P-176

Report Submitted to:

Dr. George Jumper

ADVANCED SPACE DESIGN PROGRAM

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In Cooperation with:

The Mitre Corporation

INTEGRATED SUPPORT STRUCTURE

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ABSTRACT

This Major Qualifying Project is part of the Advanced Space Design Program at WPI. The goal of this project is to design a support structure for a NASA GetAway Special experimental canister. This project team concentrated on the payload integration, weight, volume, and structural integrity of the canister as specified by NASA guidelines. The end result is a complete set of design drawings with interface drawings and data to specify the design and leave a base from which the next group can concentrate on.

EXECUTIVE SUMMARY

The Mitre Corporation of Bedford, MA. donated a Get Away Special canister to the WPI Advanced Space Design Program. The purpose of this canister is to conduct experiments in a micro-gravity environment. The NASA/USRA Advanced Space Design Program allows students to design and create experiments within their major fields which will inevitably fly onboard the space shuttle.

GAScan II will contain three experiments: the Rotational Flow in Micro-Gravity Experiment, the Micro-Gravity Ignition Experiment, and the Ionisphere Propagation Properties experiment. The objective of this project is to design a support structure which meets NASA specifications and to integrate the above experiments.

This project is the second of a three year design effort to produce flight ready hardware. It began with the design of the first MQP group. This group designed GAScan II with the payload integration concepts in mind and left many recommendations to further the design. The first task of this project was to review the designs left by the first project team and concentrate on their recommendations.

Reviewing the past design it was noticed that many parts of the assembly remained to be designed. For example, the top of the canister must be designed to attach to the experimental mounting plate. Since GAScan II utilized the same three flange system as GAScan I, WPI's first Get Away Special canister, this part of the assembly was designed with a similar design as that assembly.(figure 3.3.7) Mounting brackets were designed to

attach to the flange assembly and connect to the experimental mounting plate giving a three inch clearance for vent plumbing and electrical leads to the IPPE exterior components. The assembly procedure and details were established and oriented in such a way that access to each experiment can be done in an efficient method. The battery box and rotational flow platform were switched in the canister, with the battery box above the rotational flow experiment, to give a better mounting assembly as well as increase the frequency after a weight problem was identified.

Finally, the new design aspects included two sets of bumpers for lateral support, which will be tightened once the payload is dropped into the canister. One set of bumpers are at the bottom of the flanges, above the battery box, and the second set is at the very bottom of the canister between the bottom plate and rotational flow platform. Tables for allotted weight, actual weight, and volume were kept up, leaving this project with an updated account of all structural aspects.

With these design changes and the payload integration determined, the structure was analyzed by finite element modeling on the ANSYS computer package. (See Section 3.5) A total of five models were analyzed using ANSYS. Four of the models were created specifically to locate possible trouble areas caused by the loading experienced by the GAScan. Of these four models, three were run at the WPI facility because they had not exceeded the allowable wavefront of the WPI ANSYS package, and a fine model was run at the Mitre facility because it exceeded the campus wavefront. The final GAScan II model analysis performed by this group was a vibrational analysis. This analysis found the frequencies at which resonance occurred. Several preliminary models were also run to validate the modeling theory used.

Recommendations to the next design team were made which establish a base for them to start from. The next group must do a complete detail design of the battery box, the venting system, and central processing unit area. They must develop concepts of fastening the experiments within the support structure allowing these experiments to be easily accessible and self-contained within their own compartments. They must size the bolts in the designs using the results of fine mesh analysis in the ANSYS system. With our results present, the next group must modify the design, ensuring NASA specifications are met, and determine whether or not some assembly connections should be welded rather than bolted. The canister, with its payload, is presently over the 200 lb. limit and must be reduced without jeopardizing the stability of the canister. Finally, the next group must build and assemble the entire GAScan II and test for workmanship on a shaker table to ensure safety to the shuttle and its crew.

With the results and recommendations presented here, the canister is on schedule for completion. For a detailed explanation of the results and recommendations see sections 4 and 5 of the text.

