# MMTO Internal Technical Memorandum #04-4

MMT Observatory

Smithsonian Institution &
The University of Arizona®

# Re-Evaluation of Aluminum Thickness Distribution on the MMT 6.5m Primary Mirror using New Software

**W. Kindred**

**November 2004**

## I. Abstract

Aluminum distribution modeled with new software accommodating the existing baffle geometry is presented along with an analysis of requirements and recommendations for improvement of the system.

## II. Introduction

When the MMT 6.5 m aluminizing source array and baffle assemblies were first fabricated and assembled in the fall of 2001, the staff were under tremendous time pressure. As a result some shortcuts were taken, the most consequential involving the source baffles that limit evaporant incidence angle and contain evaporant not directed at the mirror surface. The software used to model thickness distribution allowed only for cylindrical cans over each of the 200 (point) sources and the first plan was to construct an array conforming to this restriction. The implementation turned out to be problematic and time consuming, prompting consideration of alternate schemes.

One that seemed promising from a fabrication perspective was placing concentric cylindrical cans around each source-ring *assembly* instead of each source as illustrated in Figure 1. Geometric ray-tracing showed that such an arrangement would still effectively limit incidence angle and, as a result of its more open structure, smooth some of the higher frequency spatial structure in the deposited film. We could only guess at the effect on overall distribution, however. Assuming the latter was small, the source arrays were completed using the modified scheme.

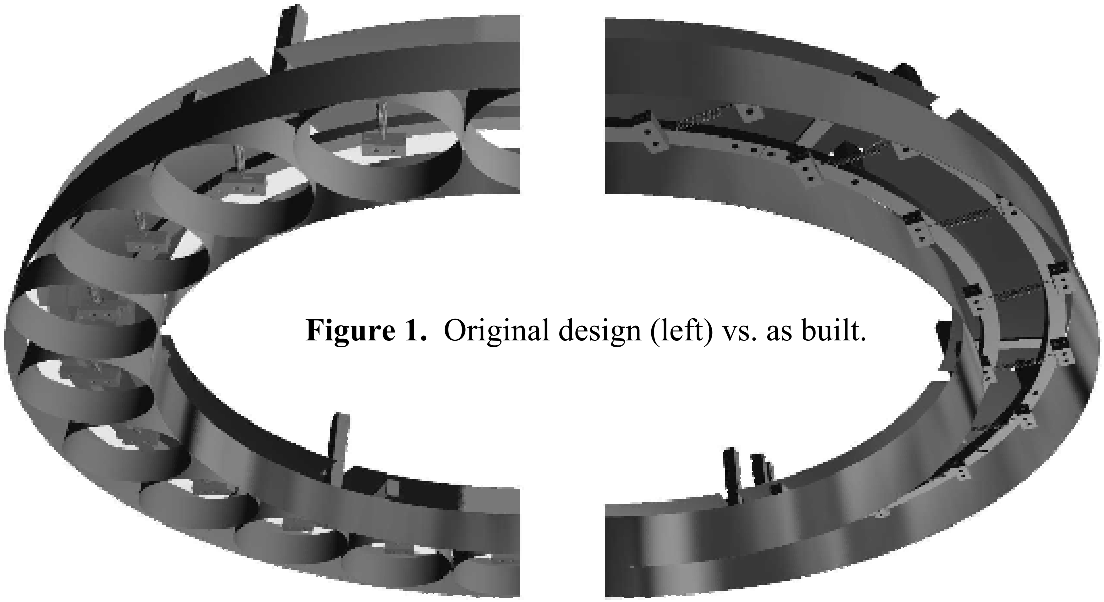

**Figure 1.** Original design (left) vs. as built.

The film deposited on November 9, 2001 with this system has performed very well and shows no sign of any zonal structure attributable to the coating.

## III. New Model Results

Tim Pickering recently rewrote portions of the modeling code to accommodate this different baffle scheme. For the first time we can predict with some certainty thickness distribution produced with this system. Figure 2 shows a predicted cross-section of the film deposited with the existing system along with the best cans-over-each-source model results.

This existing geometry gives an rms thickness variation of 14 nm with a peak-to-valley (p-v) span of 36 nm; corresponding numbers for the can solution are 1.6 nm rms and 7 nm p-v. At first this seemed very disappointing—it was hoped the modifications would result in less of a qualitative change. A 36 nm p-v variation produces an error in the reflected wavefront of about 1/7 wave of visible light. This might seem like a lot but only in our imaginations does the atmosphere exist in which this becomes a limiting factor. In effect, the primary is overcorrected by an amount that is easily negated with the mirror support system.

