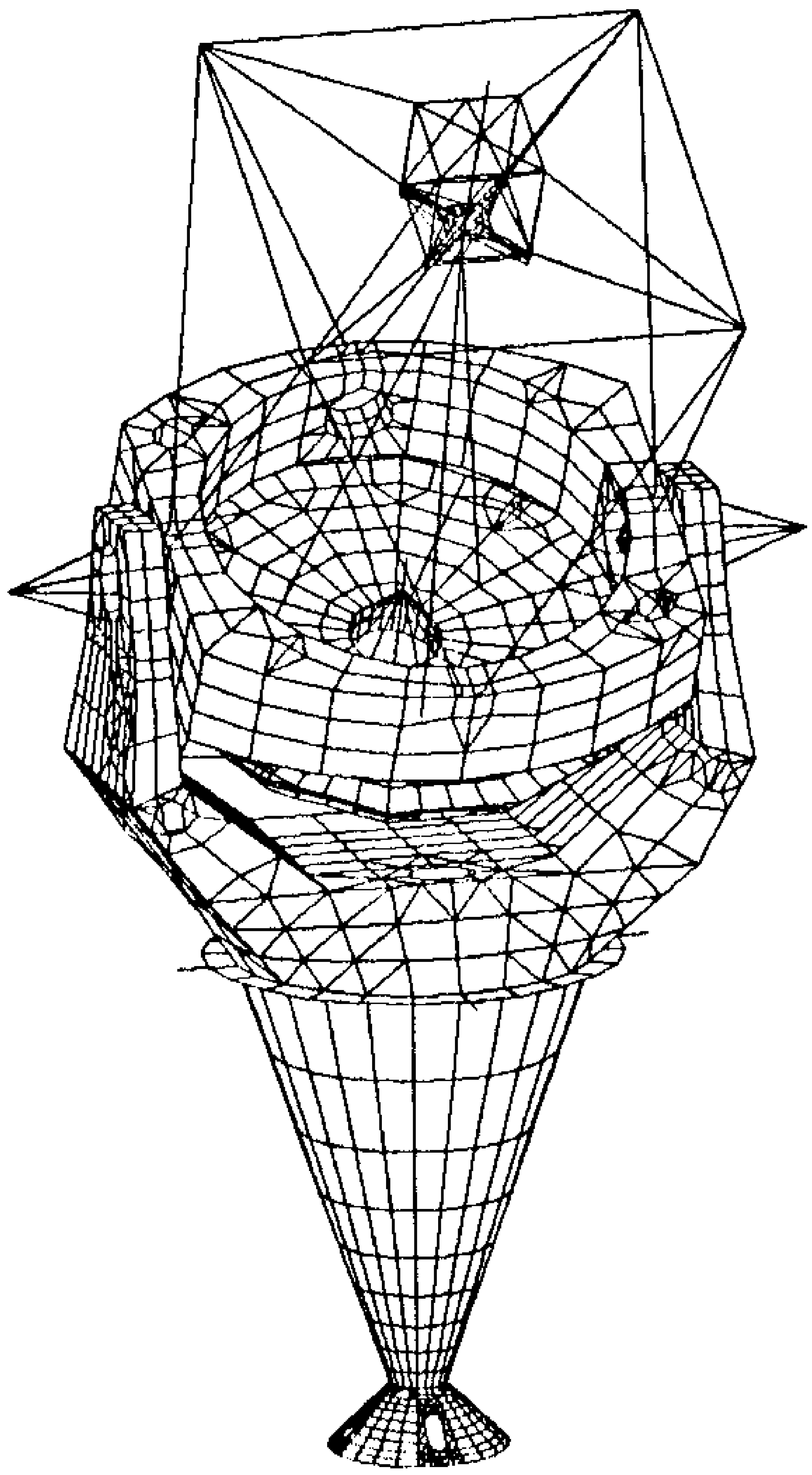
DETAIL DESIGN FINITE ELEMENT ANALYSIS OF THE WIYN 3.5 METER TELESCOPE



Wisconsin
Indiana
Yale
NOAO

for

NATIONAL OPTICAL ASTRONOMY OBSERVATORIES

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INDEX

1.0 INTRODUCTION

The Wisconsin-Indiana-Yale-NOAO (WIYN) 3.5 Meter Telescope is an alt-az fork mount currently under construction at L & F Industries. It will be installed atop Kitt Peak near Tucson, Arizona. The system will incorporate many technologies recently developed for state-of-the-art ground-based telescopes. These include fast lightweight optics, a stiff, thermally responsive mount structure, high precision friction-driven encoders and drives, and a lightweight ventilated enclosure.

The early preliminary design of the WIYN 3.5 Meter Telescope was summarized in the June 1990 report, "Engineering Report - Preliminary Design Study WIYN 3.5 Meter Telescope". That report was updated in June 1991 (WODC 02-07-01) by the report titled "Preliminary Design of the WIYN 3.5 Meter Telescope". Both preliminary design reports included descriptions of the structure and major mechanical systems and finite element analysis summaries.

The purpose of this report is to document changes in the structural design that have been implemented during the detail design phase and to summarize structural performance as predicted by finite element analysis. The work has been performed for NOAO by L & F Industries.

2.0 FINITE ELEMENT ANALYSIS

2.1 INTRODUCTION

The finite element models are shown in the form of graphics plots in Figures 1 through 18. Three types of models were created and processed during the detail design phase. Relatively small local models were used to determine stiffness and stress effects due to anticipated changes in the structural design. These changes were then incorporated in the complete telescope model and the modal performance updated.

Model WIYNTM75 was the final modal analysis of the complete telescope, incorporating the detail design changes and using "locked encoder" drive stiffness. For reference, model WIYNTM80 was created and solved using "locked rotor" drive stiffness. Also, the detail design changes were incorporated in the OSS static analysis model which was used to minimize misalignments of the optics due to rotating through the gravity field. The final static analysis used for this purpose was model OSS72.

Wind loading was not run in the detail design phase, but results from the preliminary design models are summarized in WODC 02-07-01.

Notable changes made during the detail design phase are:

1. The lower azimuth bearing pedestal (Figure 4) was made considerably longer with four large holes added for the routing of utilities.

2. The fork tines were made 1" thinner in order to better accommodate the chosen back focal distance for the Nasmyth instruments (Figures 3, 6, and 7).

3. The personnel access hole through the azimuth drive disk and bottom plate of the fork base was enlarged considerably, as shown in Figure 5.

4. Holes in the altitude drive disk webs were added to provide maintenance access to areas of the primary mirror cell (Figure 9).

5. Numerous utilities routing holes were provided in external and internal plates (Figures 6 through 8).

6. Counterweight assemblies were placed inside the center section, with access holes as shown in Figures 10 and 11.

7. The previously-planned primary truss members were replaced with flexion bars (Figures 13 through 16). These were then supported with fixity at the center section with internal gussets as shown in Figure 11. The primary mirror cell (Figure 12) was also more highly meshed to accommodate the new method of support. The flexion bars include a means of tuning their axial stiffness. This feature can be used to compensate for engineering and manufacturing tolerances to achieve precise alignment of the optics as the OSS is rotated through the gravity field. This model (OSS72) is shown in Figure 18. Installation and tuning procedures are summarized on L & F drawing no. E312001 sht. 3

8. Two lateral braces were added between each altitude drive segment and the mirror cell to minimize encoder errors. These are indicated as simple beam elements in Figure 13.

Additional local models were created and solved where needed. For example, the secondary end frequencies and modeshapes (including effects from vane pretension) were determined using a "modal analysis with load stiffening" program. These results are reported below, with the first two modeshapes shown in Figure 17.

Example model sizes are:

WIYNTM75		OSS72	
2769	nodes	1428	nodes
3354	plate elements	1672	plate elements
361	beam elements	259	beam elements
16,374	degrees of freedom	8,550	degrees of freedom
1122	bandwidth	774	bandwidth

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2.2 OPTICS, INSTRUMENT, AND TELESCOPE WEIGHTS

The following weights were used in, or resulted from, the finite element models:

Subsystems:

Mirror cell assy - 16,922 lbs
Nasmyth instruments - (2) @ 1,500 lbs
Secondary assembly - 600 lbs
Tertiary assembly - 950 lbs
Mirror cover assembly - 400 lbs
Secondary baffle - 60 lbs
Counterweights - (2) @ 426 lbs

Totals (including subsystems):

OSS Assembly - 34,040 lbs
5.9E5 lb-sec^2-in (alt axis)
6.3E5 lb-sec^2-in (optical axis)
6.0E5 lb-sec^2-in (perpendicular)

Telescope (rotating) Assembly:
81,090 lbs
1.16E6 lb-sec^2-in (azimuth axis)

2.3 MODAL ANALYSIS

The results of the finite element analyses are presented in Tables 1 thru 3. As can be seen in Figures 1 and 2, the final models were run with the OSS pointing 30° off zenith. It was felt that this was a reasonable compromise between the zenith attitude, where the lateral translation frequency would be slightly lower, and the horizon attitude, where the azimuth rotation frequency would be lower. It is estimated that the lateral translation frequency would be about 2% lower, and the locked encoder azimuth about 4% lower, than the results reported herein. The OSS was positioned at the 30° position (rather than 45°) since the telescope is used more frequently near zenith than horizon.

The calculated locked encoder modal performance for the complete telescope is summarized in Table 1. Modeshapes are not included here but are shown as Figures 17 through 20 in WODC 02-07-01. Locked rotor frequencies are listed in Table 2 for reference.

The secondary end local modal performance is summarized as a function of vane pretension in Table 3. Modeshapes are shown in Figure 17.

2.4 STATIC ANALYSIS

The main static analyses performed in the detail design phase related to the flexion bars.

Local brick element models of the actual flexure were created to analyze stresses that develop due to zenith and horizon gravity loads and side loads at the top end of the flexion bar that may occur during installation. Exaggerated deflected graphics plots are shown as Figures 14 and 15. The flexion bar clip, used to protect the flexion bar during installation and as a safety backup should a failure ever occur, was also analyzed for stress. The model is shown as Figure 16.

If the flexion bars were rigid, the secondary would deflect off (below) the primary optical axis and separate from the primary in the axial direction as the OSS is rotated to horizon. Therefore, a global model of the complete OSS (Model OSS72) was created and solved to determine what axial compliance the flexion bars should have in order to maintain the alignment of the two mirrors while rotating through the gravity field. Unloaded and exaggerated graphics plots are shown in Figure 18. The upper flexion bars were made more compliant that the lower units so that the primary points "down" at the secondary at horizon. Note the slight angular misalignment of the primary and secondary axes, which will be compensated for by active tilting of the secondary.

Detailed installation and tuning procedures are included on L & F drawing E312001 sheet 3.

FINITE ELEMENT ANALYSIS - SUMMARY OF RESULTS

TABLE 1

NATURAL FREQUENCIES AND MODESHAPES

The following modal performance is from model WIYNTM75, the complete telescope with OSS 30° from zenith, conventionally constrained ("locked encoder", or infinite drive stiffness). The four primary modeshapes are shown in Figures 17 through 20 of WODC 02-07-01.

