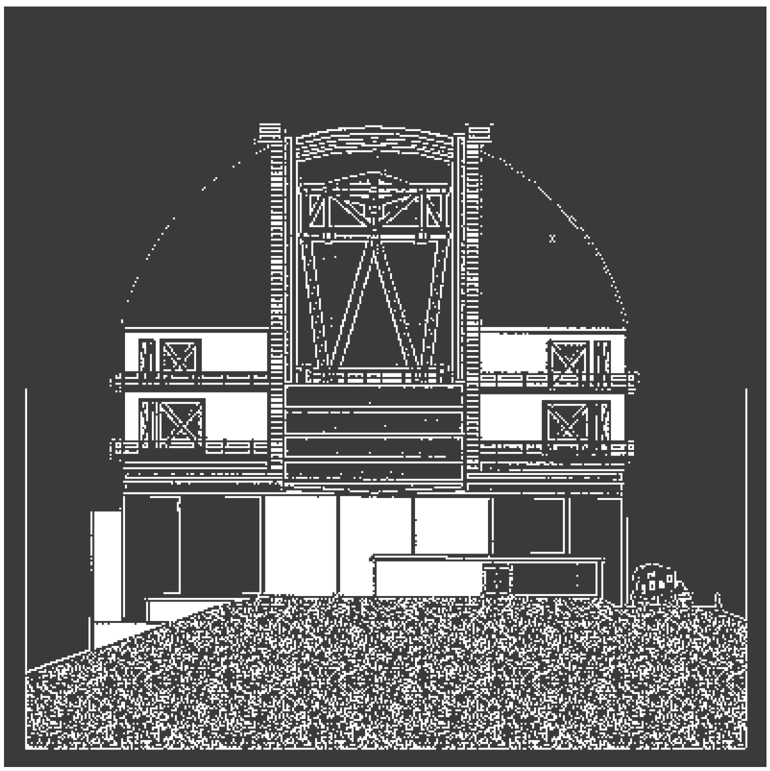
GEMINI
8-M Telescopes Project

RPT-O-G0032
Revision 1

Theoretical Active Optics Performance of the Gemini 8-M Primary Mirror



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I. EXECUTIVE SUMMARY

The Gemini Project has evaluated the capabilities of the active optics force correction system for the primary mirror. This report describes the theoretical ability of the correction system to modify the surface figure of the primary mirror to compensate for errors in its shape or errors in other telescope parameters.

This report does not address the issues of wavefront sensor accuracy or force control resolution. The finite resolution of the active optics actuators in controlling the applied forces is discussed in the Gemini technical report *Response of the Primary Mirror to Support System Errors*, which shows the available force resolution will meet the error budget requirements. The accuracy of the wavefront sensors will also be discussed in an upcoming Gemini technical report.

Test cases were established representing the possible modes in which the mirror might deform, or in which the mirror would be required to deform to maintain the required image quality at the Cassegrain focus.

A finite element model was constructed and established analysis techniques were employed to determine how effectively the active optics system could compensate for the various types of surface figure errors.

The resulting performance of the system is quite good. The system is quite effective at compensating for those bending modes and shapes that are most likely to occur. It is also capable of making changes in the conic constant of the primary mirror and compensating for the gravity sag deformation of the secondary mirror over the operational zenith angles of the telescope.

II. INTRODUCTION

The purpose of this report is to describe the performance of the active optics force correction system of the primary mirror. This system utilizes the inherent flexibility of the meniscus mirror to correct low order polishing errors in the mirror surface, make small changes in the optical properties of the primary mirror and compensate for errors due to other components in the telescope assembly.

The ability of the correction system to produce shapes corresponding to Zernike terms and natural bending modes of the blank was evaluated. These shapes accurately represent those that will be encountered during actual telescope operation. In addition, the ability to compensate for specific telescope component errors, such as deformation of the secondary mirror surface with zenith angle, was evaluated.

III. GENERAL DESCRIPTION OF THE ACTIVE OPTICS SYSTEM

The forces that change the shape of the mirror are applied by 120 force actuators driven by controlled air pressure. These actuators are combined with the passive axial hydraulic actuators located behind the mirror. They either add to or subtract from the nominal support force provided by the passive actuators. These 120 combined actuators are positioned in five circular rings and further divided into six 60° zones of 20 actuators each. The development of the location and arrangement of these actuators is described in the Gemini Technical Report, *Optimization of Support Point Locations and Force Levels of the Primary Mirror Support System*.

The pattern and level of forces that may be applied to the mirror for active optics correction vary as a function of the particular operating mode of the distributed defining system. Although the active forces applied to generate a surface figure change are exactly the same for each mode, the arrangements for producing the forces are different between the 3-zone and the 6-zone modes. Refer to Gemini Technical Report, *The Distributed Defining System for the Primary Mirrors*.