Table of Contents

Table of Figures

Authorship Page

Introduction	Stephen Bruneau
Background	Stephen Bruneau
Procedure	
Payload Integration	Stephen Bruneau
Initial Design and Design Changes	Stephen Bruneau
Structure Drawings	Stephen Bruneau
Assembly Procedure with Drawings	Stephen Bruneau
Ansys	
Introduction	Christopher Struven John Campbell
Element Selection	Christopher Struven
Analysis	
Analysis Method	John Campbell Christopher Struven
Cantilever Beam	John Campbell
Circular Plate	Christopher Struven
4 Beam Support	Christopher Struven
Gascan Model I	John Campbell Christopher Struven
Gascan Model II	Christopher Struven
Gascan Model III	John Campbell
Gascan Model IV	John Campbell
Gascan Model V	John Campbell
Results/Conclusions	Stephen Bruneau John Campbell Christopher Struven
Recommendations	Stephen Bruneau John Campbell Christopher Struven
Appendix 1	Stephen Bruneau Christopher Struven

1.0 INTRODUCTION

This project report is part of the Advanced Space Design Program at Worcester Polytechnic Institute (WPI) in Worcester MA. in conjunction with Mitre Corporation of Bedford MA. The purpose of this project is to address the design of the Integrated Support Structure of GAScan II.

The objective of the payload structure group is to integrate all the experiments into a complete package inside the GAScan II canister while conforming to all NASA structural design requirements. The focus of the project is to perform a preliminary design of the structural support of the canister ensuring its reliability and safety during flight operation.

This project is a follow on to a Major Qualifying Project (MQP) completed in May 1988 and will address similar design issues of that MQP as well as address the recommendations of this past student group. This previous group suggested five recommendations for the project to proceed into the final design stage. [1]

Battery Box Considerations: Redesign of the battery box area and venting arrangement must be accomplished. The venting of the battery must mate with the shuttle venting system.

Shelf Considerations: A shelf is currently positioned in one of the three sectioned compartments. The placement of this shelf must be redesigned based upon experiment alterations.

Assembly Considerations: Fasteners to secure each experiment to the support structure must be chosen to meet NASA structural criteria as well as enable an efficient assembly process.

Selection of Lateral Support Bumpers: The location and type of bumpers must be finalized.

Ansys Analysis: A finite element model of the entire support structure will be performed using the ANSYS FEM computer package. NASA specifications for frequency have not been met by the existing design and alterations must be made to meet these requirements. Vibrational accelerations will exceed 6 g's in all axial directions. A static and vibrational analysis will be performed to consider the forces due to extreme vibration and all other dominant static loads.

Specific concerns of this project team include access to each experiment, weight, power, and volume logs, and construction of the entire support structure.

2.0 Background

This section contains all specifications set forth by Get Away Special Small Self-Contained Payloads, Experimenter Handbook from NASA for the design of a Get Away Special Canister.