MODE	FREQUENCY Hertz	MODESHAPE DESCRIPTION
1	8.0	Lateral Translation
2	8.5	1st Altitude Rotation (fore-Aft translation)
3	17.8	2nd Altitude Rotation ("locked encoder altitude")
4	21.6	Locked Encoder Azimuth

TABLE 2

NATURAL FREQUENCIES AND MODESHAPES

The following modal performance is from model WIYNTM80, the complete telescope with OSS 30° from zenith, using a manually estimated "locked rotor" drive stiffness of 1.08E6 lb/in. (as if the encoder were on the servomotor).

MODE	FREQUENCY Hertz	MODESHAPE DESCRIPTION
1	8.2	Lateral Translation
2	8.3	1st Altitude Rotation (fore-Aft translation)
3	13.1	Locked Rotor Azimuth
4	14.0	2nd Altitude Rotation (locked rotor azimuth)

TABLE 3

The following relate the first two local vibrational modes for the secondary end of the telescope to the total pretension at each end of a vaneset. Modeshapes are shown in Figure 17. It should be noted that, since this analysis was performed, the secondary mirror cell was made lighter (it is now made from aluminum). Therefore, the 25,000 lb. preload should now yield the goal first resonance of about 10 hz.

PRETENSION each vaneset	**FREQUENCY** Optical Axis Rotation	**FREQUENCY** 1st "Guitar String"
25,000 lbs.	8.7 hz	24
35,000 lbs.	10.1 hz	28
50,000 lbs.	11.8 hz	32
75,000 lbs.	14.2 hz	38

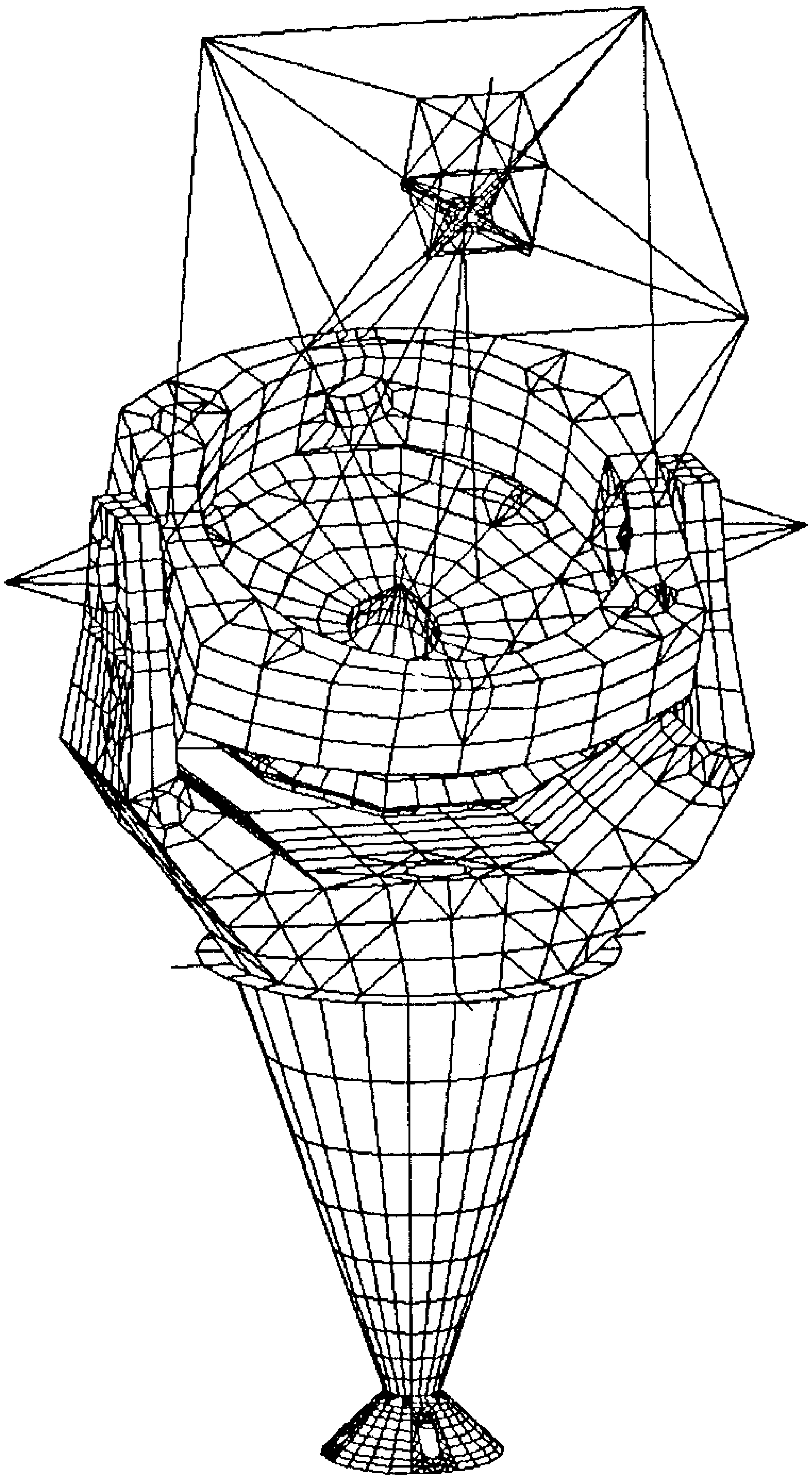


FIGURE 1

Model WIYNTM75, the detail design modal analysis model.

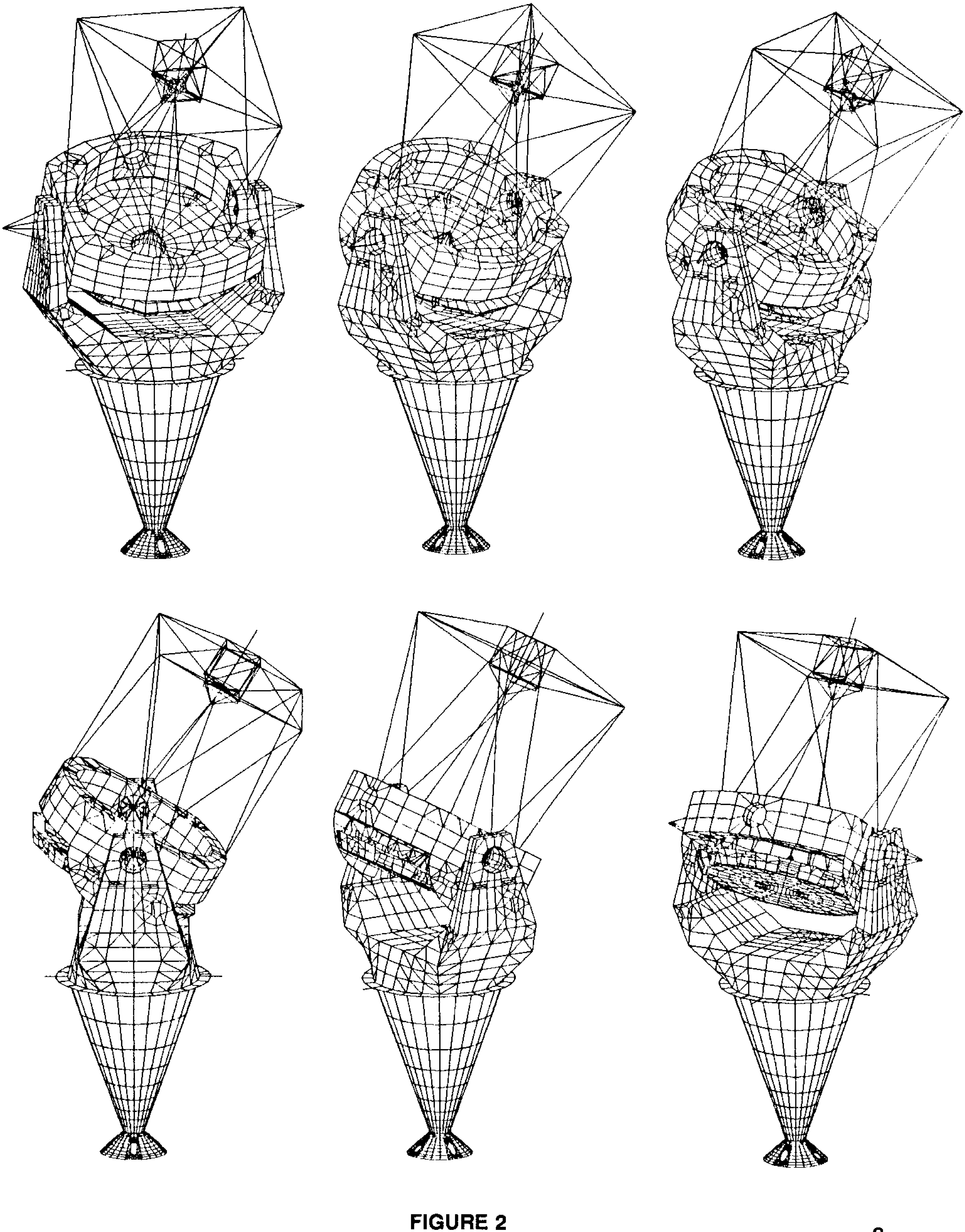


FIGURE 2
Quartering views of model WIYNTM75.

