



## MULTIPLE MIRROR TELESCOPE OBSERVATORY

Smithsonian Astrophysical Observatory and Steward Observatory, University of Arizona

*Reply to:* MMT Observatory  
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Tucson, Arizona 85721  
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### **MMT Conversion Internal Technical Memorandum #91-1**

**Support and Thermal Analysis of the F/9 Secondary**

**Dan Blanco**

**October 23, 1990**

**Report on F/9 Secondary Study**

**Lester Cohen and Jim Carnevale**

**April 18, 1991**



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To: MMT Conversion Committee  
From: Dan Blanco  
Date: October 23, 1990  
Re: Support and thermal analysis of the f/9 secondary

### Summary

An FEA model of the proposed Hextek secondary was used to examine several mounts and loading conditions. A vacuum system to suspend the mirror by air flotation will give the best axial support. Lateral support can be applied to a single point at the back plate with either three axial hardpoints or three axial whiffle trees.

### Introduction

This memo records some finite element analyses of a 40" diameter lightweight mirror blank of Schott Tempax borosilicate glass made by the gas fusion technique. The proposed mirror blank will consist of 1/2" thick front and back plates and a honeycomb structure of 1/4" thick ribs. Overall, the blank will be 6" thick for an aspect ratio of 6.67. This blank will be slumped to provide a convex surface of 110" curvature suitable for generating and optical polishing. The construction is shown in Figure 1.

One purpose of these analyses was to determine whether to purchase a blank with a central mounting boss at the mirror CG. This would be an 8" diameter, 1/2" thick plate fused into a plane between the front and back plates at the CG plane of the final slumped blank (shown in Figure 1). Several groups have proposed mounting lightweight mirrors similar to this one with a single CG point mounting boss for lateral support, three axial defining points, and axial support provided by drawing a vacuum on the back of the mirror. Since the entire blank weighs about 150 lbs and has 1256 square inches of frontal area, it requires only about 0.12 psi vacuum to suspend the mirror at zenith pointing.

The effect of a vacuum support is to dimple the top plate at the center of each cell, similar to quilting caused during polishing by the pressure of the lap. Unfortunately this model is too coarse to predict the optical performance of the mirror under this kind of loading, but a hand calculation based on the 1/2" thick faceplate and 2.56" cell spacing indicates the quilting under 0.12 psi should constitute only about 1.0 nm rms wavefront error.

### The Model

Rich Wortley of Hextek Corporation sent me an Autocad file containing a drawing of the proposed blank. Starting with this I converted the drawing into a CAD neutral file—basically an ASCII list of the endpoints of all the lines in the original drawing. This file had to be sorted to eliminate duplicate end points and to arrange the nodes into a pattern with a logical numbering sequence. The resulting pattern of 185 nodes is shown in Figure 2.

The X,Y coordinates of each node were used to determine the Z dimension of a hyperbolic surface. A second set of nodes numbered 201 to 285 were generated 5.5" above the first set to represent the mirror back. A third set of nodes numbering 401 to 417 were given an intermediate Z position to represent a plate fused into the blank at the CG location of the final slumped blank.

Each six-sided facet had to be divided into two quadrilateral plate elements for the FEA model. The pattern which resulted was a consequence of the node numbering tempered in part by my own esthetic instinct. The rib connectivity was fairly easy to determine because of the logical node numbering sequence. Plate elements were used throughout.

This is a half model, and only strictly symmetrical loading conditions have been considered. Thus all nodes along the Y axis were given symmetrical boundary conditions; translations in X and rotations about the Y and Z axes were all set to zero.

I used the PAL2 FEA program. This is a PC-based version of NASTRAN supported by MacNeal Schwendler Corporation (who also support commercial versions of NASTRAN). Two views of the model are shown in Figures 3 and 4.

## Ray Traces

Since this model represents a mirror, its optical behavior in the telescope is the most interesting result of the finite element analysis. I had hoped to use an existing program, PCFRINGE, which was written at OSC expressly for tracing rays based on the deformation predictions from various FEA programs (including PAL2 among others). Unfortunately PCFRINGE requires a strict radial geometry, rather like a spider's web, and a specific node numbering sequence totally incompatible with this particular model. So I set out to write my own ray tracing code.

PAL2 is capable of generating ASCII output files consisting of the mirror geometry (simply the undeformed X,Y,Z coordinates at each node point), as well as ASCII deformation files consisting of the dX, dY, dZ translation deformations, and the RX, RY, RZ rotation deformation at each node. Given these files it is easy to trace rays when one considers that 1) the translation deformations are negligible, 2) the deviation of a light ray striking any node is simply twice the rotation deflection at that node, and 3) the chosen geometry is divided into facets of equal area; hence, no weighting is needed.

