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Effect of Telescope Deformation on Visibility and Strehl

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ABSTRACT: In order to confine the telescope specifications we investigate the effect of deforming the primary mirror on measured visibilities and Strehl ratio. The deformations due to gravity are modeled in two ways: by using Zernike mode 7, the mode having a shape close to that of mirror sag, and by directly fitting the results of a mirror analysis. As long as we can assume all telescopes have similar sag, it is concluded that while Strehl ratios are reduced there is no measurable effect on visibility.

1. INTRODUCTION

All telescope primary mirrors will sag due to the force of gravity. The amount of sag depends on the mirror itself, its mount and the orientation of the telescope. This sag varies substantially between various designs of the mirror and mount and is coupled to cost. We therefore investigate how this sag will effect Strehl ratios and measured visibility using the CHARA simulation code.

2. SIMULATOR

The simulator, like many similar programs, generates random wavefronts for a given aperture size, wind speed and coherence length and then calculates fringe visibility and Strehl ratios for each telescope pair. Unlike previous computer models the CHARA simulator performs almost all of the calculations using Zernike coefficients. Instead of propagating complete complex two dimensional arrays of many pixels through the optical chain, we track a one dimensional array of Zernike coefficients. The atmosphere is modeled by generating random coefficients with the correct power spectra (Roddier et al, 1993 and ten Brummelaar, 1995) and variance (Noll, 1976). The tilt is then removed by setting the second and third modes to zero and the Strehl ratios for each telescope is calculated, along with the visibility as defined by Tango and Twiss (1980).

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3. VARIATION OF ZERNIKE MODE 7

Several potential designs for the mirror and mount have been presented by Larry Barr (1994) each with its own cost and maximum deformation. The peak to valley deformations range from 5 to 500 nm. In order to model this sag to first order we chose to modify the seventh Zernike mode of each wavefront. Mode 7 is the mode that resembles the sag of a telescope mirror most closely (see Figure 1). For a mirror peak to valley of 500 nm, a maximum optical path length error of 1 μm is implied. If the Zernike polynomials are used to represent an optical path length change instead of a phase change, a 1 μm peak to valley deformation is the equivalent of setting the coefficient of mode 7 to 0.208. Thus in the results that follow a value of 0.208 has been used to represent the maximum mirror deformation.

Several simulation runs were performed with the same set of wavefront models. These were:

- No telescope deformation.
- Maximum deformation in one telescope.
- Maximum deformation in both telescopes.
- 10% of maximum deformation in one telescope.
- 10% of maximum deformation in both telescopes.

These simulations were run for a wavelength of 2 μm and 1m aperture and a wavelength of 0.5 μm for both a 10 cm subaperture and the full 1m aperture. The results of these simulations are presented in Tables 1, 2 and 3.

TABLE 1. Results for 2 μm wavelength and aperture size of 1 m.

Mode 7 A	Mode 7 B	Strehl A	Strehl B	Visibility
0.0000	0.0000	0.747	0.737	0.72 ± 0.07
0.2080	0.0000	0.544	0.737	0.59 ± 0.06
0.0000	0.2080	0.747	0.530	0.59 ± 0.06
0.2080	0.2080	0.544	0.530	0.72 ± 0.07
0.0208	0.0000	0.745	0.737	0.72 ± 0.07
0.0000	0.0208	0.747	0.734	0.72 ± 0.07
0.0208	0.0208	0.745	0.734	0.72 ± 0.07

In all cases the 10% of maximum deformation had little or no effect on either the Strehl ratios or the measured visibility while the maximum deformation always reduced Strehl. Note, however, that visibility is affected only when a deformation occurs in one telescope. If each telescope has the same deformation the visibility is unchanged.