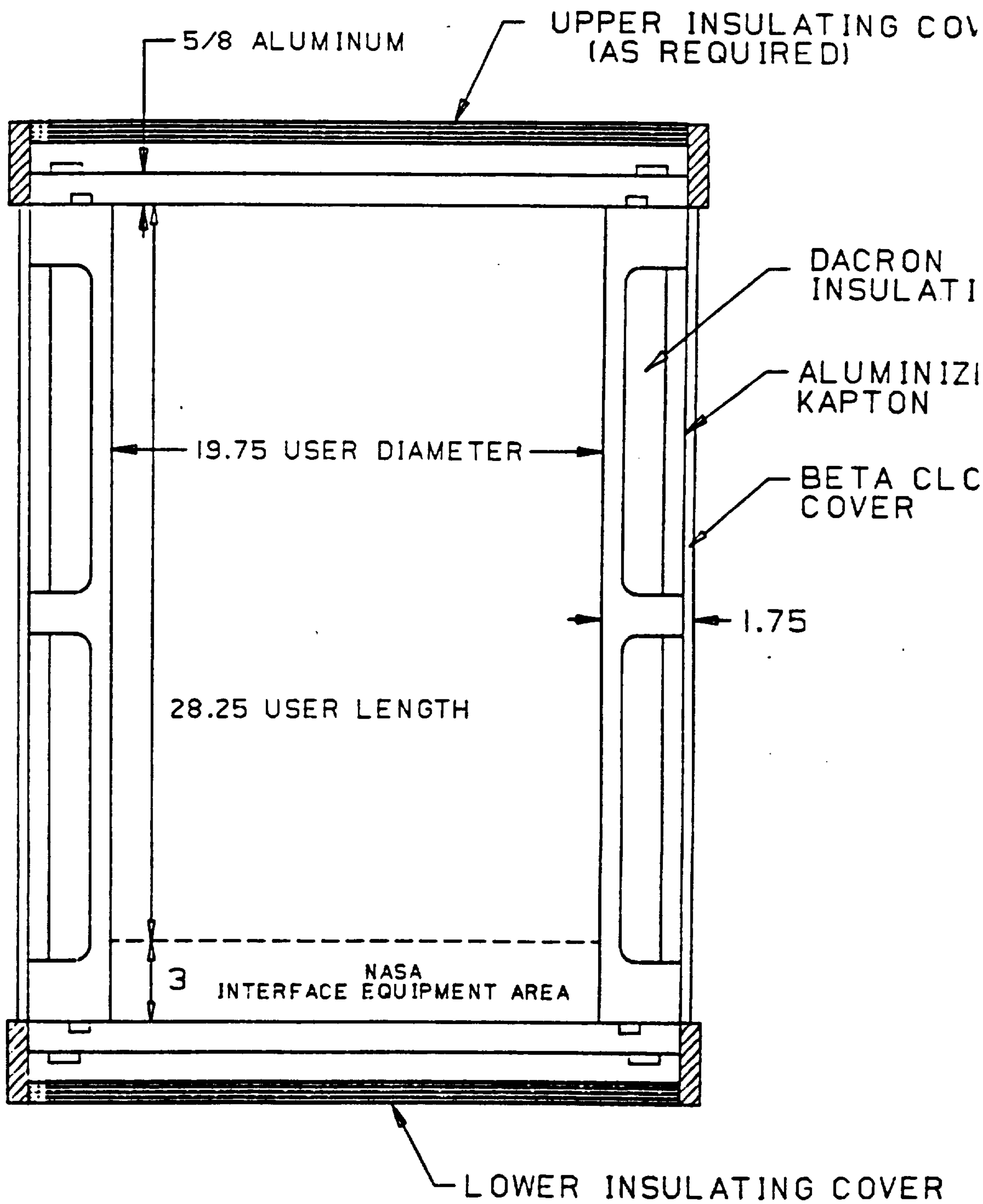
2.1 General Requirements

The GAS canister consists of the container, the experiment mounting plate, the inner structure, the NASA interface equipment plate, the bottom insulated cover, the container insulation, and insulating cover (as required),(refer to fig 2.1.0)[2].

Container Construction: The standard GAS container is made of aluminum. There is thermal insulation on the exterior. The top may or may not be insulated depending on the particular Shuttle mission and needs of the experimenter. The standard circular end plates are 5/8 inch-thick aluminum. The bottom 3 inches of the container are reserved for NASA interface equipment such as command decoders and pressure-regulating systems. This volume is in addition to the 5 cubic-foot space available to the experimenter. The container is a pressure vessel that is capable of:

a. Maintaining about 1 atmosphere pressure at all times, dry nitrogen or dry air
b. Evacuation during ascent and repressurization during reentry

GAS CONTAINER



ALL DIMENSIONS IN INCHES

FIGURE - 2.1.0

c. Evacuation before launch

Container Size: The container has a volume of 5 cubic feet. The user size is 28.25 inches in height and 19.75 inches in diameter(see figure 2.1.0)[3]. The container has a user weight of 200 lbs.

Experiment Mounting Plate: The experiment mounting plate serves three purposes;

1) seals the upper end of the standard GAS container
2) provides a mounting surface for the experimental equipment
3) acts as a thermal absorption or radiation surface

The inner surface of the mounting plate is adapted to accept 45, 10-32 UNF stainless steel screws to a depth of 0.31 inches. The two purge ports will be aimed out the right side. A grounding strap must be provided and mounted to one of the holes in the mounting plate. Venting of the battery box will also be through the mounting plate. The mounting plate may not be altered by experimenters. (see fig. 2.1.1)[4]

Venting: Batteries which can produce a combustible mixture of gases, must be housed in a sealed, corrosion proof, and vented battery box. Plumbing for the venting of the battery box is to be supplied by the experimenters. The battery must be vented through the mounting plate and through two 15 psi differential pressure relief valves provided by NASA. All plumbing should be stainless steel. To check venting prior to launch, a dummy vent turret will be shipped with the mounting plate (see fig.2.1.2)[5]

