The Smithsonian Astrophysical Observatory &
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MMT Conversion Internal Technical Memo: April 25, 1997

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FROM: Steve West

RE: Optical positions vs. optical manufacturing uncertainties for the MMT

CC: Scott DeRigne, Brian Cuerden, John Hill

1.0 Overview

This report estimates the sensitivities of the secondary, focal plane, and corrector positions vs. uncertainties in the manufacture of the primary and secondary mirrors for the MMT Cassegrain modes.

In order to accommodate realistic uncertainties, a new set of allowable errors in these parameters is proposed. The project should consider adopting these specifications, and provide the mirror lab with corresponding official manufacturing documents for each secondary mirror. I'm not suggesting that the mirror lab relax the original secondary mirror manufacturing specifications, but that the MMT project should understand just how large of uncertainties can be reasonably accommodated. This latter consideration is in some sense independent of any manufacturing specification from the mirror lab.

These new uncertainties are used to predict the maximum excursions that could be produced in the position of the secondaries, the final position of the bare image surfaces, and the corrector cell for the F/5 wide-field imaging mode. If we can accommodate realistic manufacturing uncertainties (that all co-add to yield worst case position excursions), we can be confident that our rotator and corrector cell mounting geometries will not need to be re-worked on the mountain.

2.0 Spacing variations vs. manufacturing uncertainties

For a given change in an optical parameter, the positions of M2 and the image plane which minimize the on-axis spot aberrations are estimated. No attempt herein is made to determine if these changes would adversely affect other specifications (e.g. wide field performance) because these effects have been addressed previously by Dan F. and Jim B. The OSLO procedure is to:

- put a paraxial ray height solve (0) onto the M2-image spacing.

- set the M1-M2 spacing as a variable.
- change the desired optical parameter
- let the OSLO optimizer solve for the M1-M2 spacing and M2-image spacings that minimize the on-axis spot aberrations.

Table 1 shows the changes in the positions of the secondary mirror and focal plane for very small changes in the optical constants of the primary and secondary mirrors. The wide field imaging coefficients are taken from a spreadsheet that Jim Burge developed some time ago and represent shifts that meet the wide field imaging specification throughout the 0.5-degree field of view. The corrector is focussed exactly with the BFL.

TABLE 1. Position sensitivities of the secondary and focal plane vs. change in optical constants

		Bare F/5		F/5 Wide Field		Bare F/9		Bare F/15	
Optical Constant	**Change**	**dSec (mm)**	**dBFL (mm)**	**dSec (mm)**	**dBFL (mm)**	**dSec (mm)**	**dBFL (mm)**	**dSec (mm)**	**dBFL (mm)**
Primary conic	0.0001	0.216	3.881	0.22	4.03	0.207	10.970	0.207	28.656
Primary vertex radius	1 mm	0.500	0.500	0.500	0.500	0.500	0.500	0.500	0.500
Secondary conic	0.0001	0.022	0.402	0.024	0.595	0.019	1.039	0.016	2.192
Secondary vertex radius	1mm	0.378	1.936	0.377	0.867	.413	3.531	0.457	5.839

The above table gives the sensitivities of the spacings to manufacturing uncertainties. The polarity of the spacing changes is given by the following equations illustrated for the bare F/9 optical mode. For small variations (up to 0.005 in conic and 10mm in radius), all effects simply co-add. For uncertainties in the primary mirror manufacture:

$$M1 \rightarrow \text{image} = 1777.986 - 10.970(CCP_m + 1) \cdot 10^4 - 0.5(RP_m - 16256)$$

$$M1 \rightarrow M2 = 6919.952 + 0.207(CCP_m + 1) \cdot 10^4 + 0.5(RP_m - 16256)$$

For uncertainties in the secondary mirror manufacture:

$$M1 \rightarrow \text{image} = 1777.986 + 1.039(CCS_m + 1.74922) \cdot 10^4 - 3.531(RS_m + 2805.788)$$

$$M1 \rightarrow M2 = 6919.952 - 0.019(CCS_m + 1.74922) \cdot 10^4 + 0.413(RS_m + 2805.788)$$

Where, CCP_m & CCS_m are the manufactured conics of the primary and secondary mirrors respectively. RP_m & RS_m are the manufactured vertex radii of curvatures for the primary (+) and secondary (-) mirrors.

