OPTICAL SYSTEM FOR THE UNIVERSITY OF TEXAS 7.6M TELESCOPE

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I. INTRODUCTION

As presently conceived, the large telescope now being planned at The University of Texas will have a Ritchey-Chrêtien configuration, f/13.5, with a 7.6m diameter f/2 primary of ultra-thin construction, on an alt-azimuth mount.

In this paper we will describe the current concept for the mounting, the building, mirror handling techniques, and the optical system. We will give preliminary results of the finite element flexure analysis of the mirror on its support system.

Studies have demonstrated a workable concept and have shown that there exists a method of adequately supporting an ultra-thin mirror against gravity and wind loads. We are continuing these studies, including also thermal effects on the mirror figure, in order to determine the best choice of mirror material and construction at the most reasonable price.

II. PRELIMINARY ENGINEERING STUDIES

Concept studies were carried out in collaboration with Aden and Marjorie Meinel of the University of Arizona Optical Sciences Center in January and July, 1980. Subsequently, in January 1981 an engineering study, based on the resulting concept, was completed by Ford Aerospace and Communications Corporation, Western Development Laboratories, at Palo Alto, California. The results of these studies are illustrated in Figures 1 and 2, where we show the telescope structure, its yoke, the MMT-type building, and the aluminizing building. For re-aluminizing, the primary and cell are lowered from the telescope to a cart which rolls on railroad tracks to the separate aluminizing building, via a drawbridge, with the telescope and its building locked in an appropriate orientation. In the aluminizing building an overhead crane

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lifts the cell by its trunnions and the mirror is rotated 90° to the washing position; after washing and stripping, the mirror in its cell is then moved into the aluminizing chamber.

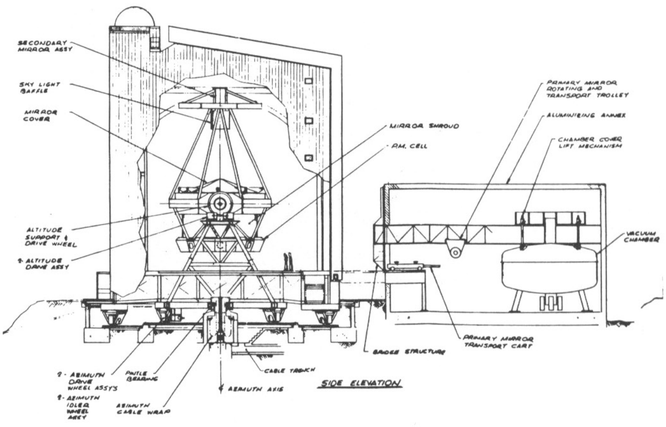


Figure 1

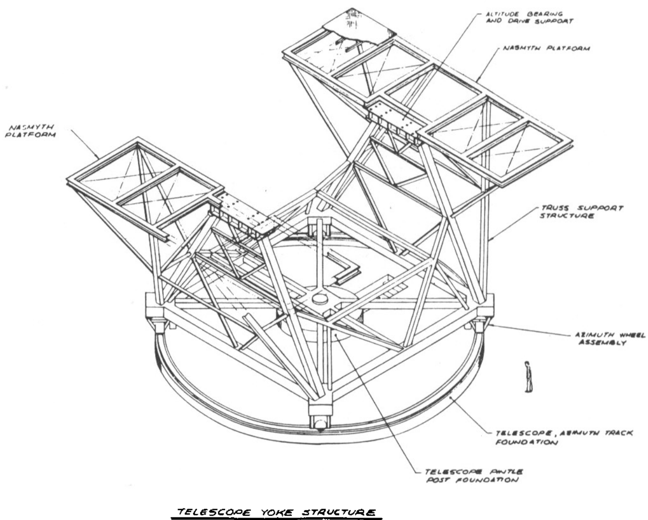
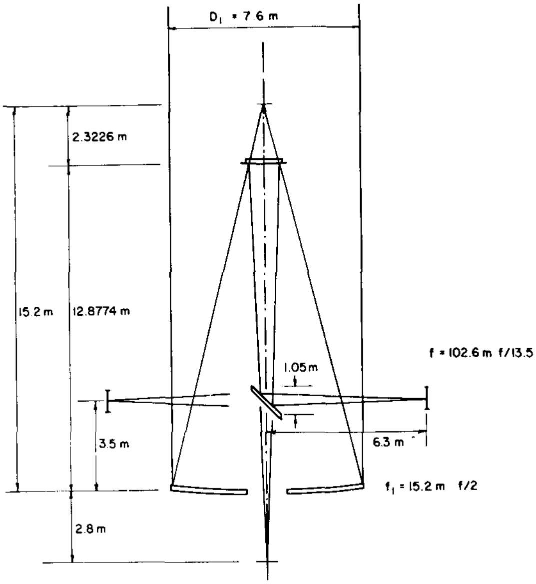


Figure 2

The primary observing positions are at the two Nasmyth foci, where two 5 x 15m platforms are provided as part of the yoke truss structure. Rotation in azimuth is on steel, self-aligning wheels on a circular track; a similar set of wheels and track support the building, which rotates in response to the telescope motions - a concept proven in the University of Arizona-Smithsonian MMT project (1). The altitude rotation is through large-diameter bearings supported by the azimuth truss and driven by friction wheels.