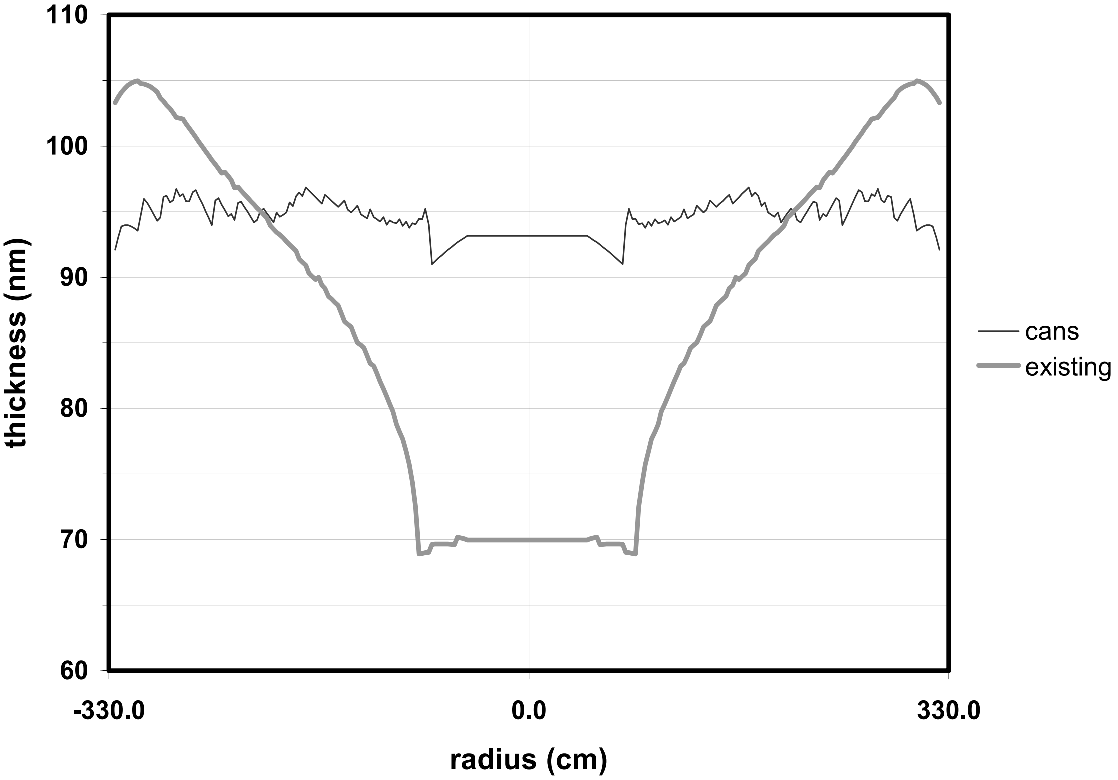

**Figure 2.** Original solution vs. as built.

As expected, the existing baffles produce a film that is smoother on small spatial scales and will result in less scattered light at the focal surface. The model also predicts 0.20 gm of aluminum evaporated from each filament (instead of 0.25 gm for the cans) to condense 95 nm on the mirror surface. This is in very good agreement with measurements taken after the November, 2001 shot[1] averaging 0.18 gm/filament.

## IV. Error Budget and Structure Function

The error budgets for telescope subsystems are given in terms of the structure function, or allowable wavefront deformation as a function of spatial scale. This philosophy is predicated on the turbulence spectrum of the atmosphere and, in a nutshell, seeks to have the telescope contributions to image degradation match those of the atmosphere in the best seeing, thus assuring that performance is seeing-limited most of the time. Said differently, this method of error budgeting allows tolerances to be relaxed (and significant money saved) at larger spatial scales where the atmosphere has already distorted the incoming wavefront. Structure function is related to Fried's parameter (or length), $r_0$ (pronounced r naught), also known as the atmospheric coherence length (or diameter) as follows:

$$\delta^2(x) = \left(\frac{\lambda}{2\pi}\right)^2 6.88\left(\frac{x}{r_0}\right)^{5/3}\left[1-0.975\left(\frac{x}{D}\right)^{1/3}\right]$$

where $\delta(x)$ is the rms wavefront difference between points separated by $x$, and $D$ is the telescope entrance pupil, usually the primary mirror diameter. This relationship includes a term to remove tilt; primary mirror tilt is not allowed to contribute to wavefront error because its optic axis defines telescope pointing. No scatter figure is assigned to the coating and none is included. The specification for the primary mirror is 3% @ 350 nm, including contributions from all sources. Specifically, $r_0$ is the lateral distance over which a wavefront difference of approximately 0.42 waves exists. A more intuitive definition—that of an "atmospheric subaperture"—arises when the following is considered: a mirror with a diameter larger than $r_0$ will produce an image the approximate size of the diffraction pattern for $r_0$. The larger the value of $r_0$, the steadier the atmosphere and the smaller the contributions to the total wavefront error induced by the telescope subsystems.

