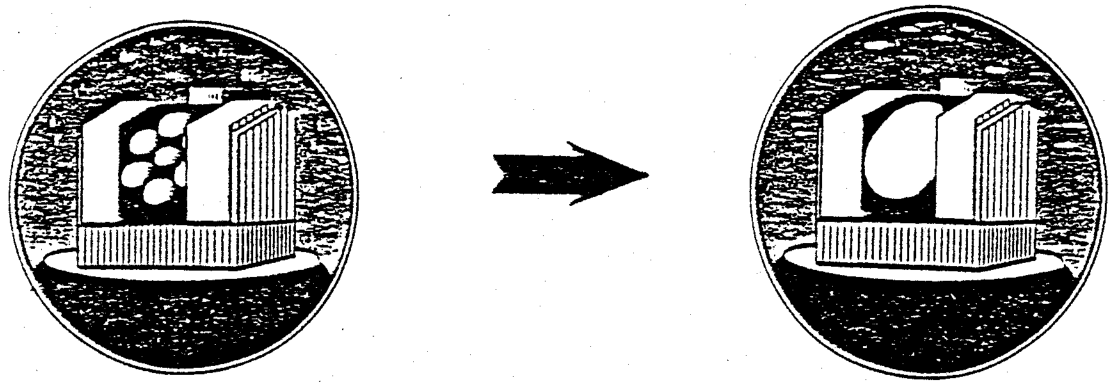
6.5 METER TELESCOPE



MMT Conversion Technical Memorandum #93-1

Analysis and Design of the Glue Joint, Pucks, and Loadspreader Used in the 6.5 m Mirror Support System

Shawn Callahan

November 1993

Analysis and design of the glue joint, pucks, and loadspreader used in the 6.5m mirror support system.

Shawn Callahan, MMTO
November 9, 1993

1.0 Abstract

This report summarizes the finite element analysis of the glue joints, puck flexure, and loadspreader frame designed for the 6.5m support system.

2.0 Introduction

Finite element models were used to analyze the forces and moments applied by the pneumatic support system to the 6.5m mirror. These model results were used to design the glue joints, puck flexure, and loadspreader frame.

The finite element models assume that ideal pneumatic loads are applied to a loadspreader frame of steel and invar. The loadspreader is attached to three steel flexures. Each flexure is bolted to a 100 mm diameter invar puck that is glued to the mirror with a thin layer of RTV adhesive.

The Young's modulus (E), apparent modulus of elasticity (E_a), apparent shear modulus (G_a), and thickness of the glue were varied to improve the glue joint design.

The Young's modulus of the puck flexure, and the choice of material were varied to understand the performance of the flexure design.

3.0 Model results

To assure that the support system loads do not exceed the allowable stresses or the error budget for optical figure, the forces and moments applied to the mirror were calculated for each model.

All forces and moments are calculated at the glue-glass interface. All loads simulate 1000N axial or lateral loads.

3.1 Glue properties

Since the RTV manufacturers do not publish Young's modulus data and the shape factors of RTV are not well understood, several models were needed to determine an acceptable glue joint design.

3.1.1 Young's Modulus (E)

The first set of models analyzed how the Young's modulus of the glue affects the pressure distribution under the puck. The ratio of the maximum pressure to the average pressure is the pressure concentration factor (PCF). The PCF and the forces (Fx, Fy, Fz) and moments (Mx, My, Mz) applied to the glue-glass interface were determined for each model. BCV has determined that the PCF must be less than or equal to 3.0 to keep the stress in the glass below 0.7 MPa. (See Reference 1.)

In these models the ratio of the lateral strain to the axial strain of the glue, the Poisson ratio, was fixed at 0.49932. The glue thickness was set at 1 mm. All mirror support forces in these models were applied to the loadspreader frame. The Young's modulus of the glue was varied logarithmically from 0.56 to 560 MPa.

The results listed in Table 1 show that the Young's modulus must be about 5.6 or less to keep the PCF under 3.0.

TABLE 1. PCF, forces, and moments as a function of the glue Young's modulus (E)

Load Case	PCF	Fx (N)	Fy (N)	Fz (N)	Mx (Nmm)	My (Nmm)	Mz (Nmm)
1000N Axial							
E= 0.56	2.66	-30	-333.3	0	0	0	300
(MPa)							
E = 5.6	2.38	-159	-333.3	0	0	0	452
E = 56	8.23	-275	-333.3	0	0	0	1403
E = 560	14.8	-296	-333.3	0	0	0	1580
1000 N Lateral							
E=0.56		297	155	161	1402	-23	-2124
E = 5.6		330	155	140	1219	-34	-2394
E = 56		357	155	123	1067	-33	-2610
E = 560		361	155	120	1040	-33	-2648

3.1.2 Glue Thickness

The apparent modulus of elasticity (E_a) is the ratio of the stress to the strain for a given shape. The ratio of the Young's modulus to the apparent modulus of elasticity is known as the shape factor. The apparent modulus of rigidity (G_a), also known as the apparent shear modulus, is the ratio of the shear stress over the shear strain.