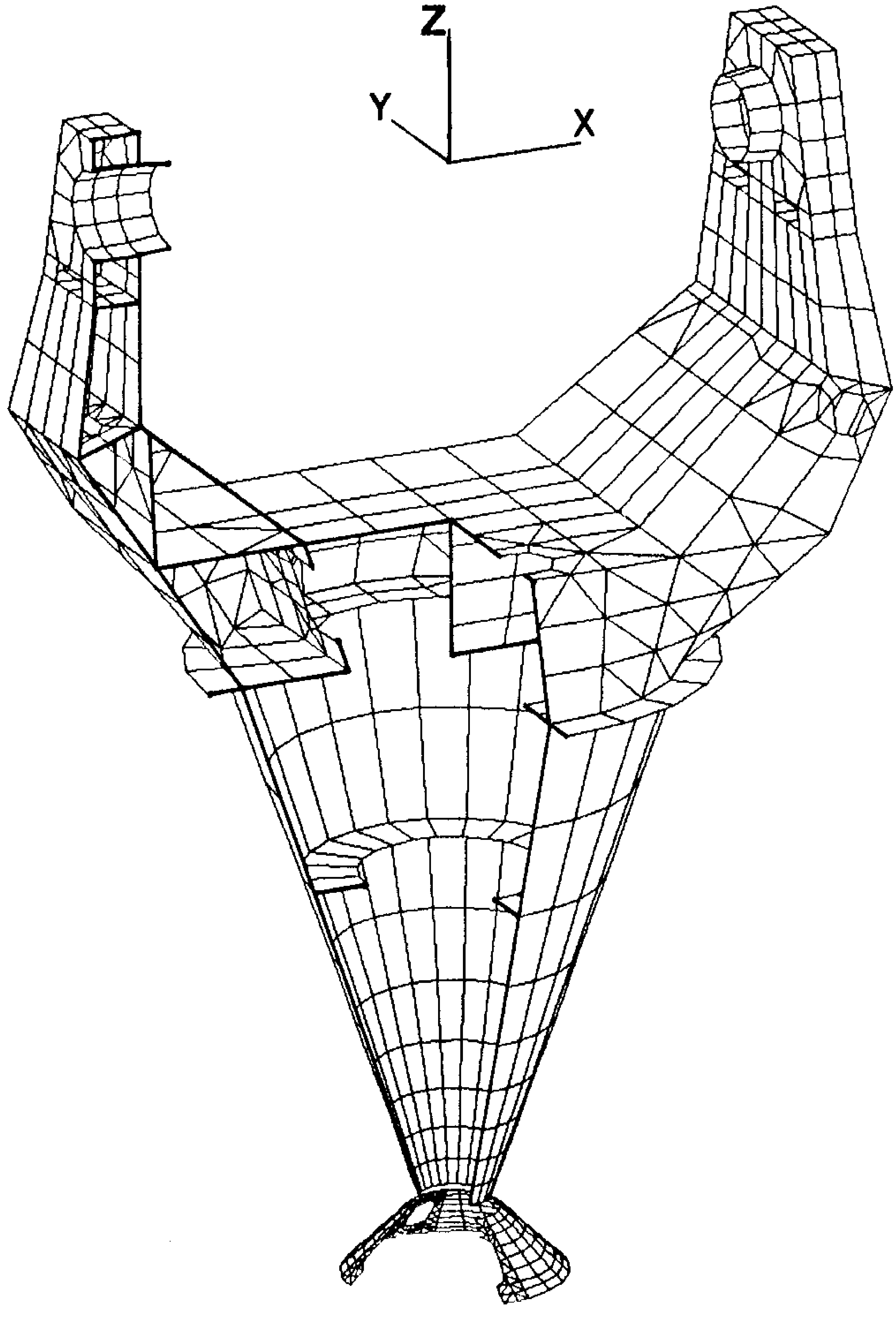


FIGURE 3

Cutaway view of fork with internal stiffening.

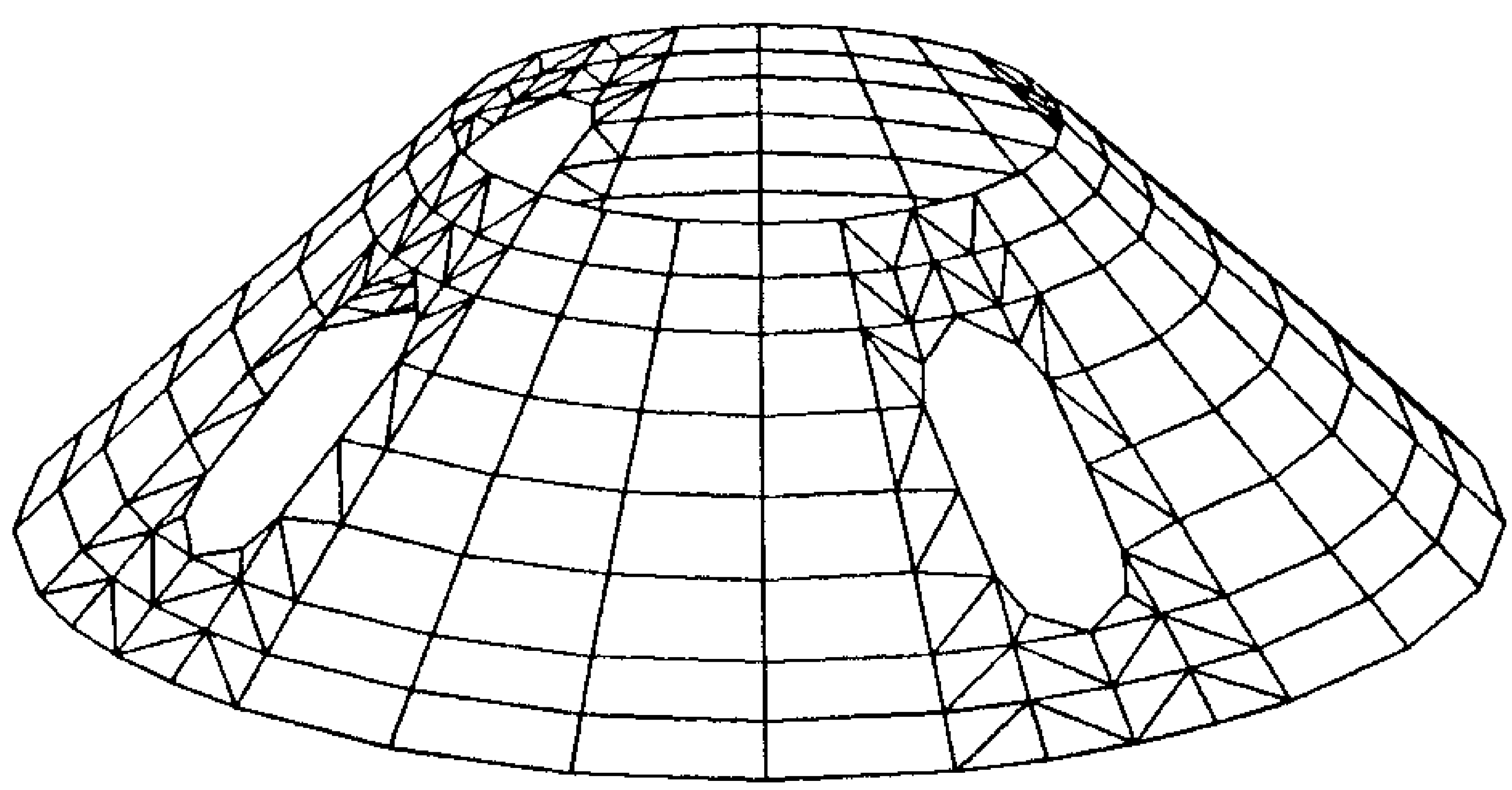


FIGURE 4

Lower azimuth bearing pedestal with utilities slots.

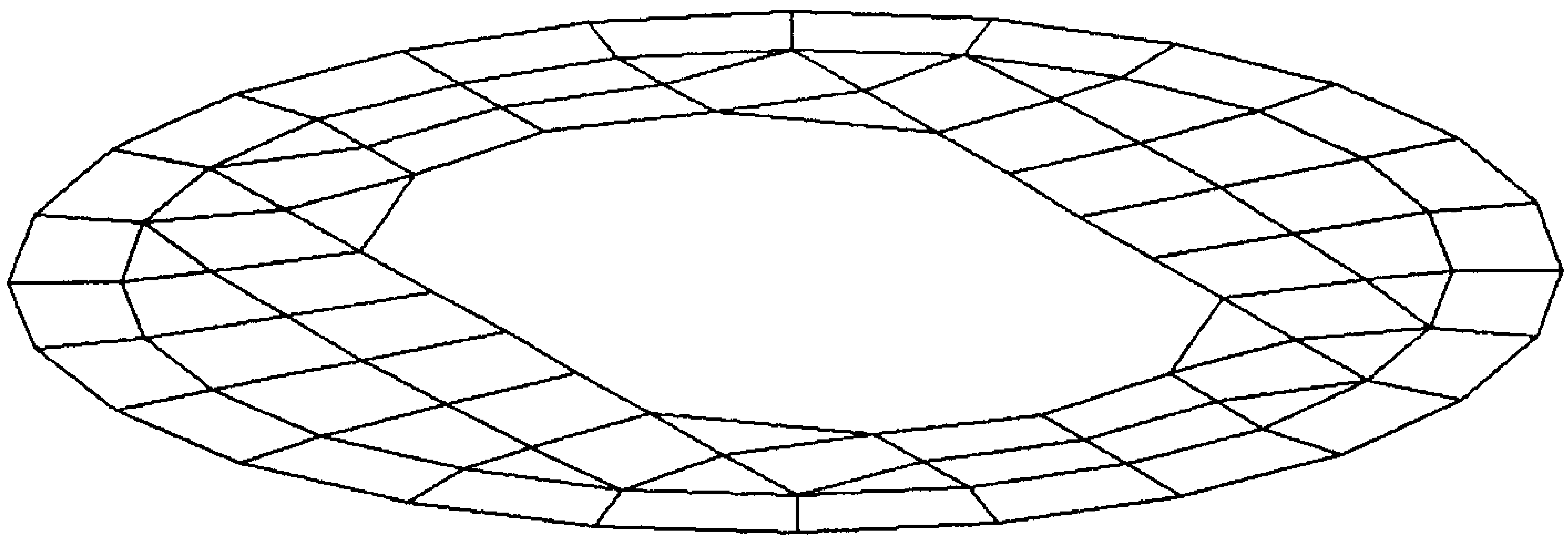
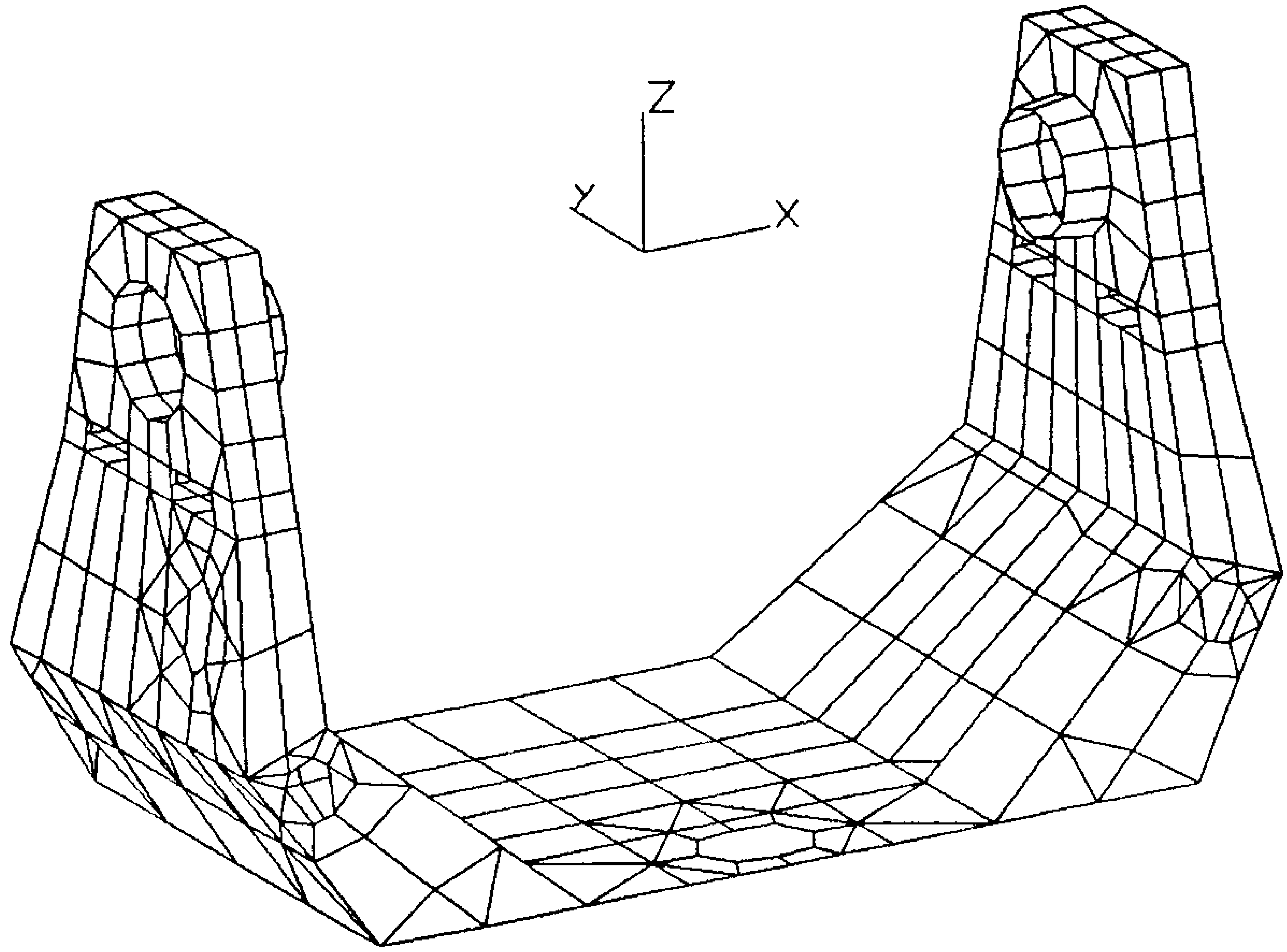


FIGURE 5

Azimuth drive disk with large personnel access cutout.