4. FITTING ZERNIKE MODES TO MIRROR ANALYSIS

To test the validity of using mode 7 to simulate mirror sag the results of a mirror analysis performed by Larry Barr were obtained. These were for a particular mirror design and several load cases:

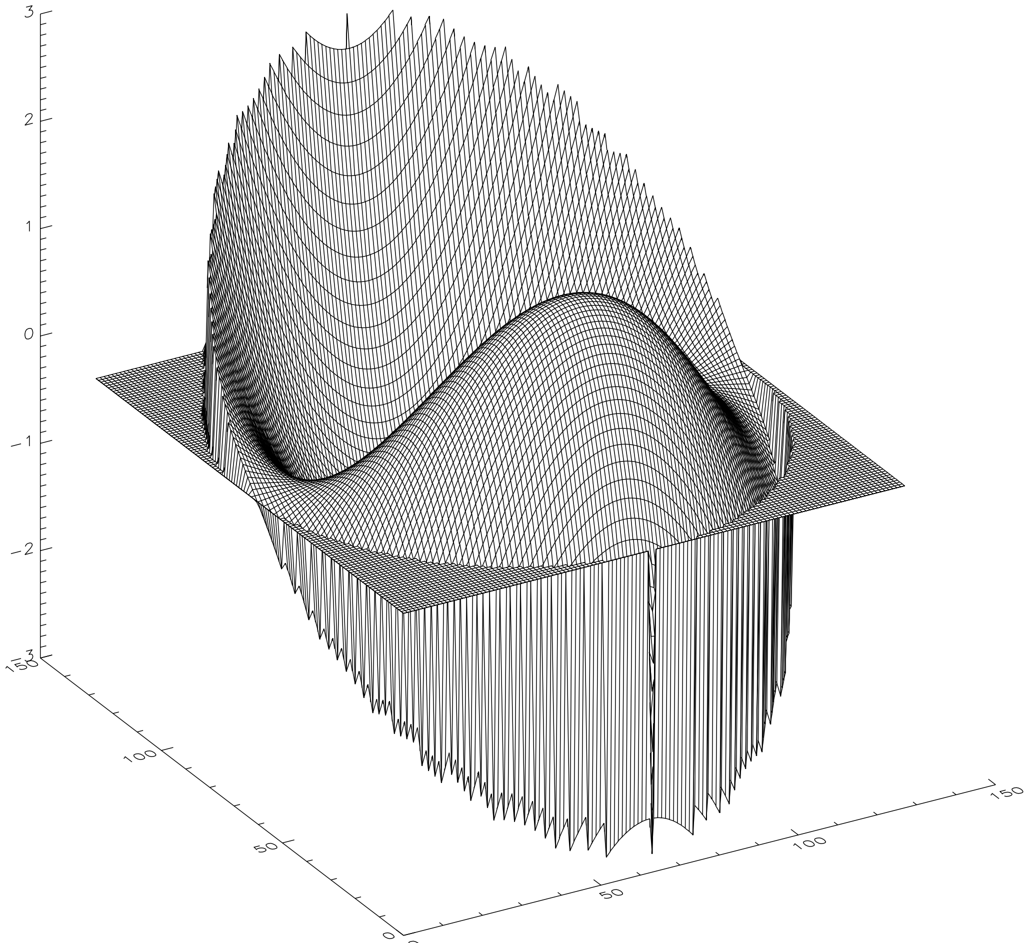

FIGURE 1. A surface plot of the 7th Zernike mode.

TABLE 2. Results for 0.5 μm wavelength and aperture size of 10 cm.

Mode 7 A	Mode 7 B	Strehl A	Strehl B	Visibility
0.0000	0.0000	0.919	0.895	0.88 ± 0.07
0.2080	0.0000	0.798	0.895	0.70 ± 0.09
0.0000	0.2080	0.919	0.790	0.70 ± 0.09
0.2080	0.2080	0.798	0.790	0.88 ± 0.07
0.0208	0.0000	0.916	0.895	0.88 ± 0.08
0.0000	0.0208	0.919	0.891	0.88 ± 0.07
0.0208	0.0208	0.916	0.891	0.88 ± 0.07

TABLE 3. Results for 0.5 μm wavelength and aperture size of 1 m.

