NICI Top Level Image Quality Error Budget
Version 1.0
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1.0 Introduction

This memo represents the first cut at the tolerance and error budgets for the NICI instrument. The purpose of this work is to provide goals for the engineering effort and a platform for exploring the cost and performance trade-off for system elements. The key results of this analysis are optical manufacturing tolerances, alignment requirements, flexure sensitivities, and predicted delivered performance.

The top-level error budget presented here is a summary of the detailed optical design tolerance and the surface scatter analyses. Details can be found in SDN 1007 NICI Optical Performance and SDN 1008 NICI Optical Figure Requirements.

2.0 Error Budget

Shown in the accompanying table is an initial top-level error budget. The results from this work will be used in several ways:

a. Surface tolerances will define bid packages optics.
b. The alignment tolerances will be input to the alignment plan
c. Flexure sensitivities will be used to guide the FEA analysis and final mechanical design.

This error budget provides a starting point for these design efforts. Once bids are requested the distribution of wavefront errors may be adjusted to account for the price variations in different optical elements, difficult or risky tasks in the alignment plan could cause a redistribution of alignment tolerances and FEA analyses results will feed back to re-evaluate flexure sensitivities. Thus the budget presented here is the first step in an iterative design specification process.

3.0 Error Budget Explanation

This top-level error budget is a combination of errors induced by NICI and by Gemini. The wavefront error numbers provided by Gemini have been taken at face value and are included in this budget so that the bottom line represents an expected Strehl at the telescope. The NICI team has no control over the telescope performance and cannot prove that these numbers are correct. Moreover the predicted performance for the 85 element curvature AO system is taken from Gemini predictions since the NICI system closely duplicates it. Pending more accurate modeling and in situ measurements of the telescope optics and peripheral wavefront sensor the NICI team cannot guarantee that the total system numbers are correct.

The following paragraphs describe each line of the error budget.

Residual Atmospheric Wavefront Error after AO Correction – This error represents the residual atmospheric phase error on a good night at Gemini South after the correction by an 85-element AO system assuming a bright guide star. The numbers were taken from the Gemini document “Overview of the GEMINI AO Program” which states that with a seeing of 0.45 arcseconds the corrected Strehl is 50% at J and 80 % at K. The wavefront error in nanometers is calculated from these Strehl values using the Marechal approximation.

Telescope – Wavefront errors for the telescope are taken from the MCAO error budget, which expressed the errors in nanometers of wavefront error. The Strehl values have been calculated from these wavefront errors using the Marechal approximation.

Instrument - Instrument wavefront errors are broken into two main categories. First is the scatter from the optical surfaces and second is the wavefront errors induced by misalignment of the optics caused by manufacturing and flexure induced alignment errors.

Scatter - The methods used for determining the wavefront errors caused by optical surface errors are described in detail in Attachment A. Simply put, each mirror was analyzed to determine the effect a surface error would have on the instrument wavefront . A surface accuracy requirement was developed for each mirror based on an instrument wavefront requirement and weighted by the difficulty of manufacturing the optic. The goals were to have the scatter from the relay optics be below the atmospheric scatter and for the rest of the system to be capable of high Strehl imaging.

Wavefront errors in the wavefront sensor (WFS) optics have been included in the budget. This may be pessimistic since the WFS is only capable of measuring wavefront errors down to a certain spatial scale. It is not clear at this time how to apply this correction so all of the wavefront errors from the WFS have been included.

Alignment Induced Errors – Based on experience and given the details of the NICI optical design, experience based optical positioning tolerances were selected based on known positioning, manufacturing and machining tolerances. For example, a decenter of 0.1mm allows +- .05mm for manufacturing error and +-.05 for machining errors. The table below summarizes these tolerances.

PARAMETER	***VALUE***	***UNITS***
Thickness (TTHI)	±0.10	mm
Decenter (TSDX/Y)	±0.10	mm
Runout (TIRX/Y)	±0.05	mm
Radius (TFRN)	±0.20	fringes@0.63μm

Using the Monte Carlo analysis capability in ZEMAX a tolerance analysis was done to determine the effect of these tolerances. As can be seen in the Top Level Budget these positioning tolerances cause very minor degradation in the image quality and are probably too tight. Since they represent values that we feel we can build we will leave them at these values until our analysis shows the need to relax them. A detailed description of the alignment tolerance analysis is given in Attachment B.

Flexure – An analysis of the optical design was done to determine the sensitivity of image position to tilt and decenter of the optics. These sensitivities are also presented in Attachment B. Flexure induced errors are ignored for this image quality budget. The flexure goals are so tight that the degradation in image quality based on flexure is negligible. For example a typical tilt to produce 1 pixel of movement is a few arcseconds. By comparison the alignment tolerance for tilt is 406 arcseconds. These alignment sensitivities will be used in the FEA analysis of the mechanical structures and mechanisms to determine the total image movement given the actual flexure values from the model.

Top Level Image Quality Error Budget for NICI V1.0

	RMS Wavefront error in Waves@633 nm	RMS Wavefront Error in nm	RSS Wavefront Error in nm	Strehl @ 1.25 microns	Strehl @ 1.65 microns	Strehl @ 2.2 microns	Strehl @ 3.8 microns	Strehl @ 4.8 microns
				1250	1650	2200	3800	4800
Residual Atmospheric Wavefront Error after AO correction		166	166	0.500	0.672	0.800	0.928	0.954
Seeing .45 arcseconds								
Telescope			117	0.708	0.820	0.894	0.963	0.977
Primary Mirror		60.0						
Secondary Mirror		60.0						
Tertiary Mirror		50.0						
Alignment Error		20.0						
Self Induced Seeing		50.0						
Instrument								
Scatter from Optical surfaces								
Science channel			112	0.730	0.834	0.903	0.966	0.979
Relay Collimator	0.044	27.9						
DM	0.037	23.4						
Relay Camera Mirror	0.044	27.9						
Relay Dichroic	0.020	12.7						
Occulting Mask	0.000	0.0						
Cryostat Window	0.000	0.0						
Cryostat Off-axis Parabola 1	0.093	58.9						
Cryostat Fold Flat 1	0.062	39.2						
Cryostat Dichroic	0.044	27.9						
Filter	0.022	13.9						
Cryostat Fold Flat 2	0.044	27.9						
Cryostat Off-axis Parabola 2	0.093	58.9						
Wavefront Sensor			117	0.707	0.820	0.894	0.963	0.977
Dichroic(back Surface)	0.013	8.2						
Collimator mirror	0.079	50.0						
Steering Mirror	0.053	33.5						
Camera mirror 1	0.079	50.0						
Camera mirror 2	0.079	50.0						
Membrane Mirror	0.000	0.0						
Lenslet mirror 1	0.079	50.0						
Lenslet mirror 2	0.079	50.0						
Alignment induced errors(maunfacturing, alignment and flexure)								
Science beam		13.8	14	0.995	0.997	0.998	0.999	1.000
Mean Monte Carlo Simulation(50 trials)								
+- 0.1 mm centration and +- .05mm runout								
Wavefront Sensor		30.0	30	0.978	0.987	0.993	0.998	0.998
+- 0.1 mm centration and +- .05mm runout								
				J	**H**	**K**	**L**	**M**
			RSS wavefront error in nm	**Strehl @ 1.25 microns**	**Strehl @ 1.65 microns**	**Strehl @ 2.2 microns**	**Strehl @ 3.8 microns**	**Strehl @ 4.8 microns**
		TOTALS	**262**	**17.8%**	**37.1%**	**57.3%**	**82.9%**	**88.9%**