I wrote a short program in BASIC (please don't laugh) to trace rays using the RX, RY node rotations predicted by PAL2 and using the geometry of the FEA model and the optical configuration of the 256 inch f/1.25 to f/9 focal ratio configuration of the MMT conversion. The central rays which would be blocked in the real telescope were omitted from the ray traces. By adding a variable to change the distance to the focal plane, I was able to manually step through the focus to find the best focus image. The RMS image size was also calculated. This program was used to generate the ray traces in the attached figures.

## Results

Several support configurations were modeled, as well as some simple thermal loading cases. In each case I generated a contour plot of the deformed mirror surface (PAL2 output), and a geometric ray trace from that surface.

Figure 5 shows the mirror suspended from three points at the back of the mirror, with the telescope zenith pointing. Since the model did not have nodes in perfect three part symmetry, three pairs of nodes straddling the lines of symmetry were used. This would represent the load spreading

effect of invar pucks glued to the back of the mirror. The node pairs were located near the 0.7 radius from the center. The resulting image is shown to the left. There was negligible reduction in image size from a focus shift, indicating that the 0.7 radius is near optimum for this mirror. The resulting image is 0"166 rms diameter.

The image on three points was sufficiently good that I wondered if a six point axial support arrange in three whiffle trees would provide adequate axial support. Figure 6 shows this loading condition. The new image is much better at 0"068 rms diameter, which may be good enough.

Several groups have proposed a lateral support from a single central hub located at the CG point of the mirror. Figure 7 shows the surface of the mirror supported in this way with the telescope at horizon pointing. The scheme works very well giving a 0"055 rms diameter image. The major distortion in the surface is a bump and a dip about 3" above and below the center support. The remainder of the surface distortion is comatic, which could be balanced by recentering the secondary.

In Figure 8 the lateral support hub has been moved to the back plate of the mirror. Since this is not at the CG plane of the mirror, there is an overhanging moment about the support hub which is countered by forces on the three hard points. The result is an image only slightly worse than the previous one, 0"058 rms diameter.

Figure 9 shows the same horizon pointing condition with a center hub support at the back plate, but with six axial points (as in Figure 6). There is a considerable improvement to 0"044 rms diameter.

The remaining figures illustrate thermal distortion from some simple temperature gradients. Figure 10 shows the effect due to a diametral temperature gradient of one degree Fahrenheit from the upper to the lower edge. The effect is to introduce a tilt with negligible image aberration.

Figure 11 shows a 1 F gradient from the front face to the back plate. The effect is to shift the focus some 0.07 inches from the original focal plane. In this telescope this would require moving the secondary about 0.001 inches to refocus the images.

Figure 12 shows a radial gradient with the center 1 F warmer than the mirror edge. This is the most sensitive gradient mode I studied causing an image degradation to 1"183 rms even after refocusing.

## Discussion

The present error budget for the MMT conversion aims for an overall image size of 0"399 on axis. The budget allows 0"10 fwhm for secondary support, equivalent to 0"085 rms diameter. Several support schemes can work within this error allowance.

Three points do not provide a sufficient axial support (0"166 rms); however, six points can (0"068 rms). A lateral support from a CG plane mounting boss will work quite well (0"055 rms), but in this scheme all the lateral force is transmitted through a few ribs at the center. The lateral support force can be applied directly to the back plate with the remaining overturning moment resisted by forces on the three hardpoints (0"058 rms diameter) or on six axial support points (0"044 rms). This scheme seems more robust since the lateral support force is distributed into all ribs equally.

The best axial support is most likely the vacuum system. On the scale of this FEA model such a support would be perfect. It is clear that a six point axial support with lateral supports applied at

the back plate will meet the error budget allowance. However, where possible we ought to choose solutions which exceed the requirements of the error budget, provided they do not add greatly to the complexity of the design. In this case the vacuum support system with either three or six hardpoints and a central lateral support at the back plate is a choice that offers superior performance with a simple and straightforward mechanical design.

Based on the thermal runs we can see that the system is fairly immune to diametral and for-aft temperature gradients, but extremely sensitive to radial temperature gradients. It would therefore be prudent to wrap the edge of the mirror with insulation to prevent radial temperature gradients. In addition, particular attention should be paid to preventing any hot spots from actuator motors and the like in the secondary support cell.