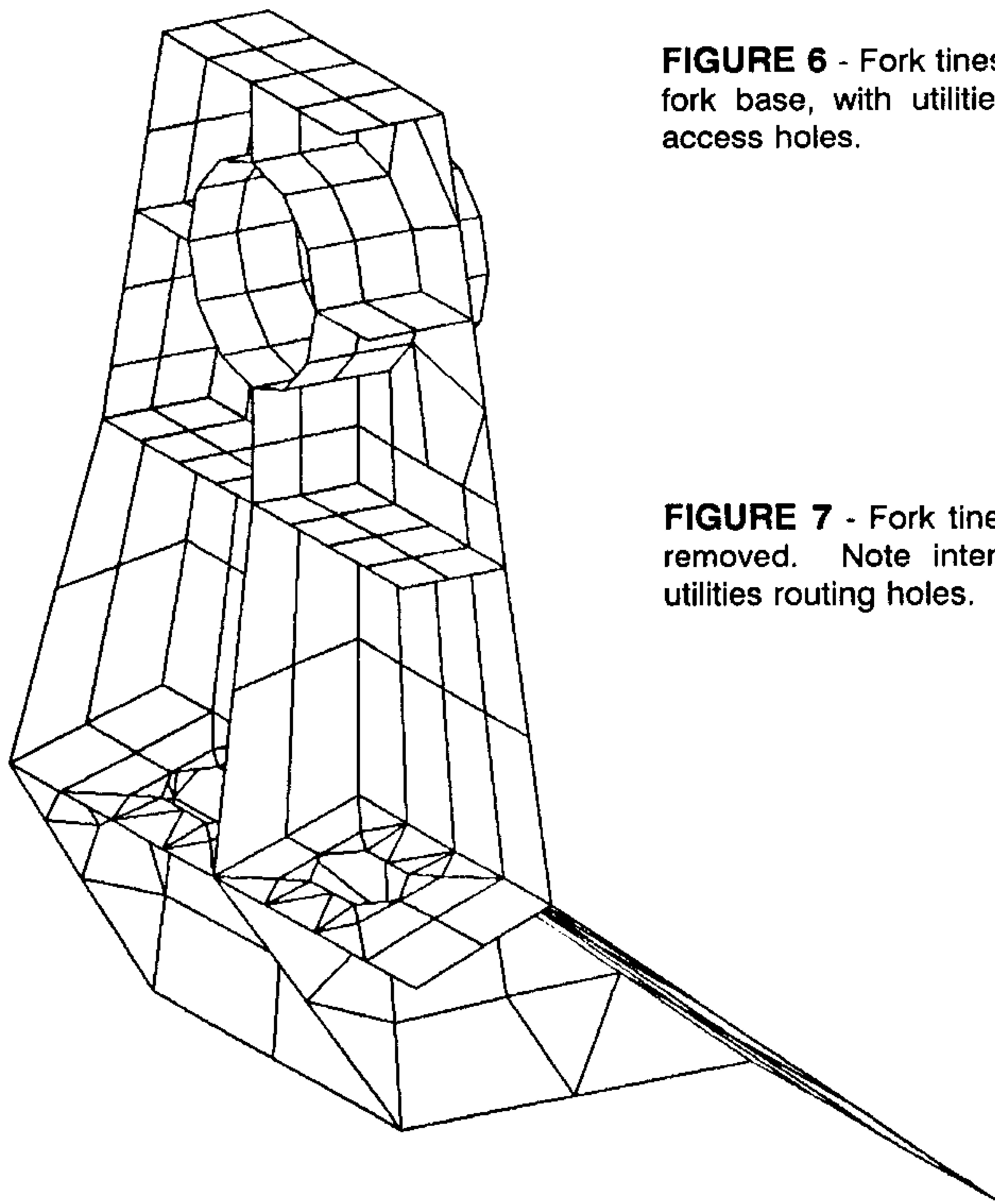


FIGURE 6 - Fork tines and top plate of fork base, with utilities and personnel access holes.

FIGURE 7 - Fork tine with near plates removed. Note internal gussets and utilities routing holes.

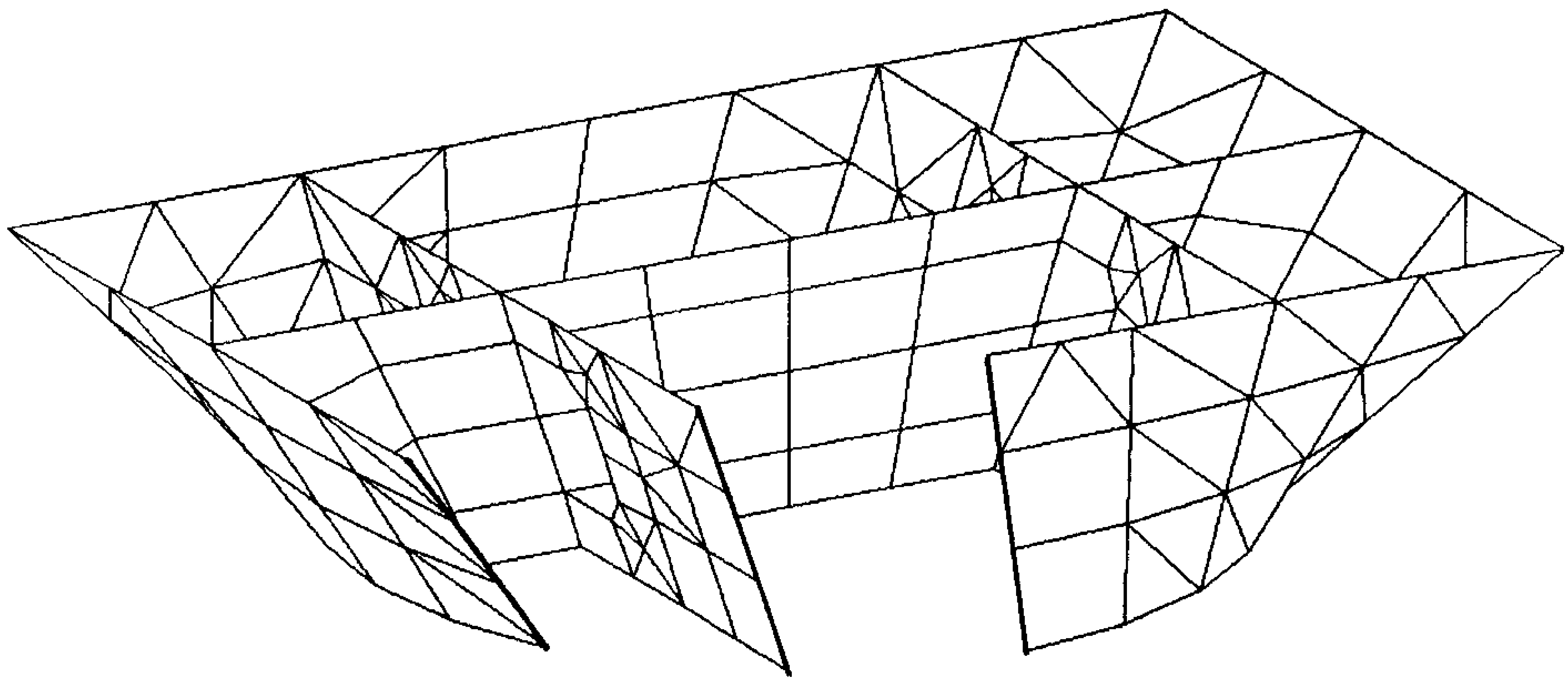


FIGURE 8 - Fork base with top and bottom plates removed.

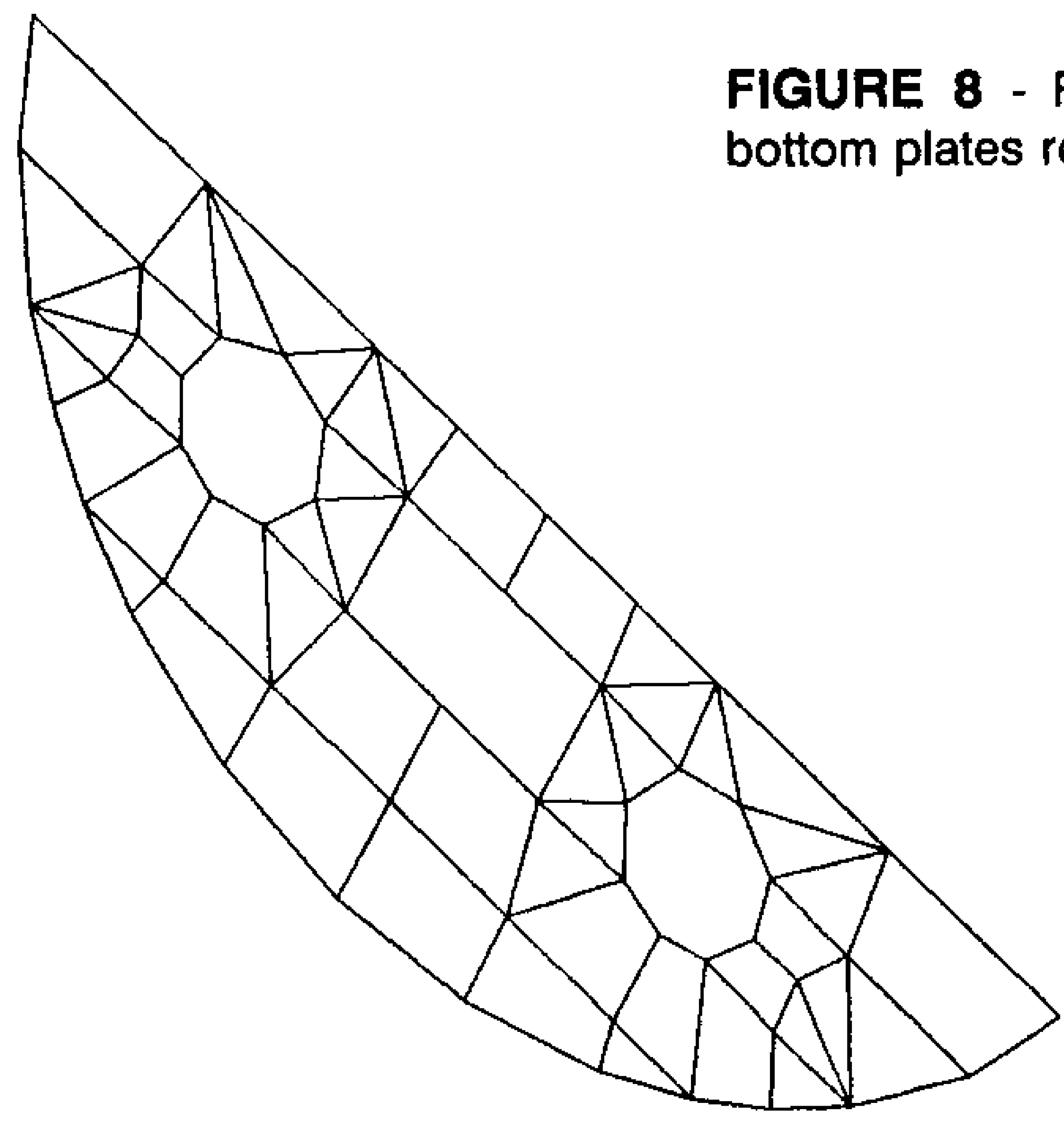


FIGURE 9

Altitude drive disk with mirror cell access cutouts.

