**			
		Support System				0.0555		See Note 4
			Axial				0.0460	See Note 4
			Lateral				0.0310	See Note 4
		Polishing Residuals				0.1240		See Note 7
	M2 Unit			(*0.1200*)	**0.1135**			See Note 15
Assembly Alignment				(*0.0900*)	**0.0800**			
		Focus				0.0140		See Note 5
		Tilt				0.0533		See Note 5
		Decenter				0.0580		See Note 5
Stability				(*0.1400*)	**0.1330**			
		Focus				0.0630		See Note 6
		Tilt				0.0066		See Note 7
		Decenter				0.0069		See Note 8
		Windbuffeting				0.0847		See Note 9
		Local Air				0.0770		See Note 10
		Thermal				0.0230		See Note 11
CIQ								See Note 17
		On axis		(*0.4900*)	**0.4870**			
		Off-axis 1.00 deg		(*0.4900*)	**0.4870**			
		Off-axis 1.65 deg		(*0.4900*)	**0.4870**			
Control				(*0.0400*)	**0.0340**			
		Open loop operation				0.0340		See Note 14
Tracking								
		Tracking Error		(*0.1900*)	**0.1848**			See Note 16
As designed on-axis				(*0.4500*)	**0.3600**			
As designed off-axis 1.00 deg				(*0.5000*)	**0.4400**			
As designed off-axis 1.65 deg				(*0.6800*)	**0.5400**			
							over 1.54:	
Total on-axis					**0.6945**		*0.4510*	
Total off-axis 1.00 deg					**0.7392**		*0.4800*	
Total off-axis 1.65 deg					**0.8027**		*0.5213*	

	Calc.:	Spec.:
SIQ on-axis	0.4510	0.5100
SIQ off-axis 1.0 deg	0.4800	0.5100
SIQ off-axis 1.65 deg	0.5213	0.6314

H band 50%EED 1.625m nested baffle, fixed M2(H), variable filter thickness

Item				Alloc'd	Calc'd		
Mirror Figuring, Polishing and Support				(*Alloc'd*)	**Calc'd**		
	Primary Mirror			(*0.1500*)	**0.1337**		
		Support System				0.0716	
			Axial				0.0150
			Lateral				0.0700
		Polishing Residuals				0.1100	
		Axial Support Force Resolution				0.0200	
		M1 Support Accuracy				0.0160	
	Secondary Mirror			(*0.1100*)	**0.0970**		
		Support System				0.0361	
			Axial				0.0300
			Lateral				0.0200
		Polishing Residuals				0.0900	
	M2 Unit			(*0.0600*)	**0.0500**		
Assembly Alignment				(*0.0600*)	**0.0524**		
		Focus				0.0100	
		Tilt				0.0410	
		Decenter				0.0310	
Stability				(*0.1000*)	**0.0884**		
		Focus				0.0450	
		Tilt				0.0051	
		Decenter				0.0039	
		Windbuffeting				0.0550	
		Local Air				0.0500	
		Thermal				0.0150	
CIQ							
		On axis		(*0.3350*)	**0.3170**		
		Off-axis 1.00 deg		(*0.3350*)	**0.3170**		
		Off-axis 1.65 deg		(*0.3350*)	**0.3170**		
Control				(*0.0200*)	**0.0140**		
		Open loop operation				0.0140	
Tracking							
		Tracking Error		(*0.1500*)	**0.1490**		
As designed on-axis				(*0.2100*)	**0.1500**		
As designed off-axis 1.00 deg				(*0.2800*)	**0.2300**		
As designed off-axis 1.65 deg				(*0.3800*)	**0.2800**		
Total on-axis					**0.4310**		
Total off-axis 1.00 deg					**0.4649**		
Total off-axis 1.65 deg					**0.4916**		