The error budget for the 6.5 m primary coating[2] is adopted from J. Hill's specifications for LBT[3] —the primary coating should introduce errors not exceeding those produced by an $r_0$ = 400 cm atmosphere. This is plotted in Figure 3 as wavefront error vs. spatial scale.

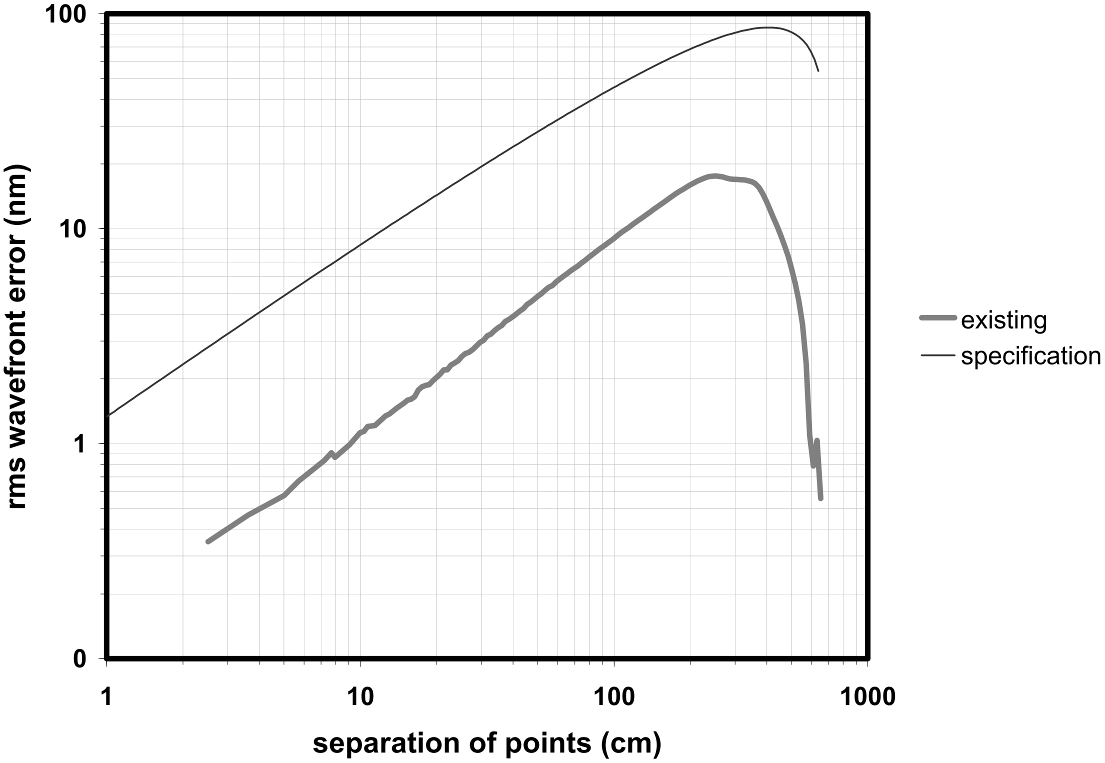

**Figure 3.** Structure function, specification and existing geometry.

An appreciation for the magnitude of the contribution to image degradation made by this coating is developed as one reflects on the fact that a 400 cm atmosphere would allow the production of 0.03 arcsecond FWHM star images—the diffraction limit of a 4m mirror. Obviously there are many other contributors swamping any effects from this source.

One of the reasons the distribution results were disappointing is that a general figure of 5 nm rms has always been in circulation here as a corollary specification that implicitly relates to $r_0$ = 400 cm. I have been unable to establish a general relationship between the two. Looking at Figure 3, the allowable wavefront error scales exponentially from a little over 1 nm at 1 cm separations to a peak of 85 nm at 400 cm separations. Allowable surface variations are half the wavefront error as the latter doubles upon reflection. A 5 nm rms surface easily meets the error budget but so does a 14 nm rms surface. Hill[3] also states that surface roughness should be less than 6 nm rms to keep scattering below 3%, and I have to wonder if this could possibly be the origin of the 5 nm figure. It appears that 5 nm rms is unnecessarily ambitious but, as will be shown in the following section, it is achievable by technically straightforward means.