In order to determine if the glue tested in-house behaves in the same way as the glue used in the finite element models, E_a and G_a were calculated from the models for four glue thickness from 1 to 3 mm.

Each model assumes a Young's modulus of 5.6 MPa, a glue area of 7585 mm^2, and an applied force of 1000/3 = 333.3N. The results of these calculations are presented in Table 2.

TABLE 2. Apparent moduli of elasticity (E_a)and rigidity (G_a): Glue

Glue Thick-ness (mm)	E_a (MPa)	G_a (MPa)	Axial Compres -sion (mm)	Lateral displace ment (mm)
1.0	60.2	1.81	.000729	.0242
1.5	52.3	1.81	.00126	.0363
2.0**	40.3	1.82	.00218	.0483
3.0	27.2	1.82	.00485	.0725

The calculated values are within a factor of two of the measured moduli.

Table 3 shows how loads on the mirror change with glue thickness. All calculations are for a single puck with ideal loading applied directly to the flexure. Note that the 2.0 mm** glue model has a finer mesh and a slightly modified geometry. This should be taken into account when directly comparing the various glue thicknesses.

TABLE 3. Glue thickness: PCF, forces, moments.

Load Case	PCF	Fx (N)	Fy (N)	Mz (Nmm)
1000/3N Axial				
1.0 mm	1.62		-333.3	
1.5 mm	1.78		-333.3	
2.0 mm**	1.61		-333.3	
3.0 mm	2.71		-333.3	
1000/3 N Lateral				
1.0 mm		333.3		-1006
1.5 mm		333.3		-1172

TABLE 3. Glue thickness: PCF, forces, moments.

Load Case	PCF	Fx (N)	Fy (N)	Mz (Nmm)
2.0 mm**		333.3		-1703
3.0 mm		333.3		-1672

Steward and MMT engineers concur that these models indicate a 2mm glue thickness has the best trade-off of properties. This is because: 1.this glue thickness has a PCF much less than 3.0; 2. the moments are small enough to allow full lateral support loads (3000N) while staying below the design goal of 8000 N; 3. the lateral displacements for 3000N lateral loads are approximately 0.15 mm which is small enough to not adversely affect the mirror support force location with respect to the ribs in the honeycomb structure of the mirror.

3.2 Flexure Properties

Both axial and lateral actuator support loads cause deflection of the loadspreader. Previous models had shown that a rigid coupling of the loadspreader to the mirror causes large stresses in its back plate and rib fillets. A flexure has been designed into the puck to keep these deflections from applying excessive moments to the glass.

The first set of flexure property models determine the maximum Young's modulus of the flexure and the second set the strength of the flexure for various steel alloys.

3.2.1 Young's modulus of flexure

In order to determine an acceptable material for the flexure, the Young's modulus of the material used in the flexure was varied from 200 to 20,000 GPa. The glue thickness for these models was fixed at 1 mm.

Table 4 shows that increasing the Young's modulus of the flexure dramatically increases the moments applied to the mirror. In order to minimize the moments, the stiffness of the flexure must minimized. The current flexure design shows acceptable PCF, forces, and moments for steel with E=200 GPa.

TABLE 4. PCF, forces, and moments as a function of Young's modulus (E).

Load Case	PCF	Fx (N)	Fy (N)	Fz (N)	Mx (Nmm)	My (Nmm)	Mz (Nmm)
Axial							
E =200 GPa	2.38	-159	-333.3	0	0	0	-452
E =2,000 GPa	2.19	-161	-333.3	0	0	0	-3458
E=20,000 GPa	6.58	-57	-333.3	0	0	0	-14363

TABLE 4. PCF, forces, and moments as a function of Young's modulus (E).

Load Case	PCF	Fx (N)	Fy (N)	Fz (N)	Mx (Nmm)	My (Nmm)	Mz (Nmm)
Lateral							
E =200 GPa		330	155	140	1219	-34	-2394
E =2,000 GPa		329	139	141	2814	-143	-3531
E=20,000 GPa		311	100	154	6296	-270	-7057

3.2.2 Stress analysis of flexure.

The maximum structural stress in the loadspreader puck assembly occurs near the minimum cross section of the flexure. The magnitude of the maximum principal stress for 1000 N loads to the loadspreader is 57.3 MPa. We define the maximum lateral load as the point at which the principal stresses equal the yield strength. Beyond this load the flexure fails.

The yield strength depends on the flexure material. For example, if we use UNS G43400 hot-rolled steel (Yield strength=475 MPa) the flexure should fail when lateral loadspreader loads exceed 475/57.3 x 1000N = 8300N. If we adopt as the criterion that the maximum lateral loads shall not exceed 3000 N, UNS G43400 provides a factor of safety of 2.8.

Table 5 shows the maximum lateral loads that can be applied to the loadspreaders for four different types of common steels. HR means hot-rolled and CD means cold-drawn. Heat treatment of these steels typically increases their yield strength by a factor of 2-3.