III. TELESCOPE OPTICAL SYSTEM

Figure 3 illustrates the telescope optical concept. A Ritchey-Chrétien optical system is under consideration; in this case the astigmatic blue circle would be about 0.5" at an off axis angle of 10'. For larger fields (as might be required, e.g., for precision offset guiding), a field flattener lens displaced slightly from focus (2) or an aspheric plate (3) could be used to correct the astigmatism at the Nasmyth focus. The optical clearance required through the elevation bearings, for a 30' Nasmyth field, is about 1 meter at f/13.5.



TELESCOPE OPTICAL CONCEPT

Figure 3

Auxiliary instrumentation will include Nasmyth focal reducer cameras (see, e.g., R.N. Wilson (4)) and a Nasmyth-platform spectrograph. The common requirements for faint-object and high-resolution spectrography with a large telescope may allow both functions to be included in one basic instrument. Some of the advantages in such an arrangement include cost savings in pre-slit instrumentation and in diffraction gratings used in common for both purposes.

IV. PRIMARY MIRROR FLEXURE ANALYSIS

Flexure studies were begun during summer 1980, using the finite element analysis program SAP IV; in these studies we are modeling the effects of gravity, wind loading, and thermal stress on the figure of the mirror and on the resulting star image. Preliminary results of gravity and wind-loading analyses are given in this section.

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The overall weight of a telescope (and therefore the cost) increases roughly in proportion to the weight of the primary mirror. For that reason it seems prudent to find ways to reduce the mirror's weight, which can be done either by thinning or by using eggcrate construction. Both methods are currently under consideration; presently, only the thin, meniscus monolith has been analyzed by the finite element method.

The thermal time constant of a mirror blank is proportional to the square of the thickness. For a large disk of thickness 10cm the time required for an induced thermal gradient between the midsurface and the outer surfaces to decrease by 63% is found to be 26 minutes, increasing to 1 hour for 15cm thickness. A thin mirror will have a thermal advantage over a thick mirror.

However, a characteristic number for flexure of a mirror is R^4/t^2 (5), from which it follows that a large diameter, thin mirror cannot support its figure against gravity without help from its support system. In extreme cases, active control of the figure is necessary.

IVA. Flexure Under Gravity

Axial support point distributions were studied for a 7.6m meniscus of thickness 10 and 15cm. Figures 4-7 and Table 1 show the computed performance of the mirror under gravity when supported by a set of 120 axial point supports distributed in 5 rings of 12, 18, 24, 30, and 36 pads. With the telescope at the zenith, 90% of the rays fell within an image diameter of 0.78 arc seconds for the 10cm thickness and 0.35 arc seconds for the 15cm thickness; i.e., the image size varied inversely as the square of the mirror thickness, all other conditions remaining the same. The results for the 15cm blank are comparable to results from Hartmann test data for the Cerro Tololo 4m primary (6).

TABLE I

Gravity Effects for 120 Axial Supports, 7.6m Meniscus

Image Diameter	Energy Concentration	
	10cm model	15cm model
0.125 arc sec	4%	24%
0.25	21%	59%
0.50	55%	98%
0.75	87%	100%
1.00	99%	
1.25	99%	
1.50	100%	

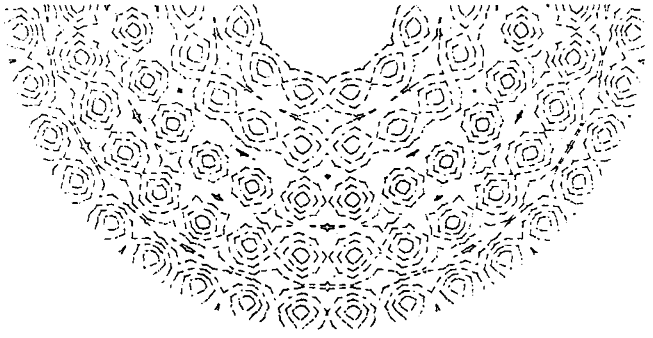

FIGURE 4
Mirror flexure under gravity. Contour diagram for 10cm blank thickness on 120 axial supports. Tenth wave contour intervals.

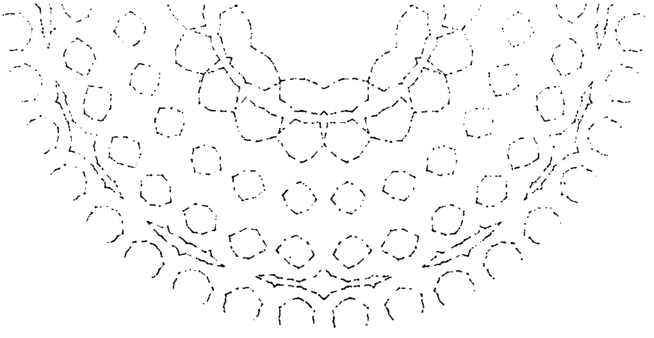

FIGURE 5
Same for 15cm blank thickness

These analyses also showed that the image size determined from ray tracing varies inversely as the 1.5 power of the number of axial support points. Extrapolating, the performance of the 10cm mirror could be improved to match that of the 15cm mirror by increasing to 200 axial support points, or, more practically, by an appropriate increase in the area of the 120 support pads; these were considered zero-area points in the analysis.