IV. TEST CASES FOR EVALUATION OF SYSTEM PERFORMANCE

The performance of the active optics force correction system was evaluated by analyzing its ability to compensate surface figure shapes corresponding to the following areas:

1) Zernike terms up to number 36
2) The first 16 natural (resonant) mode shapes
3) Changes in the conic constant and radius of curvature
4) Changes in the secondary mirror figure due to gravity sag
5) Failure of a single active force actuator

A number of other examples of the theoretical performance of the active optics system are included in the reports *Response of the Primary Mirror to Support System Errors* and *Response of the Primary Mirror to Wind Loads.*

V. ANALYSIS METHODS

To analyze the changes to the primary mirror surface figure produced by active optics forces a one-half section finite element model containing 60 support points was developed using Ideas™ software offered by Structural Dynamics Research Corporation running on a Sun Workstation. This model is shown in **Figure 1.**

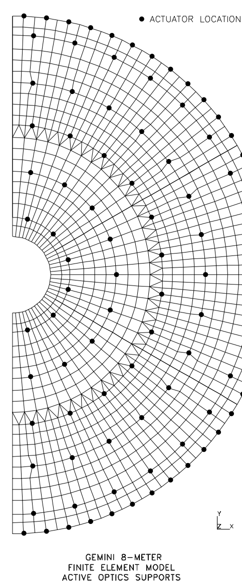


Figure 1. Finite element model used for active optics force analysis.

The analysis started by applying unit loads at each of the 60 support points of the one-half model and determining their influence on the mirror surface figure. Both symmetric and anti-symmetric cases were run for each unit load, to model the deformation of the entire mirror. Due to support system symmetry, the results of these 60 cases can be extended to represent the full 120 active force application points. These unit load cases were then combined into an influence matrix, and the matrix was used to evaluate the effect of force changes on the mirror figure.

From here, the ability of the active force system to duplicate certain shapes, such as Zernike terms or natural modes, or to compensate for aberrations in other optical elements of the system was evaluated.

VI. RESULTS

Zernike Terms

The first exercise evaluated the ability of the active optics force correction system to compensate for primary mirror surface figure shapes corresponding to the first 36 Zernike terms. A surface figure corresponding to each of the Zernike terms of 1000 nm rms amplitude was assumed for the surface figure of the primary mirror. Compensating forces were applied at the 120 support points using the influence matrix and a least squares fit until the primary mirror surface figure was as close as possible to the ideal shape. **Table 1** lists each Zernike term, its initial amplitude and the residual deviation from the ideal shape after active force correction.

Natural Modes

Next, surface errors corresponding in shape to the first 32 natural vibration modes of the primary mirror were assumed, again with an amplitude of 1000 nm rms. Compensating forces were applied at the 120 support points using the influence matrix and a least squares fit until the primary mirror surface figure was as close as possible to the ideal shape. **Table 2** lists each natural mode term, its initial amplitude and the residual deviation from the ideal shape after active force correction was applied.

Conic Constant and Radius of Curvature

Changes in the conic constant and radius of curvature have been previously analyzed and the results presented in Gemini Technical Note TN-O-G0005, *Optimum Final Surface Configuration of an 8-m Meniscus Mirror Using First and Third Order Spherical Aberration.* The technique used introduced pure spherical aberration and focus (change in radius of curvature) terms on the surface to vary the shape. The relative amounts of spherical aberration and focus were varied to find the optimum balance that produced the lowest level of residual aberration.

A later study, utilizing these techniques, evaluated the ability of the active optics force corrections system to specifically change the surface figure of the primary mirror from the baseline Ritchey-Chretien hyperboloid to a best fit paraboloid. It was found that the residual rms surface error using this optimized balance of terms was 4.0 nm with a maximum required force of 20 N when the original hyperboloid was changed to the best fit paraboloid, involving a surface rms figure change of 200 nm.

Gravity Sag of Secondary Mirror

The active optics force correction system may also be used to correct for surface deformations in other optical elements in the system. The secondary mirror undergoes gravity sag deformations as a function of increasing zenith angle of the telescope. **Figures 2, 3 and 4** show the amount of compensation possible at zenith angles of 25°, 45° and 75°. The maximum required active forces for these secondary gravity orientations are 3N, 4N, and 6N respectively. The analyses assumed that the surface error has been polished out at the zenith position.