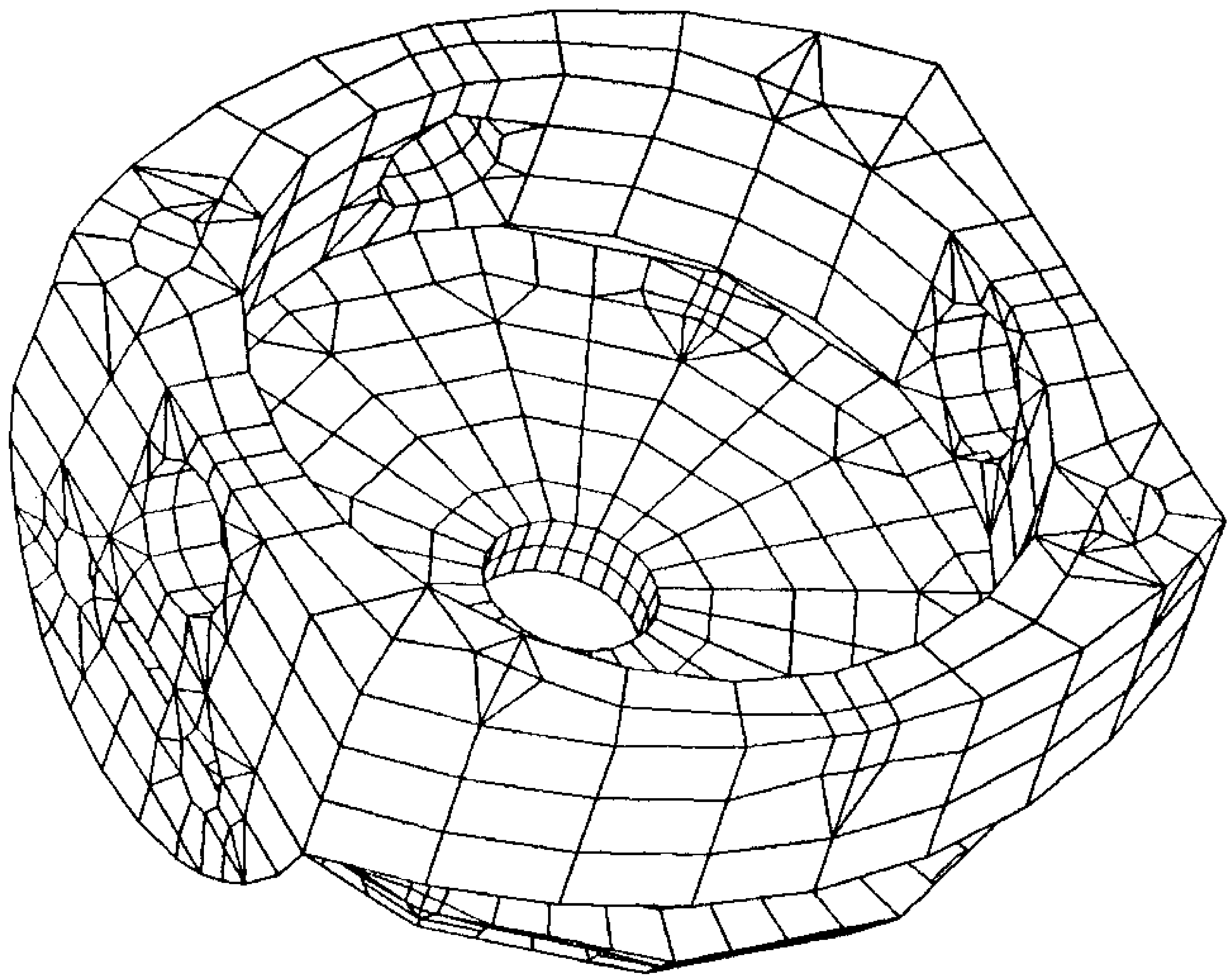


FIGURE 10 - Quartering view of plate elements in lower end of OSS.

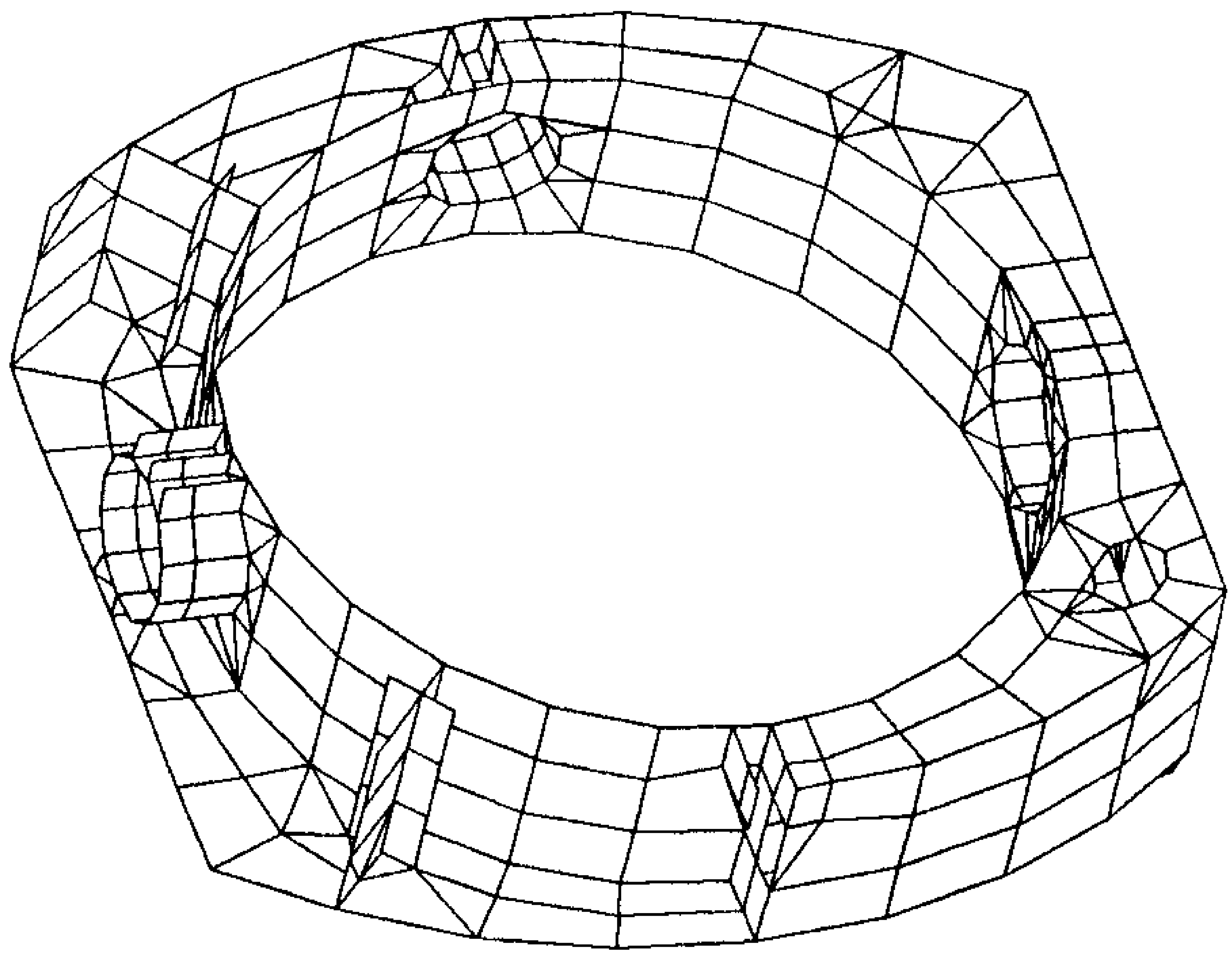


FIGURE 11 - Center section with some near plates removed.