Lateral Load Support: Because the experiment structure will be cantilevered from the experiment mounting plate, radial

GET AWAY SPECIAL
SMALL SELF-CONTAINED PAYLOADS
STANDARD EXPERIMENT MOUNTING PLATE

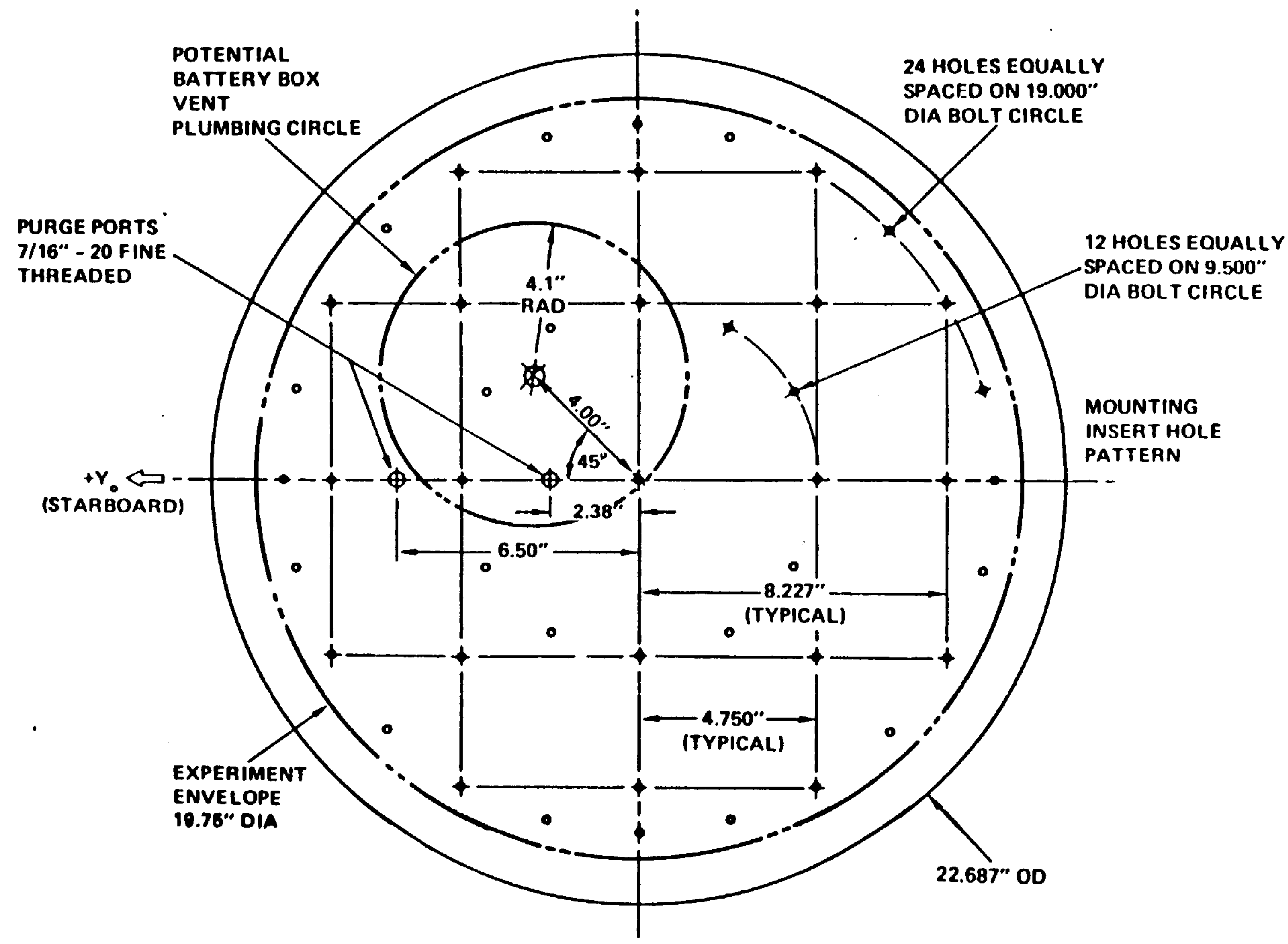


FIGURE - 2.1.1

GET AWAY SPECIAL
SMALL SELF-CONTAINED PAYLOADS

BATTERY VENT TURRET INTERFACE