Table 4 - H SIQ @ 80% & 50% EED

K_s band 80%EED		1.625m nested baffle, fixed M2(H), variable filter thickness					
Mirror Figuring, Polishing and Support			*(Alloc'd)*	**Calc'd**			
	Primary Mirror		*(0.1600)*	**0.1578**			
		Support System			0.0212		
		Axial				0.0200	See Note 1
		Lateral				0.0070	See Note 2
		Polishing Residuals			0.1490		See Note 3
		Axial Support Force Resolution			0.0270		See Note 12
		M1 Support Accuracy			0.0390		See Note 13
	Secondary Mirror		*(0.1400)*	**0.1358**			
		Support System			0.0555		See Note 4
		Axial				0.0460	See Note 4
		Lateral				0.0310	See Note 4
		Polishing Residuals			0.1240		See Note 7
	M2 Unit		*(0.1200)*	**0.1135**			See Note 15
Assembly Alignment			*(0.0900)*	**0.0800**			
		Focus			0.0140		See Note 5
		Tilt			0.0533		See Note 5
		Decenter			0.0580		See Note 5
Stability			*(0.1400)*	**0.1330**			
		Focus			0.0630		See Note 6
		Tilt			0.0066		See Note 7
		Decenter			0.0069		See Note 8
		Windbuffeting			0.0847		See Note 9
		Local Air			0.0770		See Note 10
		Thermal			0.0230		See Note 11
CIQ							See Note 17
		On axis	*(0.4900)*	**0.4870**			
		Off-axis 1.00 deg	*(0.4900)*	**0.4870**			
		Off-axis 1.65 deg	*(0.4900)*	**0.4870**			
Control			*(0.0400)*	**0.0340**			
		Open loop operation			0.0340		See Note 14
Tracking							
		Tracking Error	*(0.1900)*	**0.1848**			See Note 16
As designed on-axis			*(0.4500)*	**0.4500**			
As designed off-axis 1.00 deg			*(0.5000)*	**0.4950**			
As designed off-axis 1.65 deg			*(0.6800)*	**0.6800**			
						over 1.54:	
Total on-axis				**0.7452**		*0.4839*	
Total off-axis 1.00 deg				**0.7732**		*0.5021*	
Total off-axis 1.65 deg				**0.9029**		*0.5863*	

K_s band 50%EED		1.625m nested baffle, fixed M2(H), variable filter thickness					Top-Down Alloc. (80%)			Top-Down Alloc. (50%)
Mirror Figuring, Polishing and Support			*(Alloc'd)*	**Calc'd**						
	Primary Mirror		*(0.1500)*	**0.1337**					0.1600	0.1500
		Support System			0.0716					
		Axial				0.0150				
		Lateral				0.0700				
		Polishing Residuals			0.1100					
		Axial Support Force Resolution			0.0200					
		M1 Support Accuracy			0.0160					
	Secondary Mirror		*(0.1100)*	**0.0970**					0.1400	0.1100
		Support System			0.0361					
		Axial				0.0300				
		Lateral				0.0200				
		Polishing Residuals			0.0900					
	M2 Unit		*(0.0600)*	**0.0500**					0.1200	0.0600
Assembly Alignment			*(0.0600)*	**0.0524**					0.0900	0.0600
		Focus			0.0100					
		Tilt			0.0410					
		Decenter			0.0310					
Stability			*(0.1000)*	**0.0884**					0.1400	0.1000
		Focus			0.0450					
		Tilt			0.0051					
		Decenter			0.0039					
		Windbuffeting			0.0550					
		Local Air			0.0500					
		Thermal			0.0150					
CIQ										
		On axis	*(0.3350)*	**0.3170**					0.4900	0.3350
		Off-axis 1.00 deg	*(0.3350)*	**0.3170**					0.4900	0.3350
		Off-axis 1.65 deg	*(0.3350)*	**0.3170**					0.4900	0.3350
Control			*(0.0200)*	**0.0140**					0.0400	0.0200
		Open loop operation			0.0140					
Tracking										
		Tracking Error	*(0.1500)*	**0.1490**					0.1900	0.1300
As designed on-axis			*(0.2100)*	**0.1900**					0.4500	0.2100
As designed off-axis 1.00 deg			*(0.2800)*	**0.2600**					0.5000	0.2800
As designed off-axis 1.65 deg			*(0.3800)*	**0.3600**					0.6800	0.3800
							Spec:	**Calc/1.54**	**Calc:**	**Calc:**
Total on-axis				**0.4465**			*0.5100*	0.4892	0.7534	0.4748
Total off-axis 1.00 deg				**0.4804**			*0.5100*	0.5093	0.7843	0.5096
Total off-axis 1.65 deg				**0.5411**			*0.6314*	0.5907	0.9097	0.5707

	Calc.:	Spec.:
SIQ on-axis	0.4839	0.5100
SIQ off-axis 1.0 deg	0.5021	0.5100
SIQ off-axis 1.65 deg	0.5863	0.6314