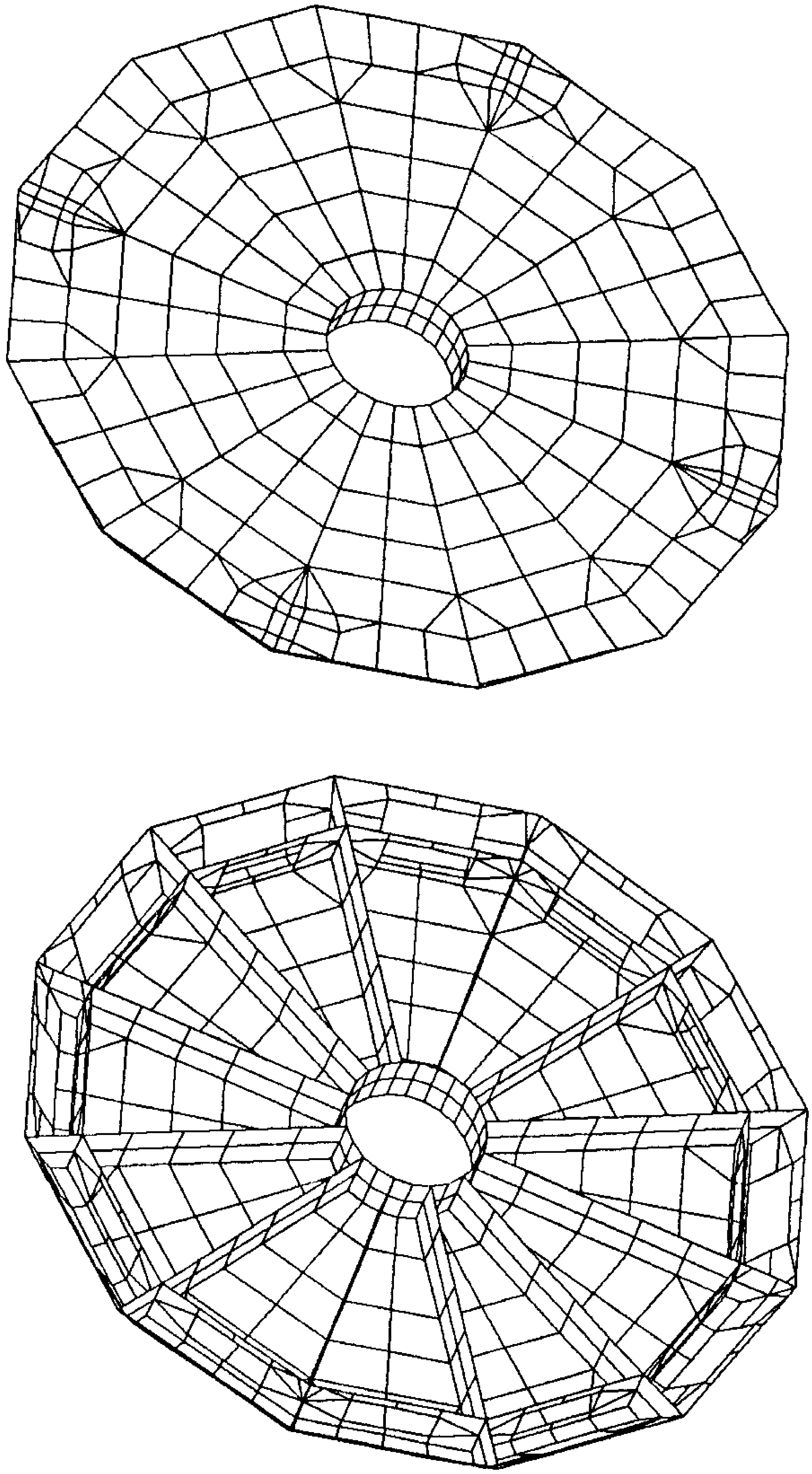


FIGURE 12 - Primary mirror cell with and without front plate.

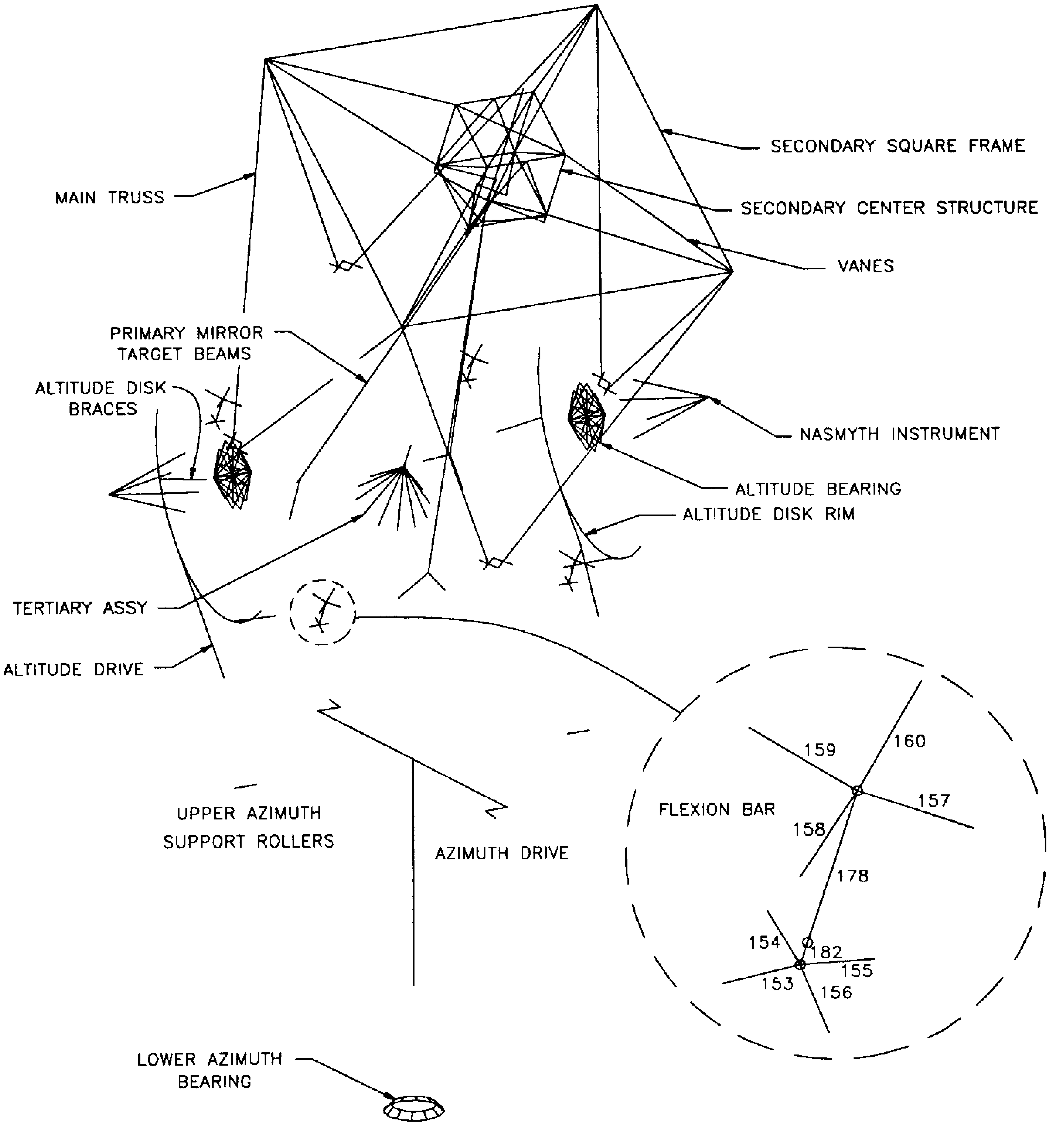
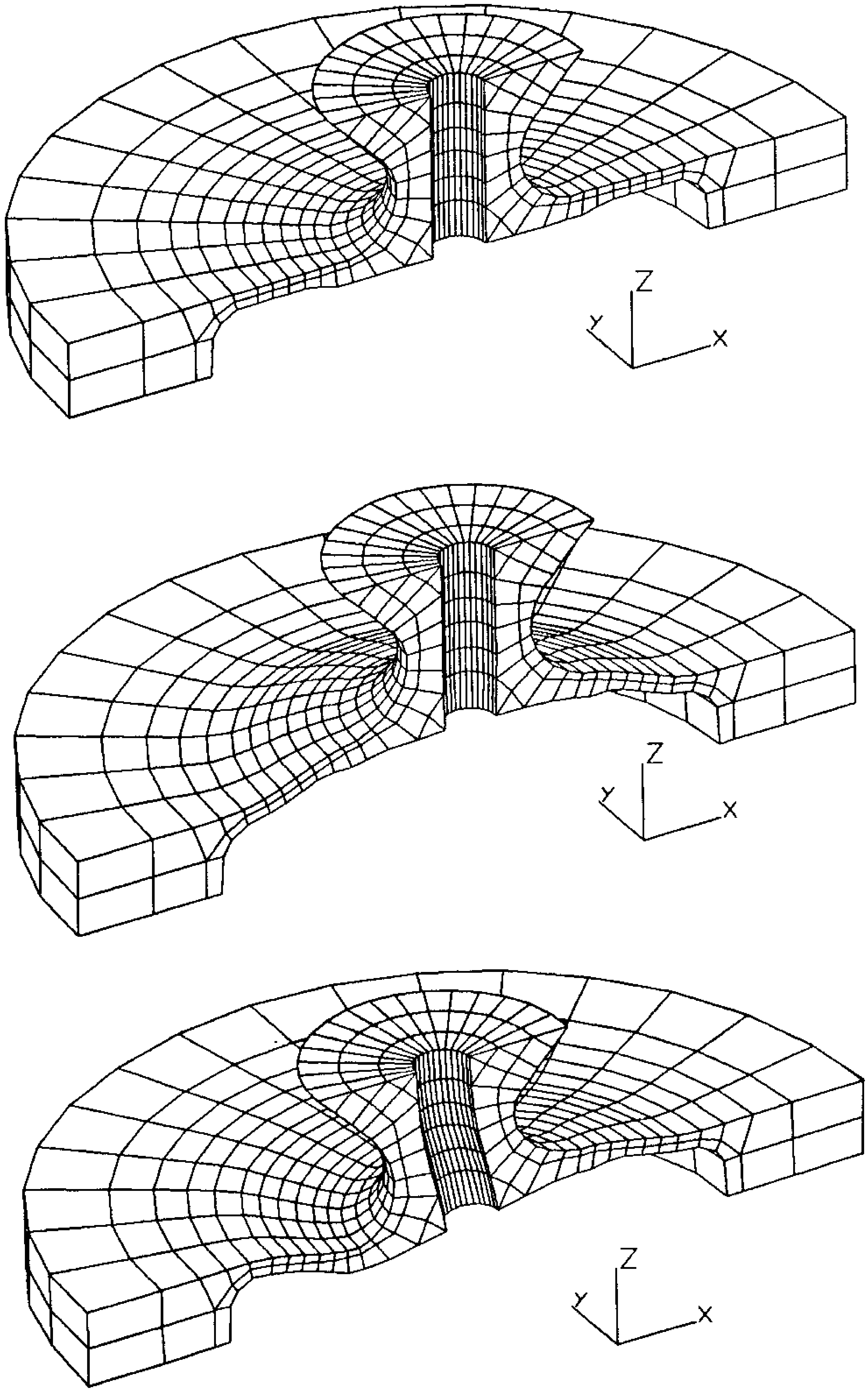


FIGURE 13

Beam elements in model WIYNTM75.