TABLE 5. Yield strengths of various steels and corresponding maximum lateral loads.

Steel UNS number	Yield strength MPa	Max Lateral Load (N)
G41400 HR	434	7,574
G41400 CD	620	10,800
G43400 HR	475	8300
G43400 CD	682	11,900

4.0 Summary:

All of the following figures are from the best loadspreader design that meets our design criteria. Figures 1 through 3 show the loadspreader and puck design with 2 mm glue joints. Figure 4 shows the axisymmetric model used to determine the PCF. Figure 5 is a graph from the axisymmetric model showing half of the pressure profile applied perpendicular to the back of the mirror. Figures 6 through 8 show the solid models of the puck. Figure 9 is a graph from the solid models of the puck showing the entire pressure profile applied perpendicular to the back of the mirror. Figures 10 and 11 show the location of the axial and lateral loads applied to the loadspreader frame.

The glue joint models show that the Young's modulus of the glue must be 5.6 or less to keep the PCF less than 3.0. The best compromise glue thickness is 2.0 mm.

In order to keep the moments applied to the mirror within the figure goals (8000N) under full lateral loads (3000N), the Young's modulus of the material used in the current flexure design should be less than or equal to 200 GPa. This also indicates that if the flexure is made from steel (E=200GPa), then its stiffness cannot be increased by increasing the minimum cross section of the flexure.

The stress analysis shows that if the flexure is made from an alloy of steel with a high yield strength, such as G43400CD, it can safely support the maximum foreseeable lateral loads per loadspreader (3000 N) with a factor of safety of four. This factor of safety could be improved with heat treatment of the flexures. Note that with G43400CD, the entire weight of the mirror could be supported on 8 of the 204 pucks attached to three loadspreaders.

5.0 Future modeling:

A thermal analysis of the loadspreader remains to be completed. This analysis will determine the displacements and resulting forces and moments that are caused by the differential coefficients of thermal expansion of the materials.

The force and moments calculated by this report could be applied to the BCV finite element model of the 6.5m mirror. Each set of mirror loads could be scaled to the proposed mirror support forces to determine the affect of the current design of the glue, pucks, and loadspreader on the point spread function produced by the supported mirror.

Once the allowable forces in the back plane of the mirror are better understood we can, if necessary, further reduce the magnitude of these forces by stiffening the design of the loadspreader frame.

6.0 List of Figures:

7.0 References:

1) BCV report N.144 Rev.0 11/92

This report explains the finite element model results that set the maximum PCF, forces, and moments that can be applied to the of the 6.5m mirror.

2) Experimental Investigation of Silicone Adhesives for Mirror Support: Report #1 by Peter Gray, Steward Observatory memo. 10/14/93.

This report explains experimental tests of the material properties of an RTV made by Dow Corning.

3) Columbus Tech memo UA-92-03: Performance test results of the 6.5 meter support actuator design by Shawn Callahan, MMTO 9/16/92

This report shows the forces and moments that the mirror support actuator applies to the loadspreader in this report.

4) Large Binocular Telescope Project Tech Memo UA-93-xx: Mirror Support System for Large Honeycomb Mirrors II by John Hill 11/2/93

This report explains the general concepts for supporting large honeycomb mirrors.