Table 5 - K_s SIQ @ 80% & 50% EED

Notes to the tables

General

- The as-designed Image Quality reports the values computed in RD01.
- The ratio between 50% EED and r.m.s. wavefront slope error is 1.83 (average of effect of the first 13 modes of the primary mirror) unless the nature of aberration is known and a better value can be used.
- The ratio between 80% EED and r.m.s. wavefront slope error is 2.48 (average of effect of the first 13 modes of the primary mirror) unless the nature of aberration is known and a better value can be used.
- The typical ratio between 80% EED and 50%EED used for specific aberration is: 1.86 for 3rd order coma, 1.3 for 3rd order astigmatism, 1.4 for defocus and 2.5 for spherical aberration.
- For unknown errors the ratio is assumed to be 1.54 (assumes a Gaussian PSF).

Specific notes to the values in the tables at the present stage

Note 1: This is a print-through error. It assumes a maximum value of *0.035 arcsec r.m.s*. (at 90 degrees zenith distance) wavefront slope error which at 40 degree zenith angle corresponds is *0.008 arcsec r.m.s*. (RD02, RD03) or *0.015 arcsec 50%EED.*

Note 2: Lateral support (from VLT analysis). This covers the effect of the residual of the lateral support system and the effect of the friction in the lateral supports joints. The latter is quantified at 130Nmm producing approximately 0.012 arcsec r.m.s wavefront slope error, equivalent to 0.024 arcsec 50%EED. It is assumed that the effect is correctable to 80% by the active optics system, if sufficiently stable. Described in RD02.

Note 3: From M1 Figuring and Polishing Spec. (RD10). This assumes that the specification for the polisher is 0.06 arcsec r.m.s WF slope.

Note 4: M2 overall WFE requirement. Derived from RD11. This assumes that the specification for the polisher of M2 is 0.15arcsec r.m.s WFE slope after active correction with the primary. This produces 0.05 arcsec r.m.s WFE slope on sky. The M2 specification includes the support system, however these individual contributions have been incorporated into the SIQ budget as "placeholders" to facilitate analysis should any issues with the support system arise.

Note 5: This assembly tolerance was specified in RD09 and was felt to represent a value that was sufficiently good in terms of optical alignment without excessively driving telescope cost/risk/schedule. Its effect on image quality was calculated from the sensitivity analysis in RD05 Tables 15 & 16.

Note 6: The effect of gravity-induced flexure of the Telescope on focus is analysed in RD07 Table 5. This assumes a maximum M2 defocus of 2.0 micrometers which produces 0.08 arcsec 50%EED in the visible and 0.10 in the IR (RD05). The same defocus produces 0.12 arcsec 80% EED in the visible and 0.15 in the IR.

Note 7: The effect of gravity-induced flexure of the Telescope on M1/M2/Instrument tilt is analysed in RD07 Table 5, along with the resultant effect on image quality.

Note 8: The effect of gravity-induced flexure of the Telescope on M1/M2/Instrument decentre is analysed in RD07 Table 5, along with the resultant effect on image.

Note 9: The effect of wind buffeting on M1/M2 position/tilt is analysed in RD07 Tables 9, 10, & 11, along with the resultant effect on image quality.

Note 10: This is an intuitive estimate of dome seeing effects, based on VLT experience and included for completeness.

Note 11: The effect of thermal expansion of the Telescope (mainly on focus) is analysed in RD07 Tables 13 & 14, along with the resultant effect on image quality.

Note 12: From discrete force step-size of M1 Axial actuator. Described in RD02. *Potential to revise when manufacturer's detailed design/prototype is available.*

Note 13: From random errors in M1 axial actuator force, as described in RD08.

Note 14: Errors generated by open-loop operation between updates of the active optics system This assumes the use of look up tables between two consecutive wavefront analyses separated by 5 minutes, and corrections every 21 seconds. This results in an error of around 0.016 arcsec on 50%EED. (RD02). The error will mainly translate in astigmatism.

Note 15: From the discrete step compensation movement of the M2 Unit – calculated in RD07 Tables 17, 18 & 19. This SIQ contribution is consistent with the performance of the M2 Unit now contracted to NTE S.A., with a "realistic" degree of contingency added to it.

Note 16: Obtained from Pointing and Tracking Budget RD06.

Note 17: This is the CIQ figure provided by the camera Consortium, as detailed in RD12.

_____oOo_____