For the other focal modes, simply substitute the nominal spacings from Table 3 (also change the secondary conic and radius appropriately) and the sensitivities from Table 1 (for the coefficients of the terms) while preserving the signs given in the equations.

3.0 Expected Manufacturing Errors for F/5 and F/9

After discussions with mirror lab personnel, it would be prudent for the MMT project to relax its official specifications for the manufacture of the secondary mirrors (section 6.2.4 of “Optical Specifications for the MMT Conversion”). Although the mirror lab believes that the original specifications are achievable in a best-effort sense, the project will benefit from insuring that larger errors can be mechanically and optically accommodated. If we allow the corrector to be co-positioned with the BFL, Jim and Dan have verified that the wide-field imaging specifications are met for optical manufacturing errors significantly larger than the original project specifications.

Table 2 summarizes the original project specifications and the proposed changes that the project should discuss adopting. The accuracy of the secondary mirror conic constant depends predominantly on the accuracy of the radius of the test plate: dCC/dR ~ CC/R.

TABLE 2. Original and proposed optical manufacturing uncertainties

Optical constant	Original project specification	Proposed specification[a]
Primary conic	±0.0001	±0.00025
Primary vertex radius	±2.5 mm	±2.5 mm

TABLE 2. Original and proposed optical manufacturing uncertainties

Optical constant	Original project specification	Proposed specification[a]
Secondary conic F/5, F/9, F/15	±(0.0003, 0.0004, 0.0005)	±(0.001, 0.0009, 0.001)
Secondary Vertex radius F/5, F/9, F/15	±(0.6, 1.1, 1.8) mm	±(2.0, 1.5, 1.5)

a. Changes to primary mirror specifications have already been adopted.

Changes to F/5 and F/9 secondaries are suggested for the MMT project to adopt.

Specifications for the F/15 are proposed for a fixed secondary and guesses for the adaptive secondary.

4.0 Maximum possible excursions

Given the maximum manufacturing errors suggested above, we can find the maximum possible displacements if all errors add constructively. Although not likely, this places conservative bounds on the positions of the secondary mirrors, focal planes, and correctors. The displacements should be accurate to 0.1 mm.

TABLE 3. Maximum possible excursions

Item	Nominal mm	Max. displ. +/- mm
Bare F/9 (M1-M2)	6919.952	2.6
Bare F/9 (M1-image)	1777.986	43.3
Bare F/5 (M1-M2)	6178.499	2.8
Bare F/5 (M1-image)	1842.31	18.8
WDFI (M1-M2)	6184.851	2.8
WDFI (M1-image)	1803.87	19.0
Bare F/15 (M1-M2)	7312.06	2.6
Bare F/15 (M1-image)	2286.99	104

In each case, the change in secondary mirror position is easily accommodated with the hexapod. *I would like others to determine whether or not the mechanical restrictions preclude these maximum possible changes in image and corrector positions*. For reference, we note that the aft surface of the instrument rotator is 1466.8 mm from the M1 vertex and 2089 mm above the observing floor.

5.0 Some remaining questions

5.1 For the MMT project:

- Can the F/5 wide field corrector cells be repositioned to the extents suggested above?
- Am I correct in assuming that the previous tolerancing done by Jim and Dan co-move the corrector cell with the BFL *without* any changes to the corrector element spacings?
- Can the F/5 and F/9 instruments live with these BFL variations?

5.2 For the SOML:

- Are the suggested manufacturing uncertainties reasonable and absolutely guaranteed?

5.3 For the fixed F/15 camp:

- Can your instruments accommodate the BFL variations shown in Table 3 -- will the instrument be too close to the floor or instrument rotator?
- Is there any other optical manufacturing considerations this memo overlooks?

5.4 For the CAAO folks:

- Do you have pre-existing conic and radius specs for the adaptive F/15?
- How much conic can be adaptively corrected without exceeding your DC power operating limits?
- How do the standard polishing specifications change for the shell? I assume they relax at some scales because of the adaptive correction--please quantify these changes.