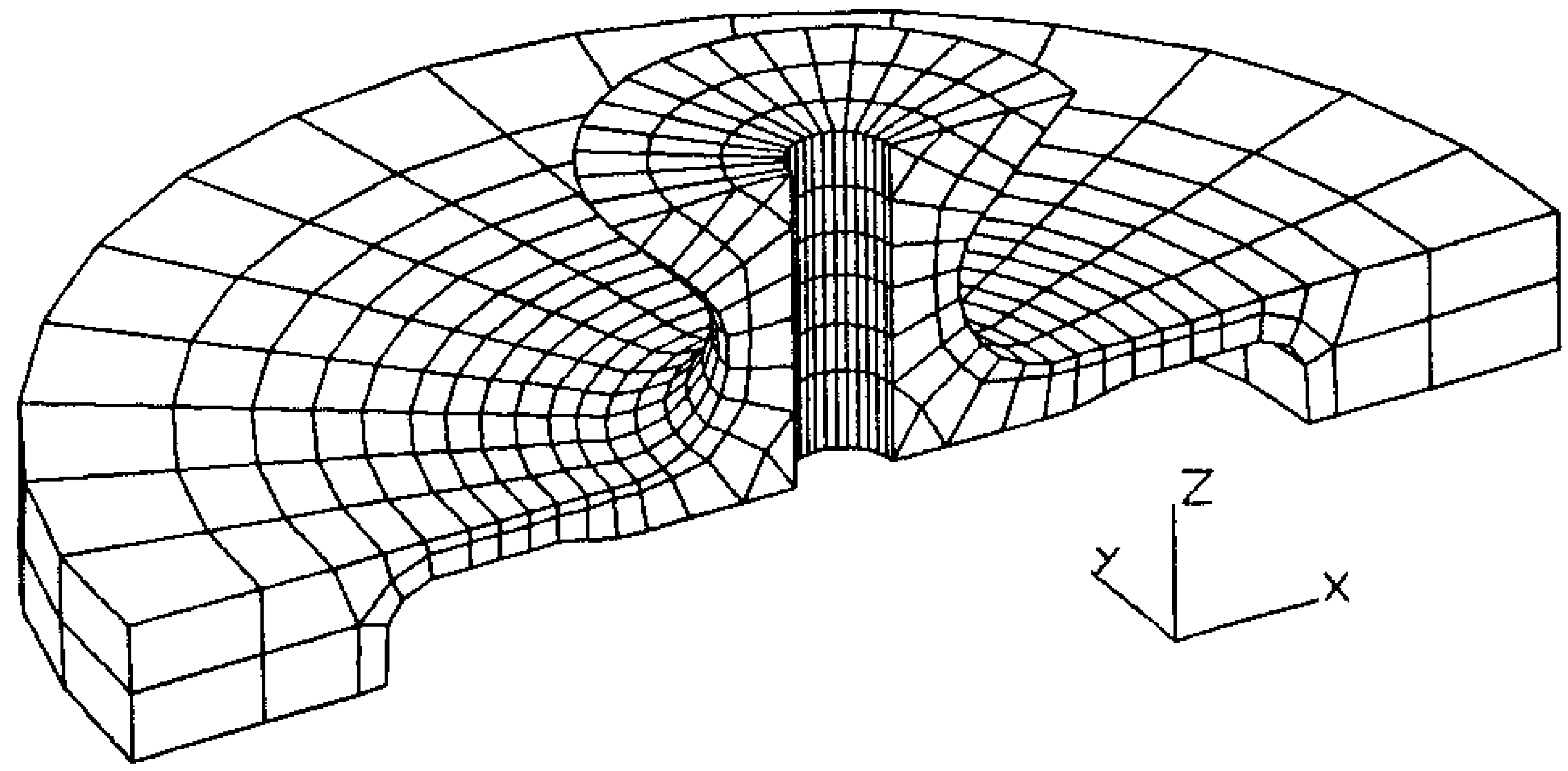


UNLOADED

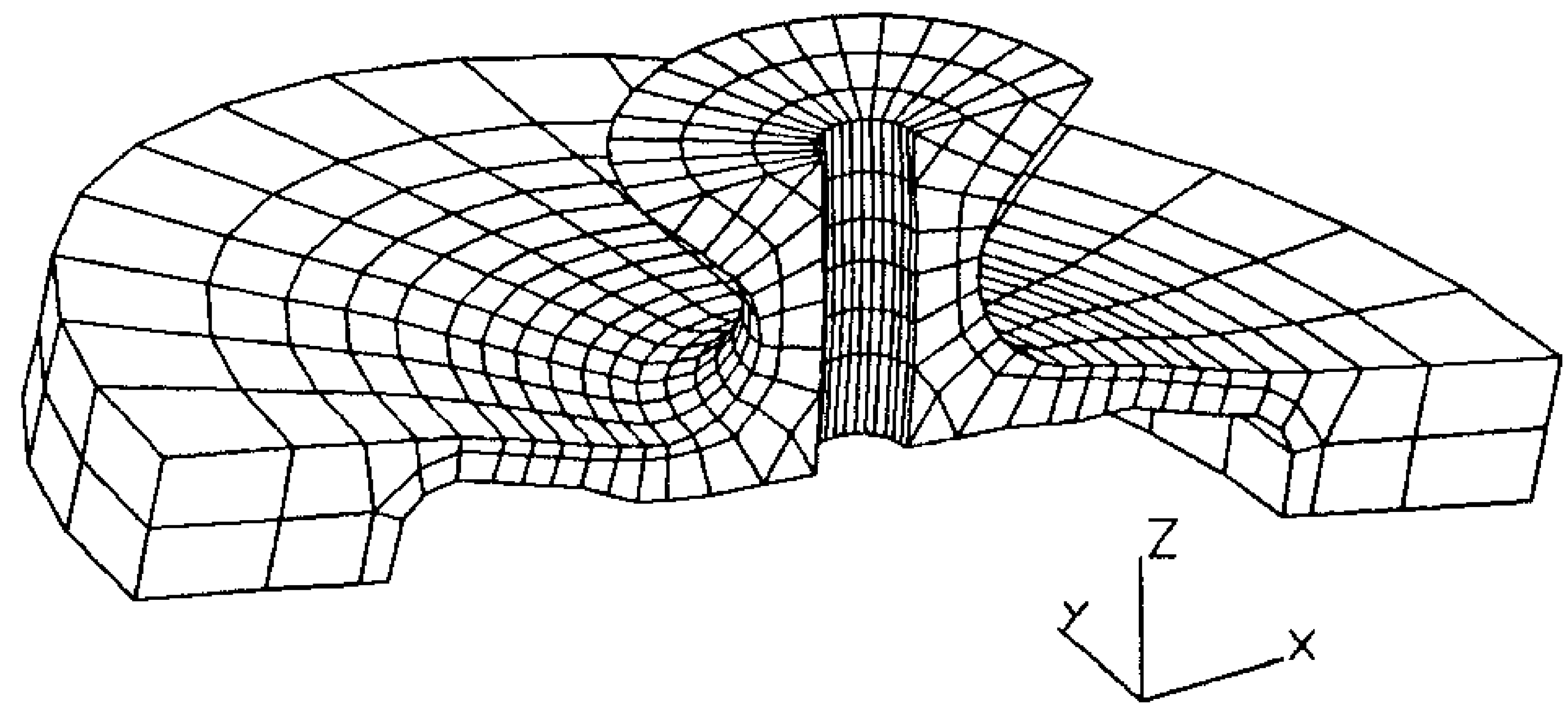
ZENITH GRAVITY
scaled 100:1

HORIZON GRAVITY
scaled 500:1

FIGURE 14
UPPER (THIN) FLEXION BARS



UNLOADED



SIDE FORCE
DURING INSTALLATION
"25,000#"

FIGURE 15
LOWER (THICK) FLEXION BARS

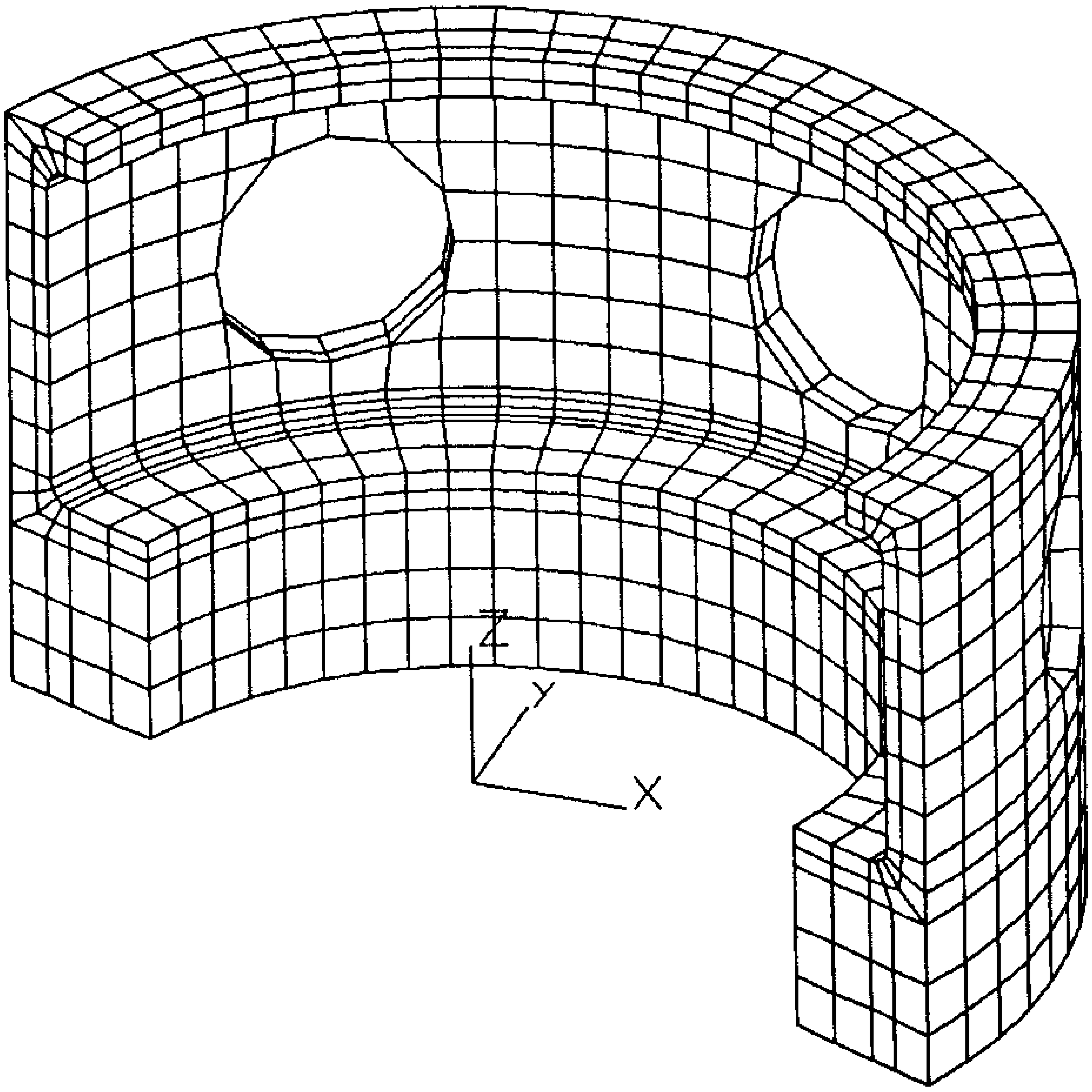
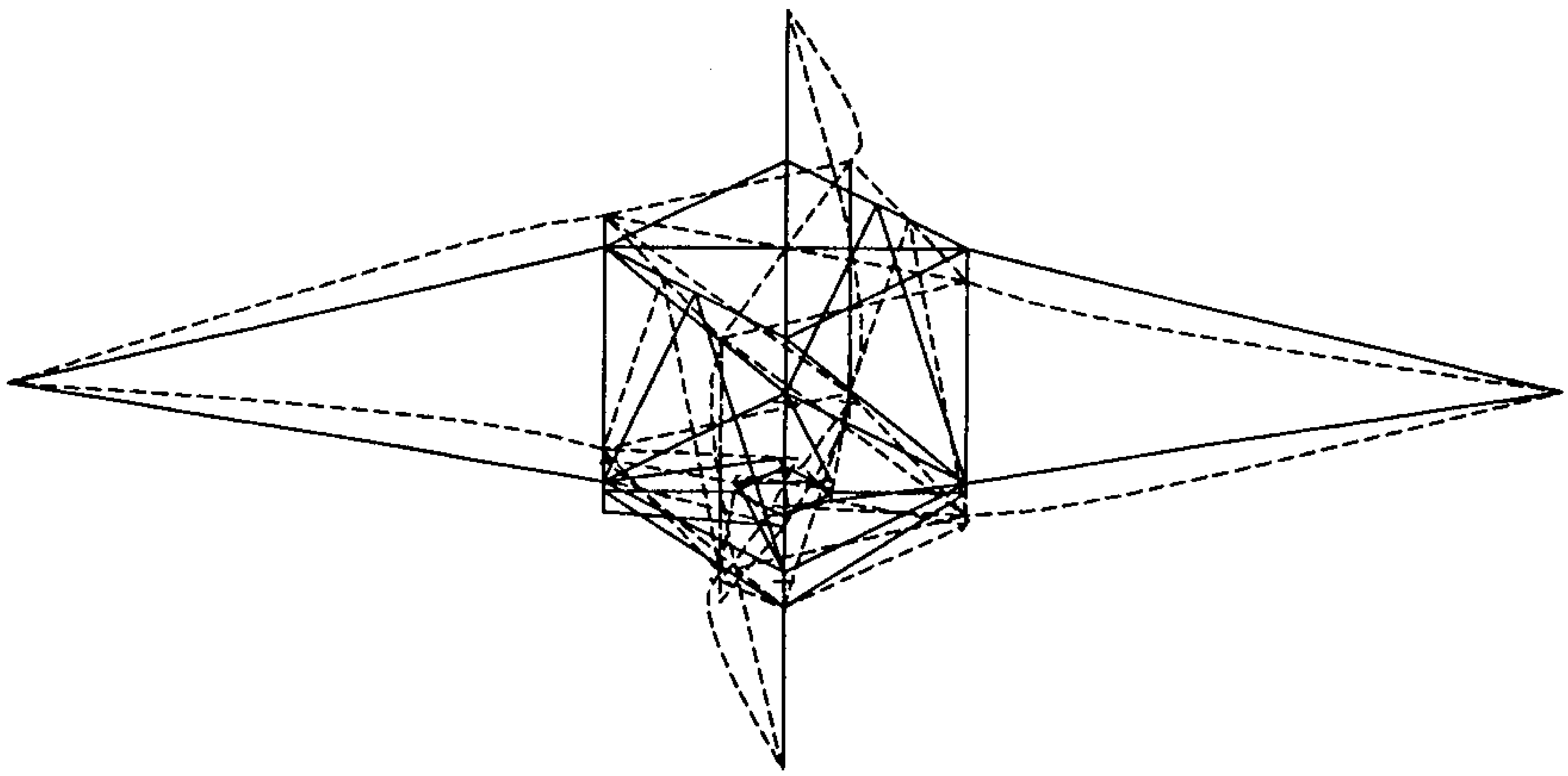