## LIST OF FIGURES

1. Mirror construction.
2. Node geometry and numbering sequence.
- 3 and 4. Perspective views of the FEA model.
5. Suspended on three points, telescope zenith pointing.
6. Suspended on six points, telescope zenith pointing.
7. Center hub support at cg plane, telescope horizon pointing.
8. Center hub support at back plate, three axial hard points, telescope horizon pointing.
9. Center hub support at back plate, six axial hard points, telescope horizon pointing.
10. Diametral temperature gradient of 1 F.
11. Front to back temperature gradient of 1 F.
12. Radial temperature gradient of 1 F.

HEXTEK CORP. WORKING DRAWING

REVISED 10/15/90

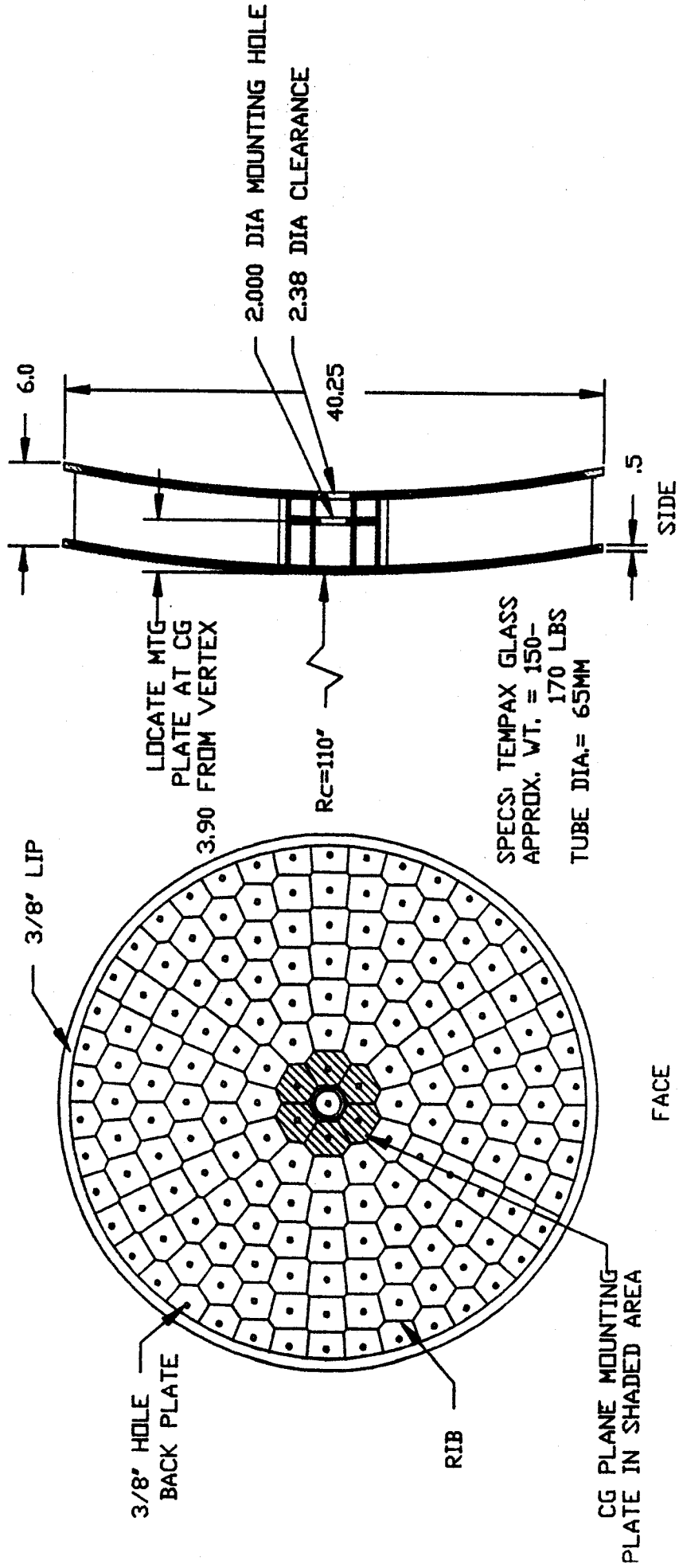


Figure 1

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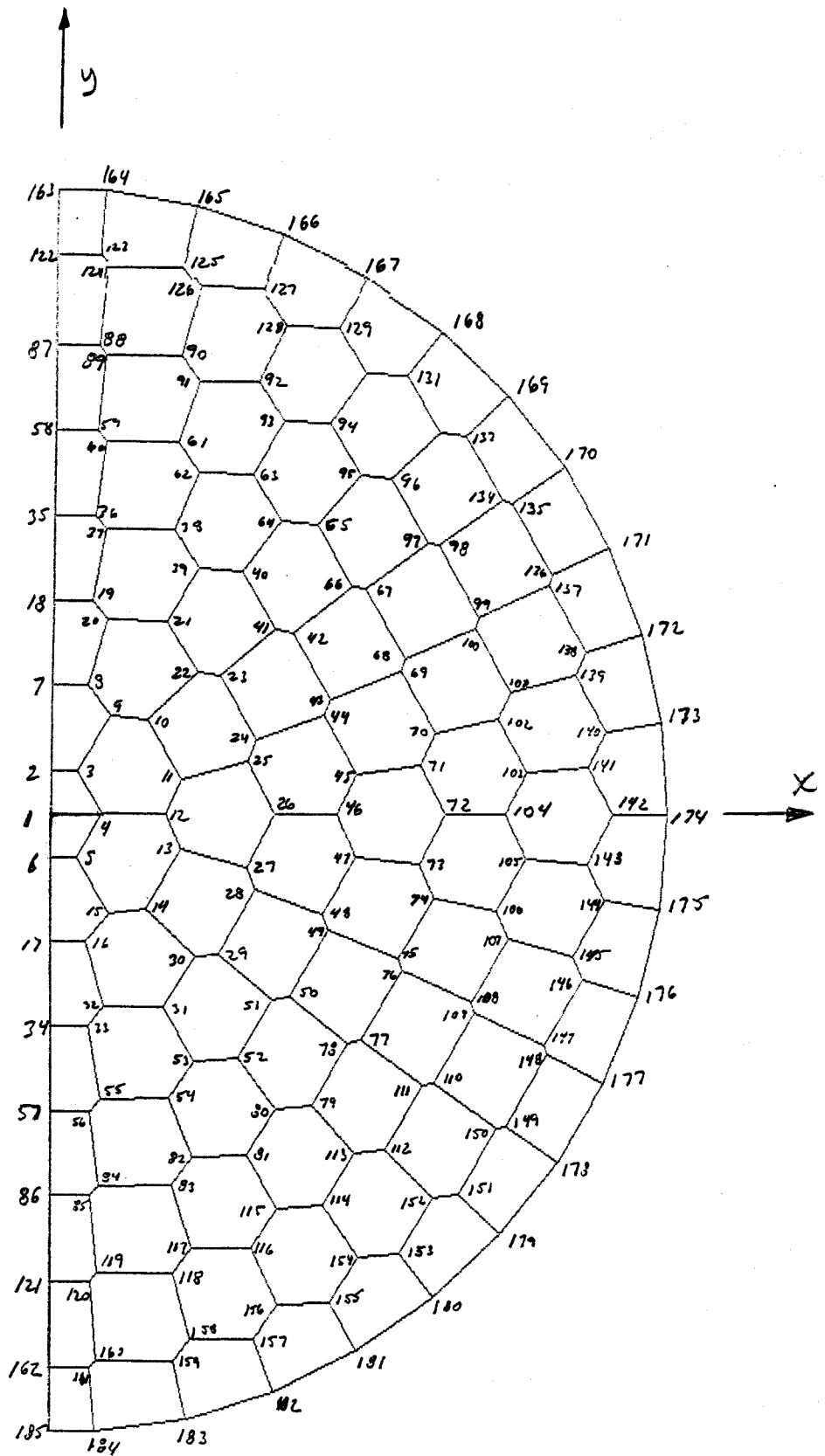