Mode 7 A	Mode 7 B	Strehl A	Strehl B	Visibility
0.0000	0.0000	0.167	0.160	0.13 ± 0.03
0.2080	0.0000	0.128	0.160	0.09 ± 0.02
0.0000	0.2080	0.167	0.128	0.09 ± 0.02
0.2080	0.2080	0.128	0.128	0.13 ± 0.03
0.0208	0.0000	0.166	0.163	0.13 ± 0.02
0.0000	0.0208	0.167	0.156	0.13 ± 0.02
0.0208	0.0208	0.166	0.156	0.13 ± 0.02

- LDCASE2 - Zenith-pointing attitude for the telescope.
- LDCASE3 - 30° zenith angle pointing.
- LDCASE4 - 45° zenith angle pointing.
- LDCASE5 - Horizontal pointing.

These data were fitted using 105 Zernike polynomials and added to the array simulator. An example of such a fit, along with a plot of the resulting Zernike coefficients is given in Figure 2. Note that there are three peaks in the plot of the Zernike coefficients. The first two of these correspond to piston and tilt and will, to a large extent, be servoed out by the OPLE and tip/tilt systems. The third peak corresponds to mode 7, the mode used in the previous section. The fit is good except for some peaks in the data at the mount points which would require many more Zernike terms. The maximum residues are all smaller than 0.01 μm while the rms residues of the fits are of the order of 0.001 μm.

Once again the array simulator was run for the wavelengths of 2 μm for the full 1 m aperture and for 0.5μm for both the full aperture and a 10 cm subaperture. The case of equal deformation in both telescopes was not included this time as the results of the previous section demonstrated that no reduction in visibility occurs. Table 4 shows the simulation results. In all cases the affect on visibility is small (a maximum change of 0.017) and within the error bars. The Strehl of the telescope with the aberrations (telescope A) is reduced in each case but also only by a small amount.