## V. Recommendations

There does not appear to be sufficient justification for undertaking an overhaul of the deposition system as far as MMTO is concerned, but LOTIS requirements are more stringent and will require that modifications be made. There will be a window within which this can be accomplished after the August ‘05 shoot when the belljar resides temporarily at the base camp. Given that the work needs to be done anyway, there would certainly be advantages to having it ready for August ’05 but MMTO simply doesn’t have the available manpower. We also do not have the luxury of pretesting the modified system, and having one more untested subsystem to deal with in August would just add to an already heavy workload.

While changing the ring radii or number of filaments would entail a dramatic rework, it is a relatively uncomplicated matter to “piston,” or raise/lower the individual ring assemblies. The solution plotted in Figure 4 is achieved by moving the inner ring assembly down 8”, the middle ring assembly up 2-3/8”, and the outer ring assembly up 8”. The rms thickness variation is 2.8 nm over the entire surface and considerably better if the innermost zone is excluded (it is occulted by all secondaries except *f*15). Note the lack of abrupt changes in slope, a very desirable result from a scattering standpoint. The rms deviation can be reduced to well below 2 nm by adjusting the individual baffle heights and further optimization will occur before any changes are made. Structure functions of the existing solution and the one described above are plotted in Figure 5.

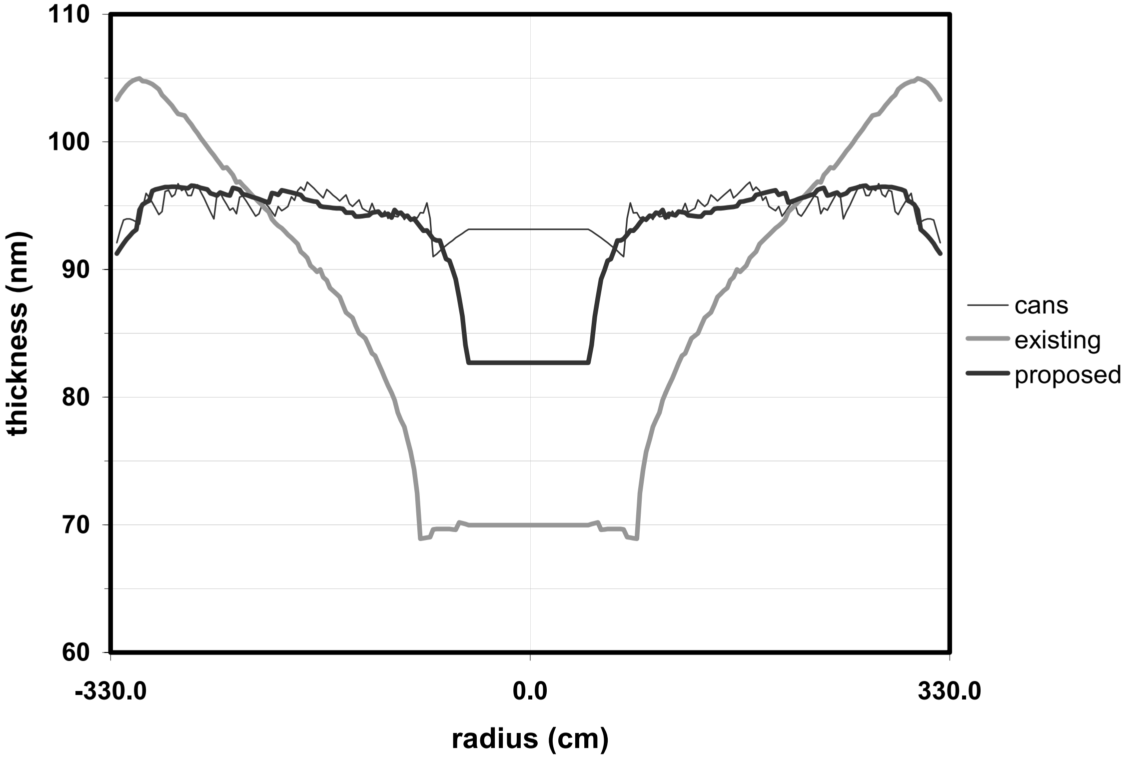

**Figure 4.** Proposed solution involving pistoning of the ring assemblies.

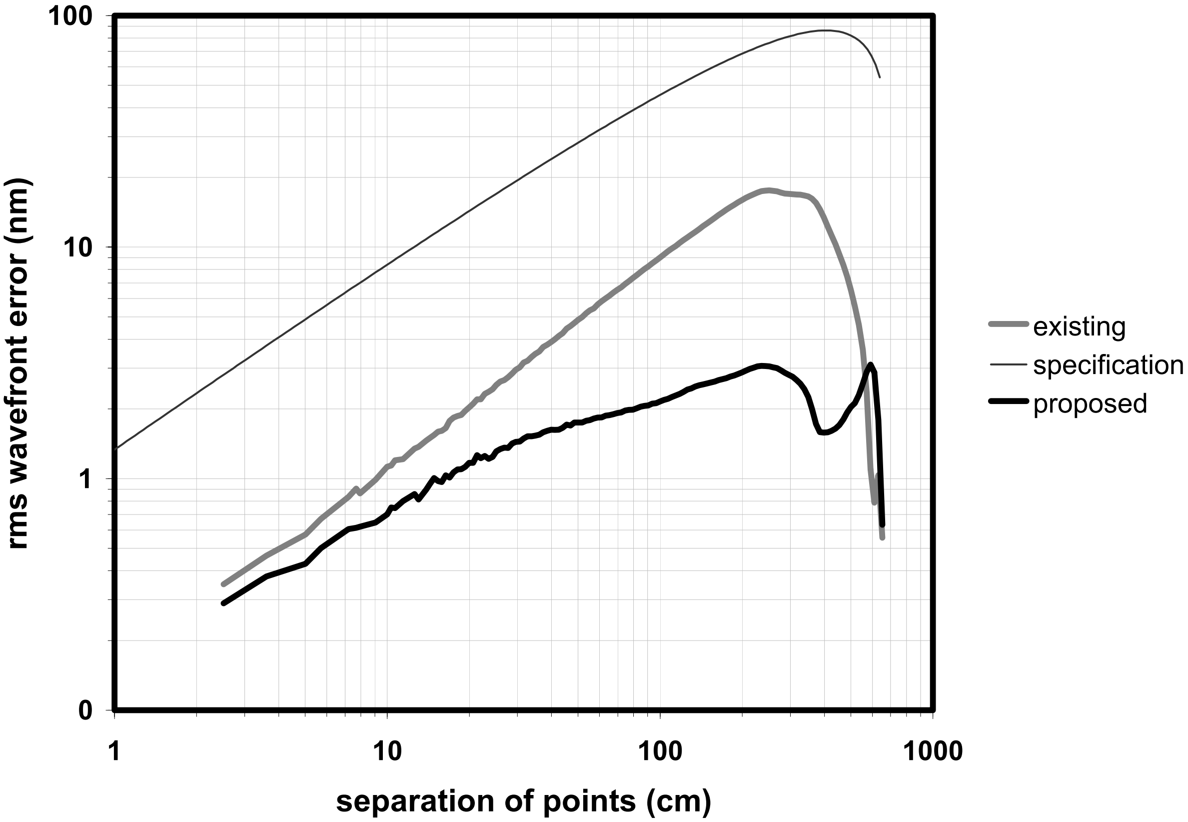

**Figure 5.** Structure function of proposed solution.

## VI. Conclusions

The modifications made to the baffle system produced a larger-than-hoped-for variance in thickness. Even so, the film easily meets its error budget and one could argue effectively that further improvements are unnecessary for the purposes of MMT Observatory. LOTIS requirements are more stringent; some modifications will be necessary. A very good solution is achievable by pistoning the source-ring assemblies and possibly varying the individual baffle heights. I estimate a two man-month effort spanning four calendar months for the conversion.

## VII. References

1) W. Kindred, J. T. Williams, and D. Clark, "In Situ Aluminization of the MMT 6.5 m Primary Mirror," MMTO Technical Report **03-8** (2003) http://www.mmto.org/MMTpapers/pdfs/tm/tm03-8.pdf

2) D. Fabricant, B. McLeod, and S. West, "Optical Specifications for the MMT Conversion," MMT Technical Report **35** (1999)

3) J. M. Hill, "Error Budget and Wavefront Specifications for Primary and Secondary Mirrors," LBT Project Technical Memorandum **UA-94-01** (1994) http://medusa.as.arizona.edu/lbtwww/tech/ua9401.htm