REVISIONS			
REV.	DESCRIPTION	DATE	APPROVED

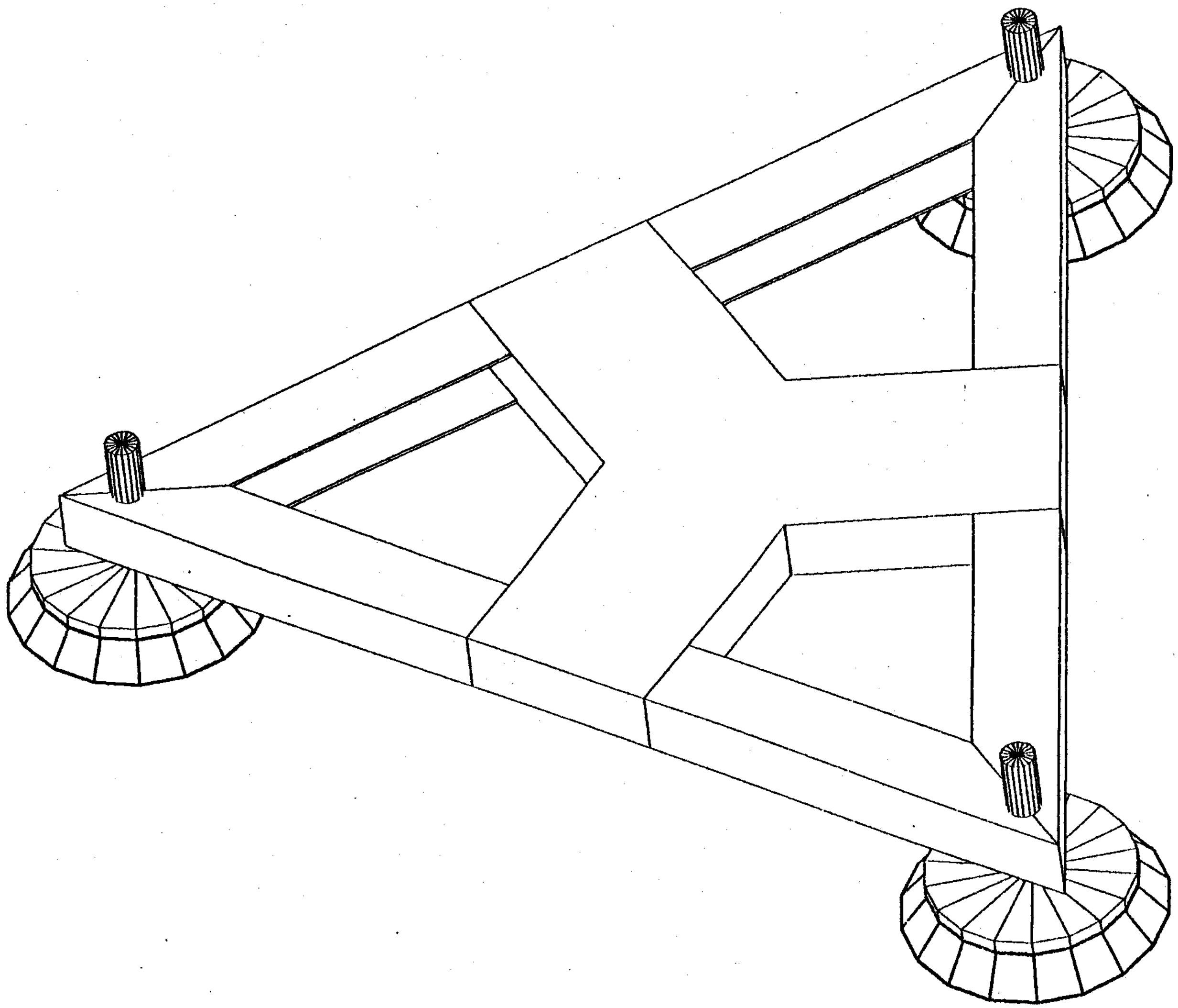


Figure 1

UNLESS OTHERWISE SPEC.	
TOLERANCES ON:	
DECIMALS	ANGLES
DIMENSIONS ARE IN: ENGLISH X METRIC __	
MATERIAL:	
FINISH:	

QTY REQD	PART NO.	DESCRIPTION	ITEM NO.

LIST OF MATERIALS

DRAWN BY: S. Callahan	DATE: 10/12/93	UNIVERSITY OF ARIZONA & SMITHSONIAN INSTITUTION MULTIPLE MIRROR TELESCOPE OBSERVATORY Tucson, Arizona 85721 (602) 621-1558
CHECKED BY:		
CHECKED BY:		TITLE: 6.5m Mirror Support Loadspreader
APPROVED BY:		SCALE: / SIZE A / DRAWING NO. / REV.
APPROVED BY:		CAD FILE: loadspreader2 / SHEET NO.