Zernike term	Before Active P-V Error (nm)	Force Correction RMS Error (nm)	After Active P-V Error (nm)	Force Correction RMS Error (nm)	Maximum Force (N)
4	4585.8	1000	25	3	31
5	4689.1	1000	29	3	33
6	5108.2	1000	391	44	380
7	5108.2	1000	392	44	348
8	3416.8	1000	920	183	540
9	5447.8	1000	115	14	121
10	5447.8	1000	114	14	111
11	5294.8	1000	710	93	821
12	5733.1	1000	763	96	863
13	6104.0	1000	2134	252	1872
14	6104.0	1000	2149	252	1710
15	4447.8	1000	2214	445	1970
16	5709.8	1000	191	31	267
17	6136.3	1000	245	28	273
18	6349.7	1000	1401	170	1616
19	6349.7	1000	1389	170	1519
20	5547.7	1000	3020	385	2363
21	6370.2	1000	3256	396	2551
22	6899.8	1000	5607	609	3057
23	6899.8	1000	5625	609	2998
24	4249.2	1000	4466	774	1570
25	6390.0	1000	461	50	494
26	6390.0	1000	456	50	454
27	5447.2	1000	1788	258	2509
28	7051.0	1000	2367	261	2545
29	6854.9	1000	4617	526	3386
30	6854.9	1000	4600	526	3355
31	5618.1	1000	6024	695	2844
32	6655.6	1000	6609	721	2971
33	7532.6	1000	8426	749	3155
34	7532.6	1000	8431	749	2200
35	4545.1	1000	4855	704	2365
36	4740.7	1000	4814	903	1285

Table 1. Active Optics Force Correction Performance for 36 Zernike Terms.

		Before Active Force Correction		After Active Force Correction		
Mode Term	Frequency (Hz)	P-V Error (nm)	RMS Error (nm)	P-V Error (nm)	RMS Error (nm)	Maximum Force (N)
1	17.5	4340	1000	6	1	5
2	40.0	4195	1000	340	80	514
3	41.0	4852	1000	17	3	31
4	68.8	4206	1000	37	5	89
5	71.3	5214	1000	32	5	105
6	108.4	5246	1000	70	9	233
7	109.1	4141	1000	51	9	223
8	124.3	4437	1000	79	13	242
9	152.1	5452	1000	142	14	503
10	163.5	4258	1000	116	19	385
11	179.0	6704	1000	148	23	531
12	202.4	5905	1000	249	22	910
13	225.1	4285	1000	223	33	818
14	249.8	5252	1000	276	43	1038
15	259.0	6245	1000	421	35	1469
16	283.7	5343	1000	339	53	1226
17	286.4	4872	1000	441	74	993
18	292.7	4398	1000	395	53	1605
19	321.6	6527	1000	634	49	1686
20	333.0	5061	1000	485	76	2054
21	344.0	9268	1000	584	91	1966
22	366.4	4428	1000	589	79	2689
23	371.8	8624	1000	578	79	2149
24	390.3	6545	1000	891	72	3325
25	403.4	4900	1000	421	61	1401
26	421.3	5160	1000	890	126	3042
27	446.1	6654	1000	982	156	3463
28	446.3	4559	1000	918	117	4106
29	464.8	6494	1000	1151	100	4990
30	495.5	5000	1000	796	84	3334
31	512.7	5173	1000	1242	186	4582
32	520.9	4758	1000	1386	275	3829

Table 2. Active Optics Force Correction Performance for 16 First Natural Modes.

Actuator Failure Mode

Next, a failure mode where a single active force actuator malfunctions and exerts a force of 400 N upward on the mirror was evaluated. This force is in addition to the nominal support force provided by the hydraulic passive support. **Figure 5** shows contour plots of the surface of the primary mirror with a single active force actuator exerting a force of 400 N and after compensation with the other 119 active optics force actuators.

VII. SUMMARY

The ability of the active optics force correction system to compensate for surface figure errors that will occur in the primary mirror has been analyzed. It exhibits good performance for those bending shapes and modes that are most likely to occur and is also quite effective at compensating for the gravity sag deformations of the secondary mirror over the operational zenith angles of the telescope.

Figure 2. Wavefront Aberration Plots before and after active optics force correction compensating for the gravity sag of the secondary mirror at a zenith angle of 25°.