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Figures 6 & 7: Image spot diagrams for the 10cm thickness (left, shown with 0".47 circle diameter) and the 15cm thickness (right, 0".21 circle diameter).

Tests of lateral support configurations, with the mirror axis horizontal, showed that adequate support can be achieved, for the 10cm blank, with 64 lateral supports distributed in the surface midway between front and back of the mirror, requiring 64 blind holes milled into the back of the blank. Performance was poor when the lateral supports were located at the back surface; controlled moments applied to the axial support pads would be required to compensate for the force couples introduced by moving the lateral support points away from the midsurface.

IVB. Wind Load Studies

A major concern for ultra-thin mirrors is the effect of incremental errors on the figure of the mirror. A potential source of error is wind pressure on the mirror surface: in a conventional mirror support system designed only to account for the changing direction of gravity, any increased force on the mirror due, for example, to wind pressure will cause the entire mirror to move axially. Traditionally, axial movement is prevented by "fixing" three of the axial support points; but force errors induced by wind will bend a thin mirror at the fixed points. The ideal solution is to "fix" all of the axial supports, producing an overall mirror system which would be stiff against wind as well as other sources of load errors. Such a "position controlled" support system is under study for the 7.6m telescope.

In practice, the cost of position control at all support points is likely to be high. We are therefore studying compromise solutions in which some small subset of the support pads are position controlled, with the others programmed as force followers. In this concept, a force transducer at each position-controlled pad will monitor the force on that pad and this will be used to adjust the forces in the group of surrounding pads.

The load f expressed in percent of the mirror's weight due to an axial wind of speed V m/sec can be written

$$f = \frac{50\rho_a V^2}{\rho g t}$$

where ρ_a = air density, kg/m^3

ρ = glass density, kg/m^3

g = gravitational acceleration = 9.8 m/sec^2

t = mirror thickness, meters.

Using the f/2 meniscus model, the deformation of the mirror and the resulting image spot diagrams were computed as a function of the load error f resulting from wind when the mirror was supported on 3 fixed axial points in a gravity-free field. Results of this analysis for a mirror of thickness 0.15m are shown in the upper curve of Figure 8, where image size is given as a function of axial wind speed. The wind speed tolerance for this case is 9.9 km/hr. for which the image degradation is 0.5 arc sec.

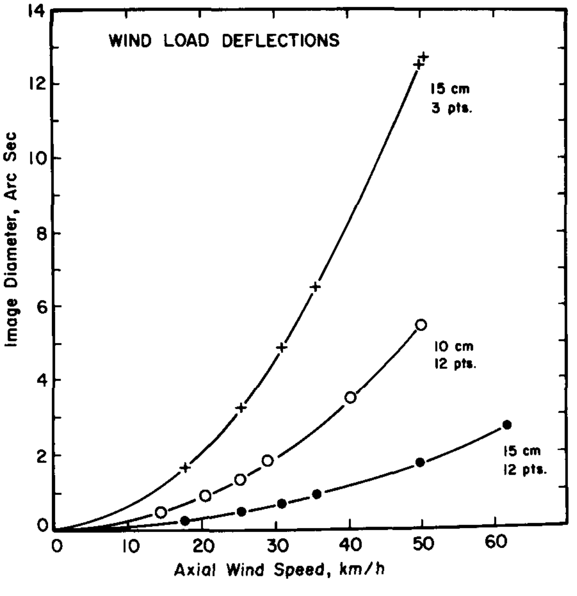

FIGURE 8

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If the number of fixed supports or the mirror thickness is increased, the tolerance to wind is also increased. Results for the 10cm and 15cm blank thickness are shown as functions of wind speed in Figure 8, for two fixed point distributions. For the 10cm blank, image degradation exceeds 0.5 arc sec for axial wind speeds greater than 15.2 km/hr with 12 position-controlled supports, while the 15cm mirror can withstand axial wind, for 0.5" degradation, to 26.4 km/hr - i.e., wind speed tolerance increases in proportion to the 1.4 power of the mirror thickness. Image size is found to vary as the square of wind speed and as the -2.8 power of mirror thickness. These exponents compare favourably with the theoretical values 1.5 and -3.0 appropriate to an ultra-thin mirror.

We have demonstrated, in this analysis, that the stiffness of the mirror to wind-induced flexure can be increased as $t^{2.8}$ (by increasing the mirror thickness) or by increasing the number of position-controlled support pads.

Dramatic improvement in performance is expected by the application of the force follower technique described above; this approach has not yet been modeled.

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