Figure 2

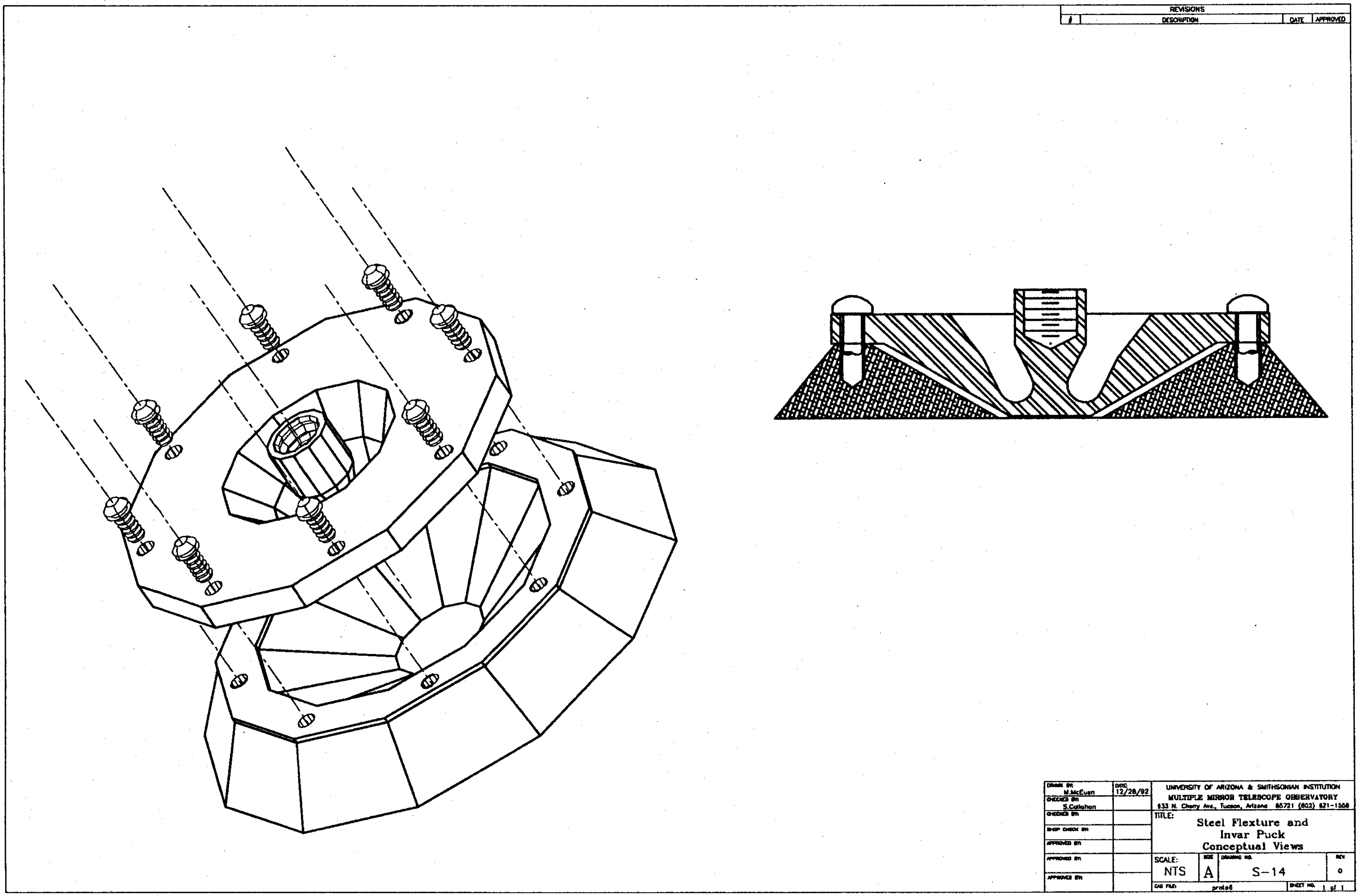
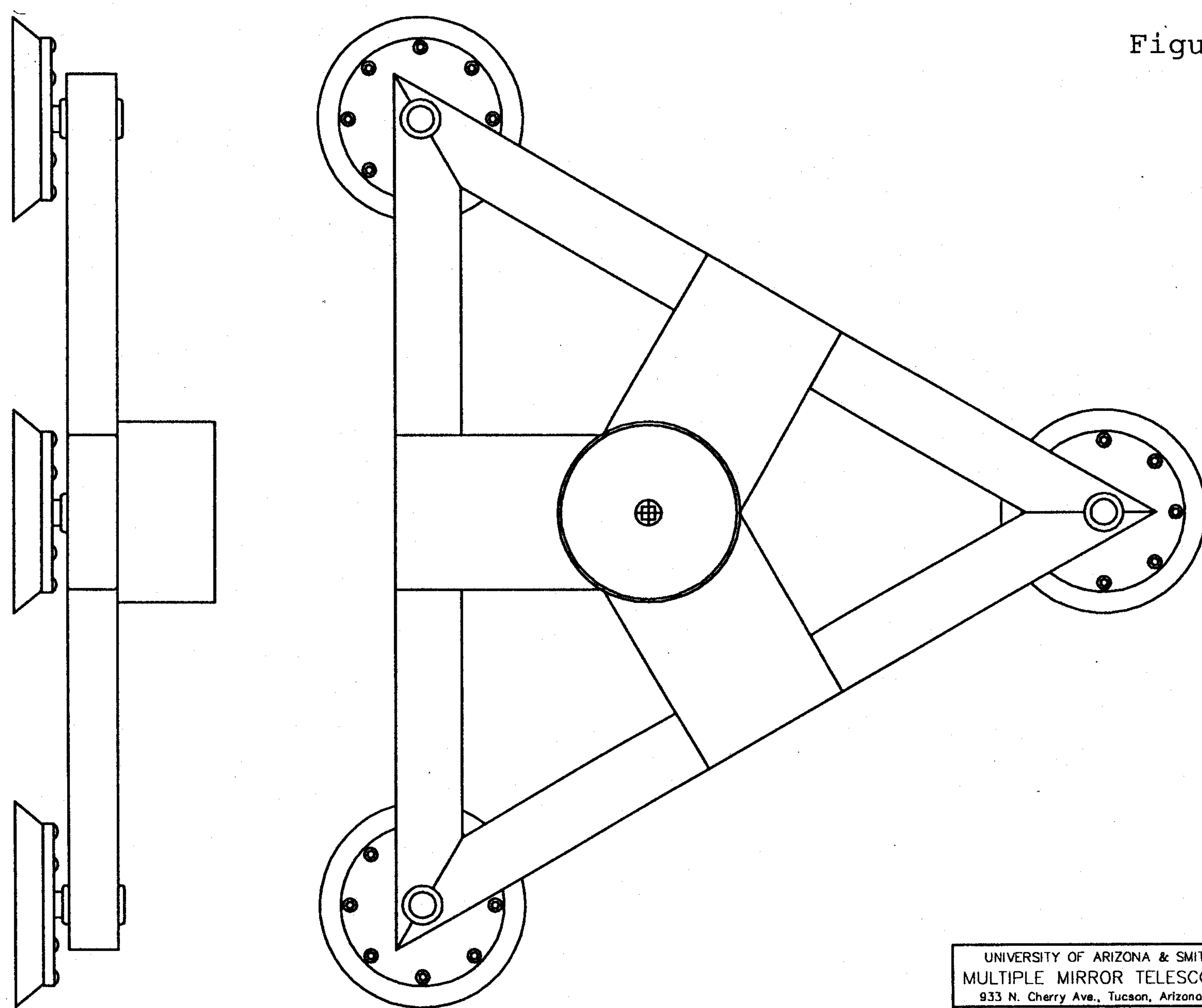