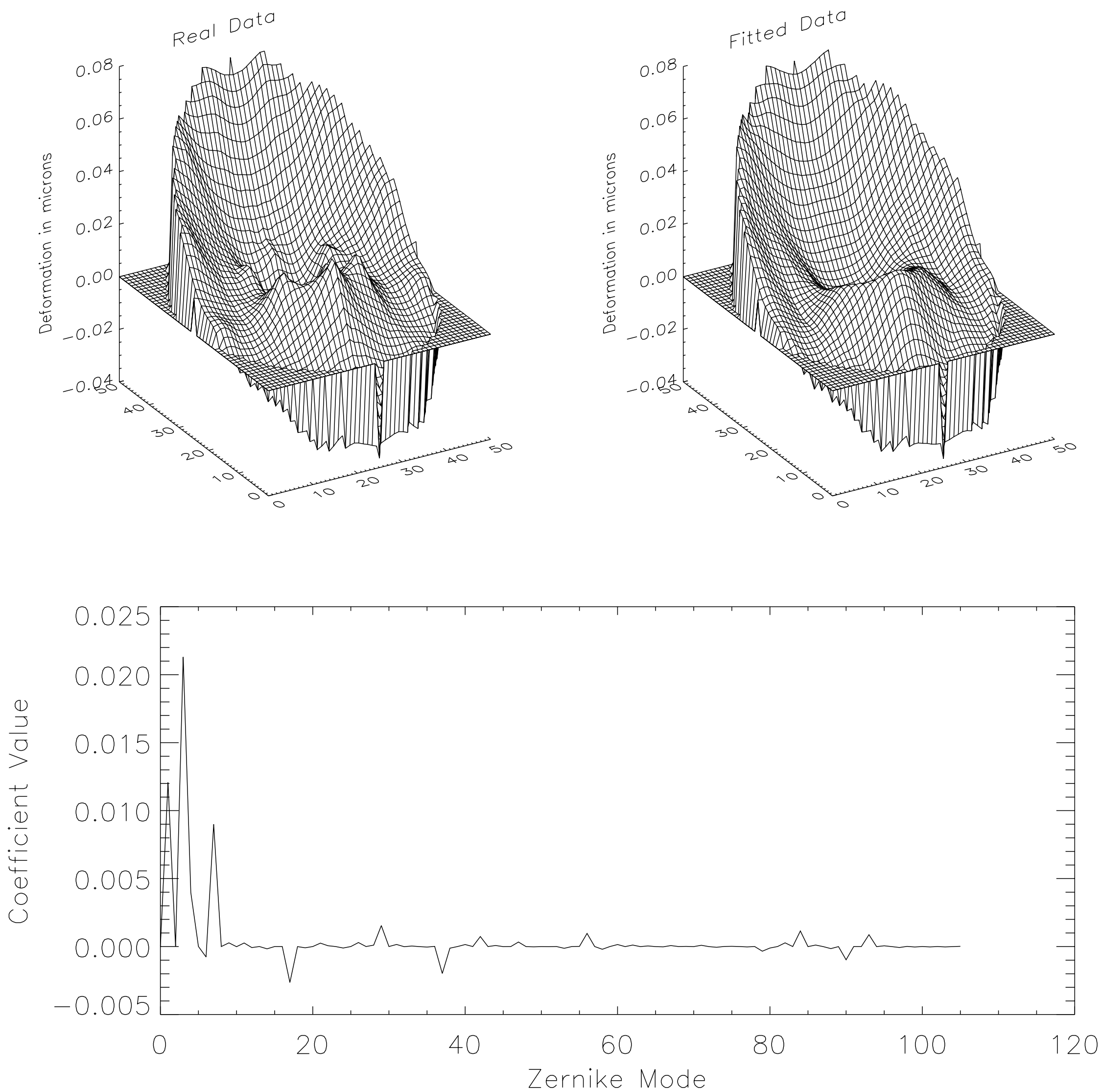

FIGURE 2. The mirror sag analysis for the case of 45° zenith angle point (top left) and the resulting fit using 105 Zernike terms (top right). The Zernike coefficients of the fit are shown at the bottom.

TABLE 4. Results of fitted data.

λ	Aperture (m)	Sag	Strehl A	Strehl B	Visibility
2.0	1.0	None	0.8928	0.8928	0.897 ± 0.050
2.0	1.0	ldcase2	0.8913	0.8928	0.896 ± 0.050
2.0	1.0	ldcase3	0.8902	0.8928	0.896 ± 0.050
2.0	1.0	ldcase4	0.8890	0.8928	0.895 ± 0.050
2.0	1.0	ldcase5	0.8864	0.8928	0.894 ± 0.050
0.5	0.1	None	0.9560	0.9580	0.959 ± 0.048
0.5	0.1	ldcase2	0.9553	0.9580	0.959 ± 0.048
0.5	0.1	ldcase3	0.9522	0.9580	0.958 ± 0.048
0.5	0.1	ldcase4	0.9490	0.9580	0.956 ± 0.049
0.5	0.1	ldcase5	0.9422	0.9580	0.953 ± 0.049
0.5	1.0	None	0.2526	0.2478	0.331 ± 0.051
0.5	1.0	ldcase2	0.2476	0.2478	0.329 ± 0.051
0.5	1.0	ldcase3	0.2431	0.2478	0.325 ± 0.051
0.5	1.0	ldcase4	0.2379	0.2478	0.322 ± 0.051
0.5	1.0	ldcase5	0.2271	0.2478	0.314 ± 0.050

5. CONCLUSION

As long as each telescope has the same sag response to within a few tens of nanometers, the absolute peak to valley of the deformations does not affect the measured visibility. So while it would be advantageous to have as little telescope deformation as possible it is not necessary to go to extreme lengths to minimize telescope sag and unduly increase the cost of the mirror and mount.

6. REFERENCES

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