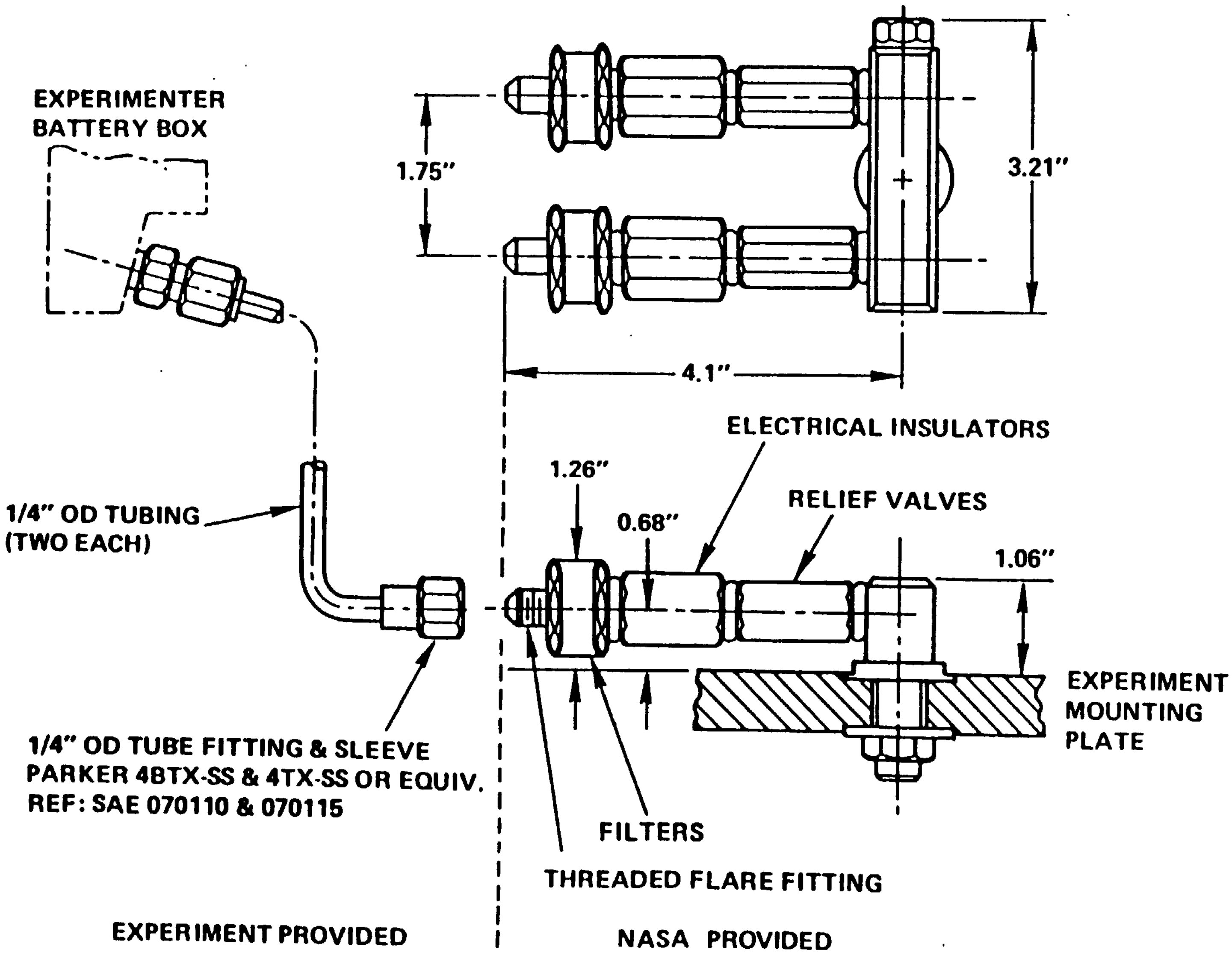


FIGURE - 2.1.2

loads at the free end of the experiment structure must be supported by at least three equally spaced bumpers between the experiment structure and the standard GAS container. The experimenter is responsible for providing the bumpers as part of his hardware. The bumpers should meet the following five criteria:

1) A minimum surface area of 2x2 square inches should be used for each bumper pad. The bumper face should have a 10 inch radius where it contacts the container.
2) Bumpers are to be equally spaced around the circumference of the payload.
3) Where the bumper contacts the container wall, it should be faced with a resilient material at least 1/8 inch thick to protect the container. If the container is evacuated, the bumper should be made of a non-outgassing material such as viton. If the bumper face is not round, every corner should have a minimum radius of 0.4 inch.
4) The bumpers should have a positive locking device to hold them in place. You should not depend on friction or a set screw alone to hold them in place.
5) After installing your payload in the container, the bumper adjustment should be accessible from the open lower end of the container. (see fig. 2.1.3)[6]

<u>Orientation</u>: The container will always be mounted with the mounting plate facing out of the payload bay.

GET AWAY SPECIAL
SMALL SELF-CONTAINED PAYLOADS
LATERAL SUPPORT

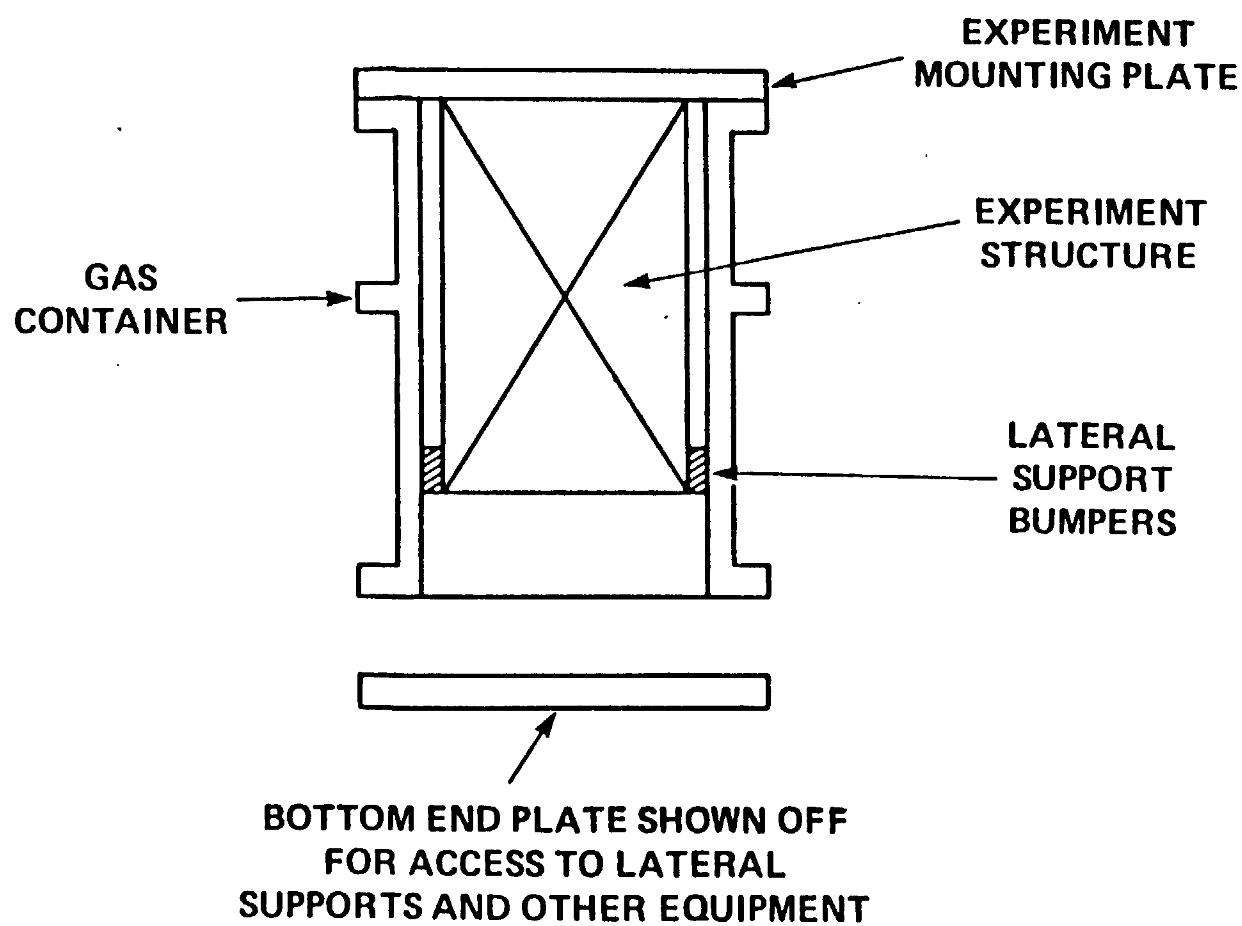


FIGURE - 2.1.3

LOAD SPECIFICATIONS

The structure fully loaded with experiments must be able to withstand the following environmental conditions.