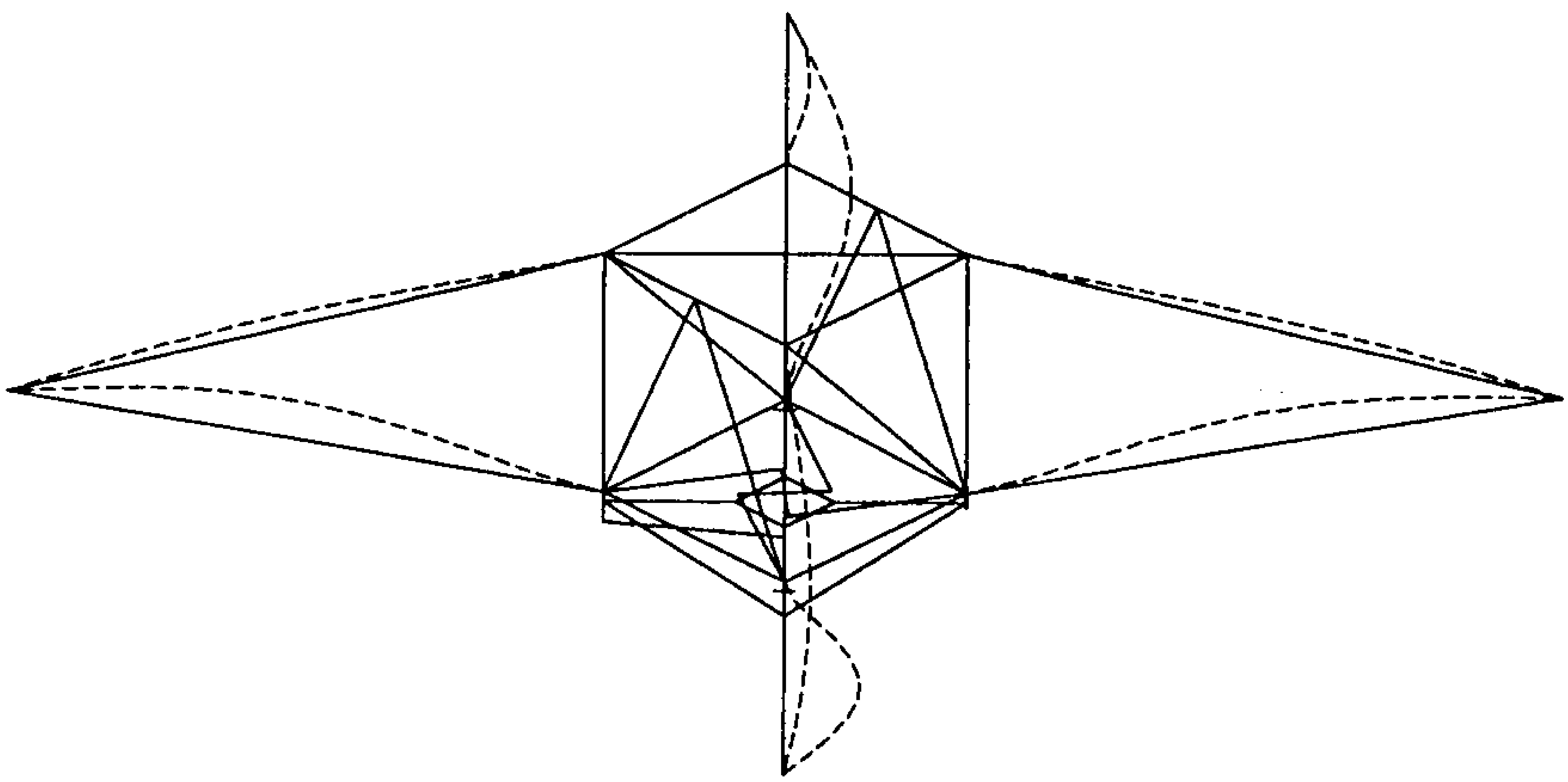
FIGURE 16

Finite element model of Flexion Bar Clip



MODE 1 - OPTICAL AXIS ROTATION

8.7 HZ @ 25,000# PRELOAD/VANESET



VANE LOCAL VIBRATION (1ST 'GUITAR STRING' MODE)

23 HZ @ 25,000# PRELOAD/VANESET

FIGURE 17
Secondary end resonant modeshapes.

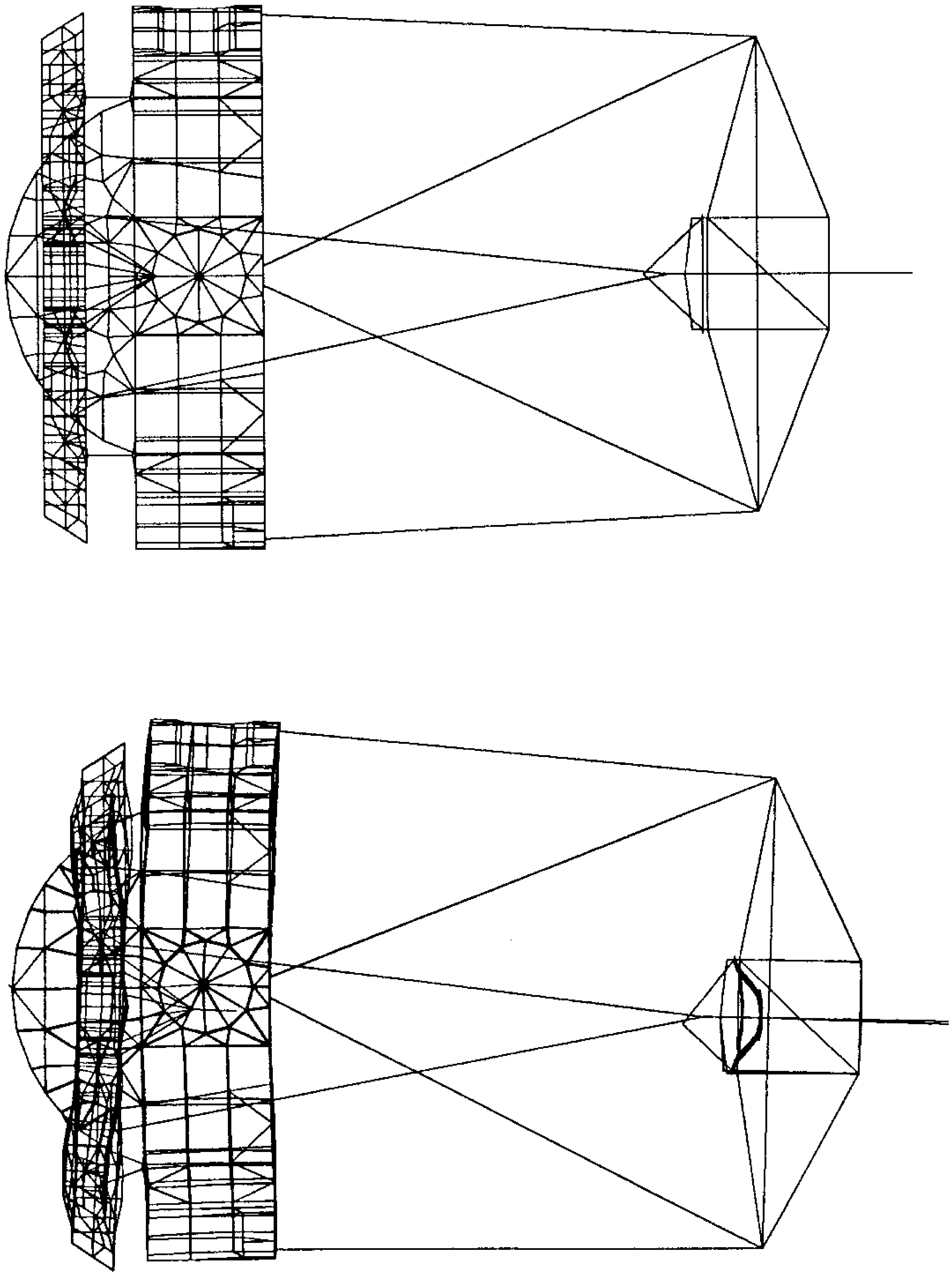


FIGURE 18

Model OSS72 before and after rotating through gravity field (zenith to horizon).

Deflected view scaled 750:1