REVISIONS
#
DESCRIPTION
DATE
APPROVED
DRAWN BY: M.McEuen
DATE: 12/28/92
CHECKED BY: S.Callahan
CHECKED BY:
SHOP CHECK BY:
APPROVED BY:
APPROVED BY:
APPROVED BY:
UNIVERSITY OF ARIZONA & SMITHSONIAN INSTITUTION
MULTIPLE MIRROR TELESCOPE OBSERVATORY
933 N. Cherry Ave., Tucson, Arizona 85721 (602) 621-1558
TITLE: Steel Flexture and Invar Puck Conceptual Views
SCALE: NTS
SIZE A
DRAWING NO. S-14
REV. 0
CAD FILE: prote6
SHEET NO. 1 of 1

Figure 3



UNIVERSITY OF ARIZONA & SMITHSONIAN INSTITUTION MULTIPLE MIRROR TELESCOPE OBSERVATORY 933 N. Cherry Ave., Tucson, Arizona 85721 (602) 621-1558			
TITLE: Conceptual general layout of loadspreader			
SCALE: NTS	SIZE A	DRAWING NO. m9001	REV.
DRAWN BY: M.McEUEN	DATE: 11/93/93	CAD FILE: loadspreader	SHEET NO. 1 of 1

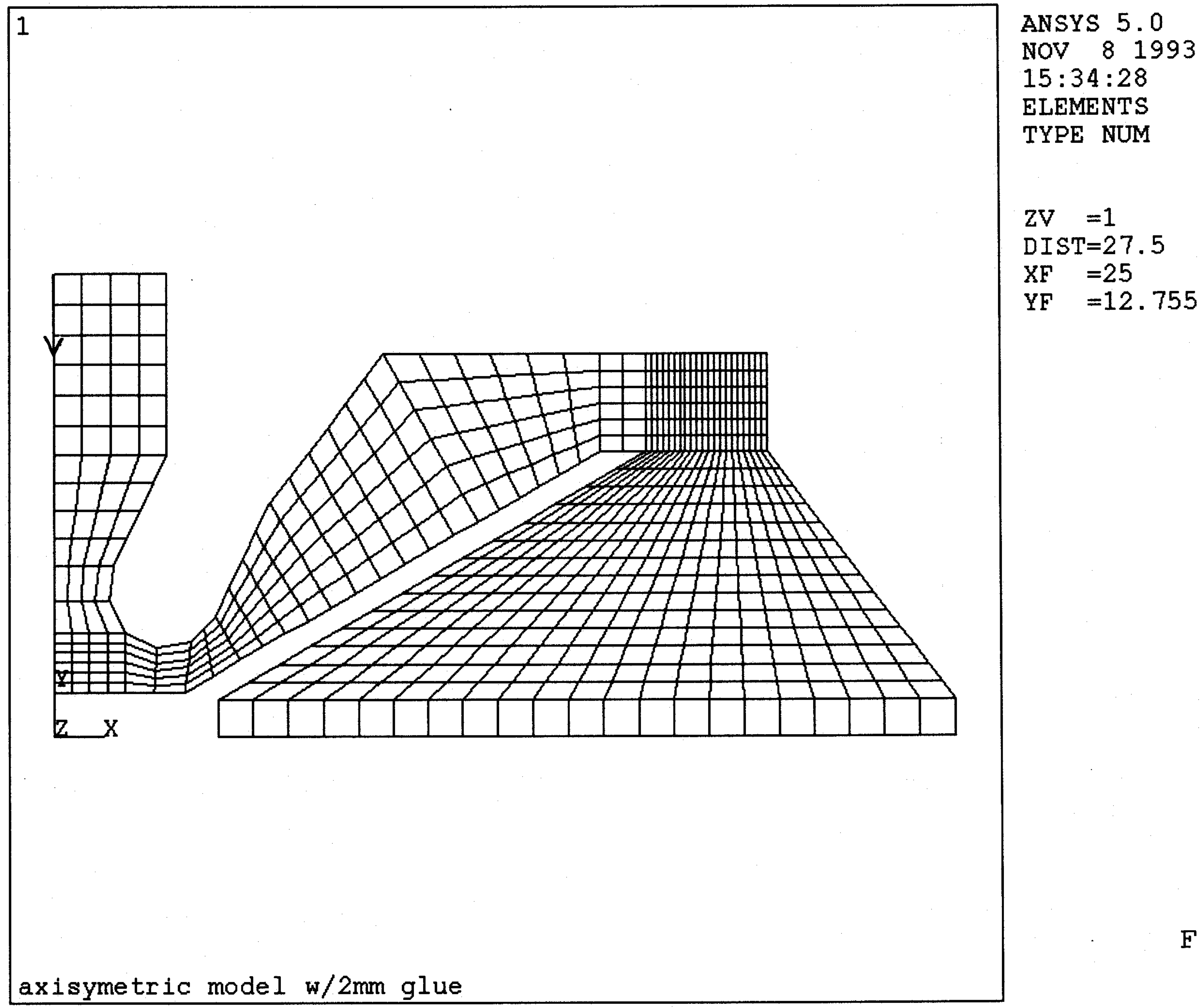

1
ANSYS 5.0
NOV 8 1993
15:34:28
ELEMENTS
TYPE NUM
ZV =1
DIST=27.5
XF =25
YF =12.755
Y
Z X
axisymetric model w/2mm glue

Figure 4

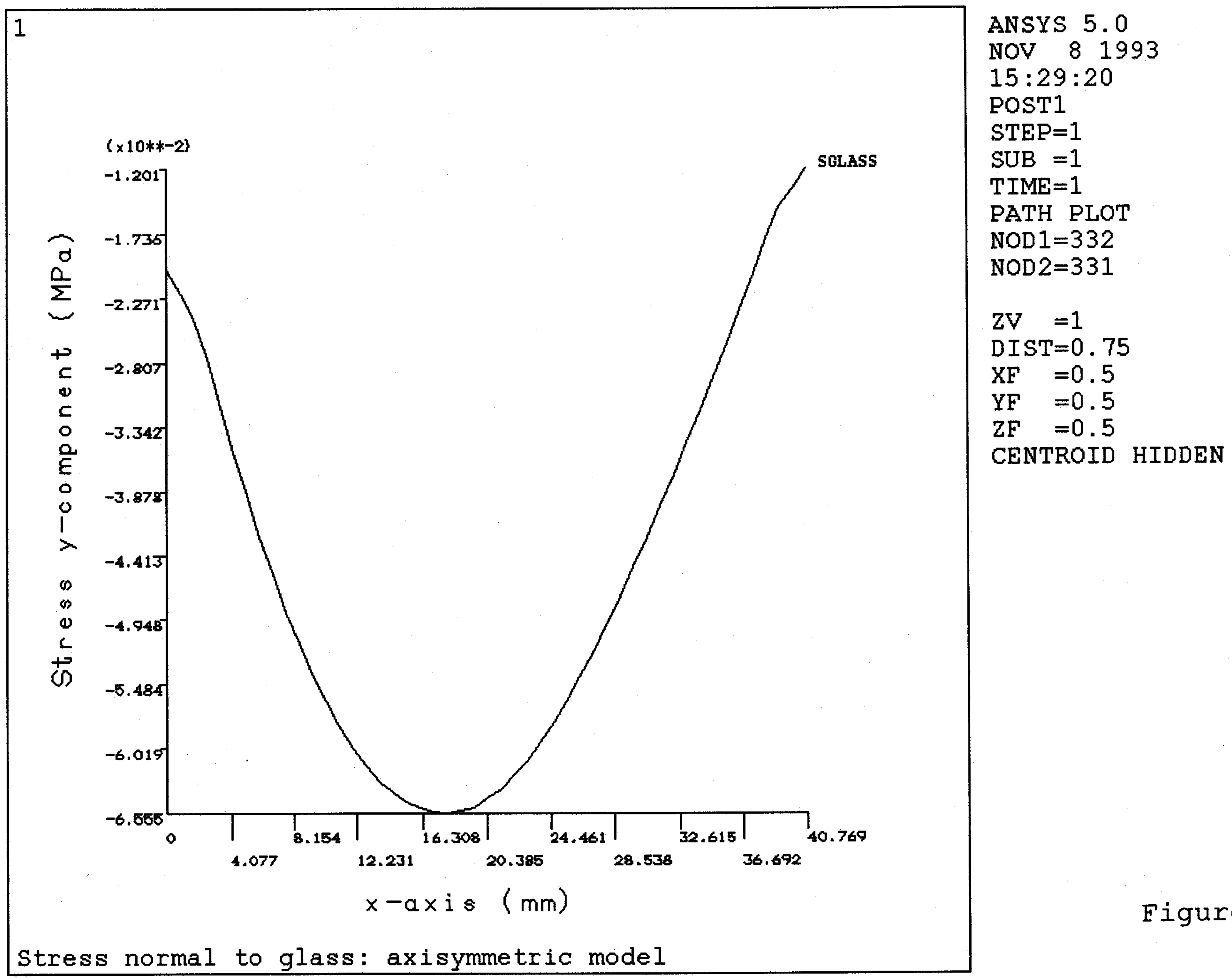

1
(x10**-2)
-1.201
-1.736
-2.271
-2.807
-3.342
-3.878