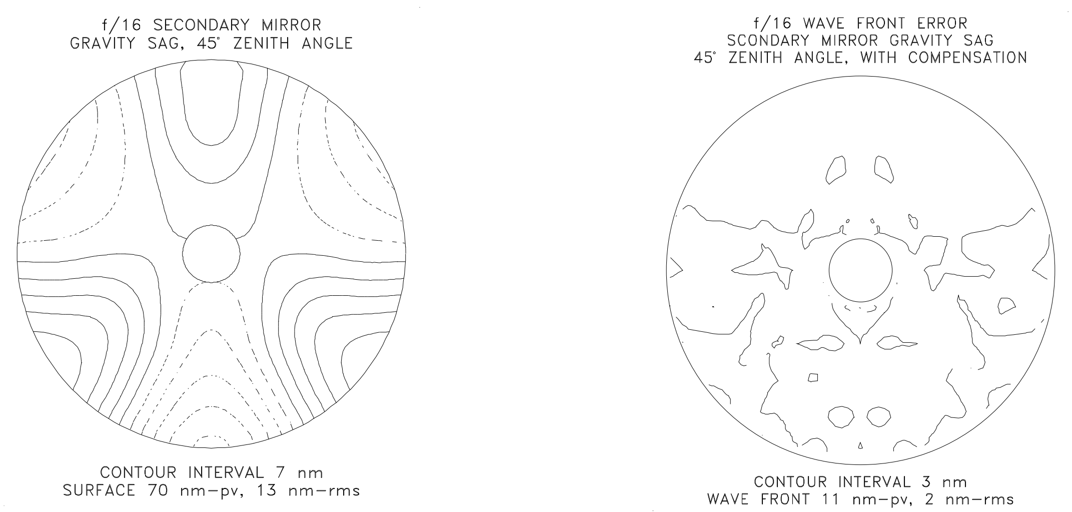


Figure 3. Wavefront Aberration Plots before and after active optics force correction compensation for the gravity sag of the secondary mirror at a zenith angle of 45°.

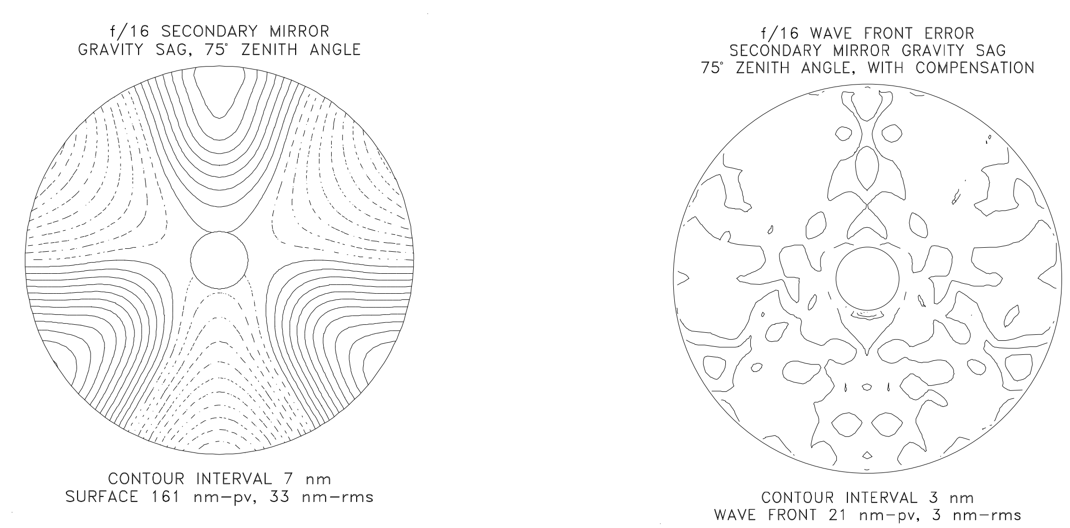
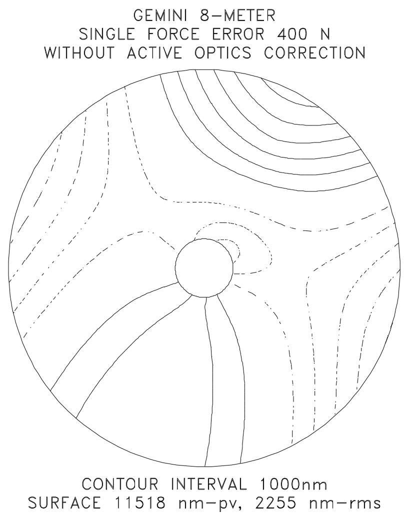


Figure 4. Wavefront Aberration Plots before and after active optics force correction compensation for the gravity sag of the secondary mirror at a zenith angle of 75°.



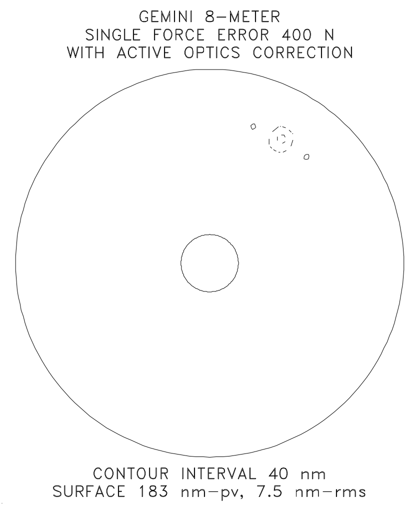


Figure 5. Primary mirror surface contour plots before and after active optics correction of a single actuator force error of 400 N. Note the change in contour interval.

VIII. ACKNOWLEDGEMENTS

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