Figure 2

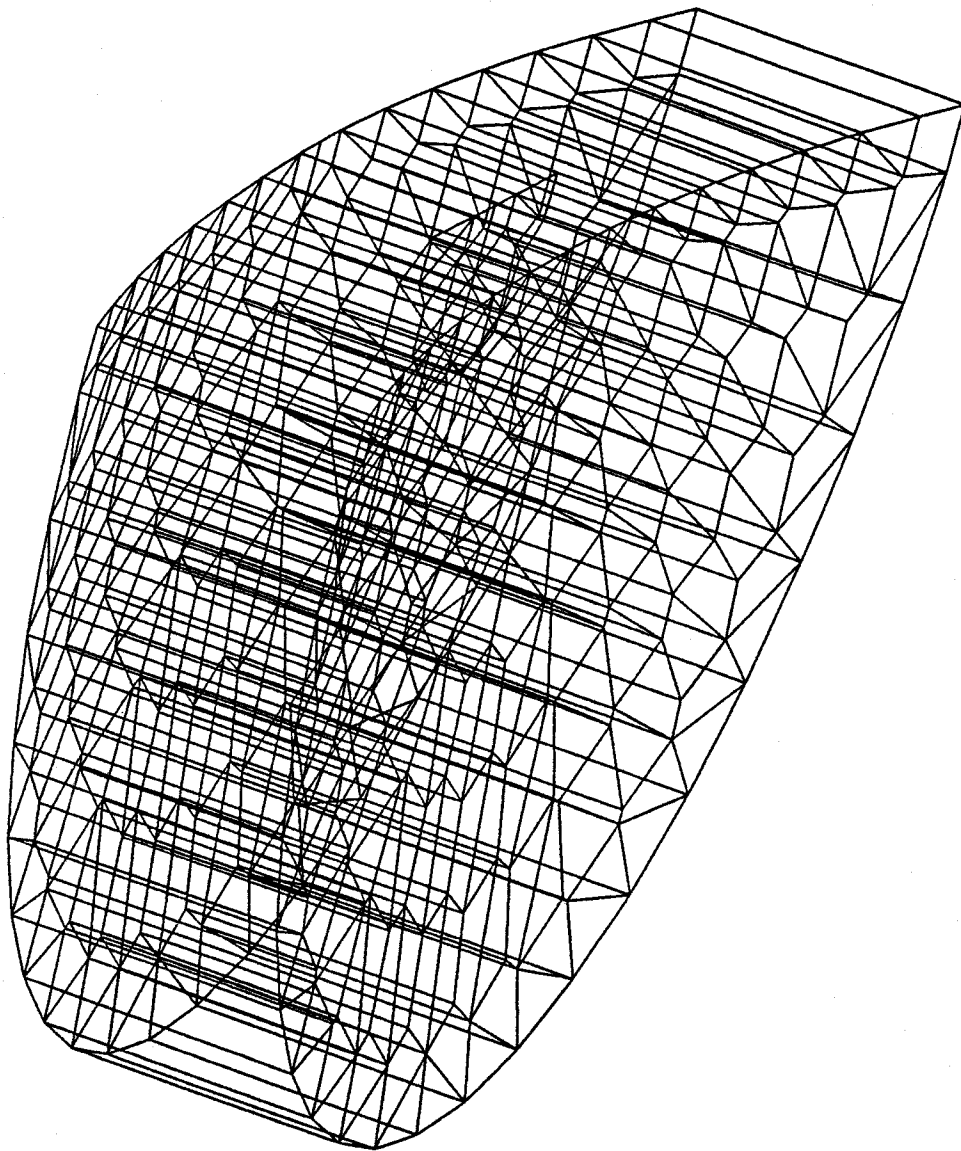


Figure 3

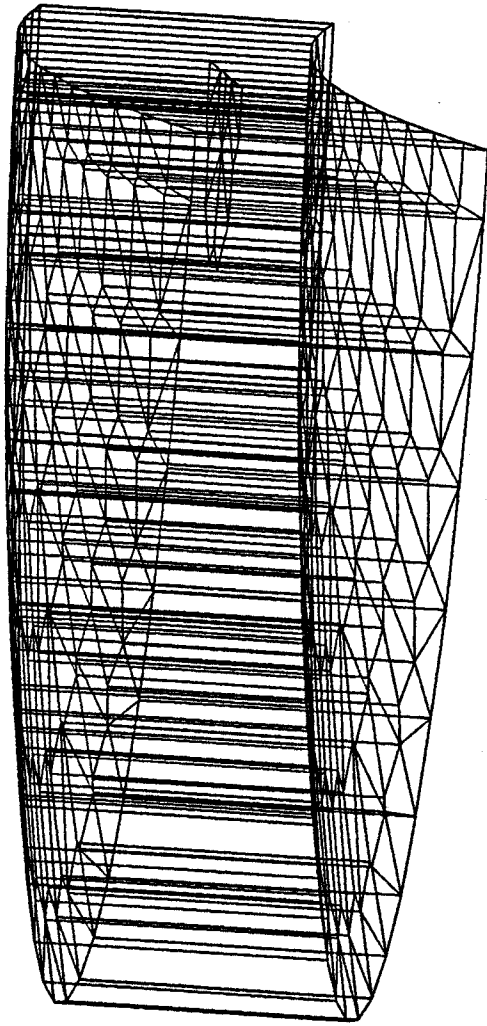


Figure 4