-4.413
-4.948
-5.484
-6.019
-6.555
Stress y-component (MPa)
SGLASS
0
4.077
8.154
12.231
16.308
20.385
24.461
28.538
32.615
36.692
40.769
x-axis (mm)
Stress normal to glass: axisymmetric model
ANSYS 5.0
NOV 8 1993
15:29:20
POST1
STEP=1
SUB =1
TIME=1
PATH PLOT
NOD1=332
NOD2=331
ZV =1
DIST=0.75
XF =0.5
YF =0.5
ZF =0.5
CENTROID HIDDEN

Figure 5

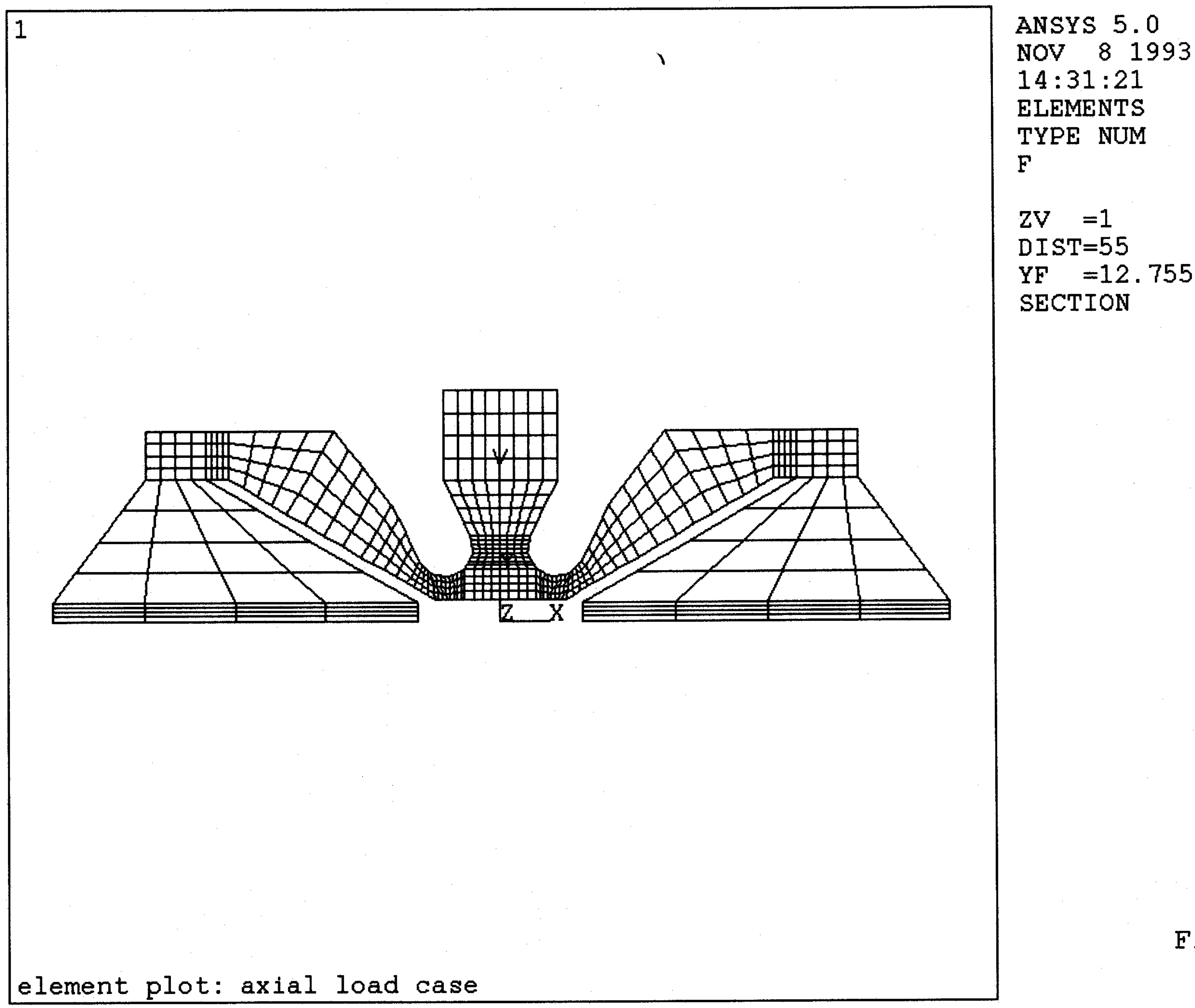

1
ANSYS 5.0
NOV 8 1993
14:31:21
ELEMENTS
TYPE NUM
F
ZV =1
DIST=55
YF =12.755
SECTION
Z
X
element plot: axial load case

Figure 6