Length of Operation:

Prior to launch:	Normal:	3 months shelf life
Launch Phase:	Normal:	5 minutes
Orbit Phase:	Normal:	3 days minimum, 10 maximum

Pressure:

Normal:	14.7 - 17.0 psia
Adverse:	0.0 - 45.0 psia

Atmosphere:

Normal:	Low humidity, non-condensing, Nitrogen.
Adverse:	Vacuum to 45 psia, non-inert gas, non-caustic, condensing liquid.

Temperature:

Internal:	Normal: -10 C - +40 C
	Adverse: -50 C - +80 C
At window:	Normal: -40 C - +60 C
	Adverse: -80 C - +100 C
At landing:	Normal: As high as 60 C for 30 minutes

Note: BATTERY OPERATION SHOULD BE SPECIFIED AT 0 C

Vibration:

Launch:	Normal: 3 Grms, 20-2000 Hz, 5 min.

	Adverse:	12 Grms, 20-1000Hz
	Normal:	5 G Static, each axis
Orbit:	Normal:	Negligible vibration
		.1 g with thrusters
Landing:	Normal:	Negligible vibration
		5 g static along can axis
Acoustical:	Normal:	145db (Re: 20 uN/M-sq)
		10-5000 hz. 5 min. max.

Orbit:

Altitude: 220-300 km(160 N miles most likely)

Period: 80-100 minutes.

Coverage: +/- 57 degree latitude max.

General Requirements:

Your system must be as small as possible

Your system must be as light weight as possible.

Your system should consume a minimal amount of power

3.0 PROCEDURE-PAYLOAD INTEGRATION

Each experiment has characteristics which require certain mounting and orientation design. This section will address these design issues and detail the payload integration that will give a structural integrity which meets NASA specifications.

IPPE EXPERIMENT- This experiment has some unique requirements which must be adapted into the support structure. Two components, an ion collector and an antenna, are to be protruding out of the experiment mounting plate. These components will be located at a yet to be determined position on the mounting plate and could be anywhere on the diameter. The leads to these components therefore must also have access to the entire diameter. With these considerations, it is necessary to place the IPPE controller box at the top of the GAScan II support structure. [7]

Rotational Flow Vortex Experiment- This experiment has a 19.75 inch diameter rotating platform. The experiment project team feels that they need to use the entire user diameter to achieve the results that they are looking for. Therefore supports for the support structure must be above and below the rotational area.[8]

Battery and Battery Box- The battery weight has been initially calculated at 79.13 lbs. by Professor Fred Looft and is subject to change. However for our analysis we have used this number as the battery weight.

Micro-gravity Ignition- Has no specific requirements.[9]

The following interface drawing of the support structure, with the experiments in it, is the model used to do a finite element model using the FEM pc linear package here at WPI. The results obtained by this MQP will come directly from this Ansys computer package and further design considerations will stem from our analysis.

3.1 INITIAL DESIGN AND DESIGN CHANGES

The basic design of GAScan II was left to this project team by the previous payload integration structural team (see figure 3.1.0)[10] and with it came the previously mentioned recommendations. It was quickly determined that there were many areas which remained to be designed. These areas had to be addressed immediately to allow the other Advanced Space Design project teams to commence their respective assignments.

This first design included the experiment mounting plate within the user interface. This plate is 5/8 inches in thickness and therefore detracted from the amount of space that the experiments could actually take advantage of. In the previous design, it was also unclear how the flange/centerpost assembly would be attached to this mounting plate. In order to address this issue, the team researched the specifications of the GAScan II interface. It was discovered that the experiment mounting plate should not have been included into design of the previous structure since the user interface was to begin at the

GASCAN II
FINAL INTERNAL STRUCTURE

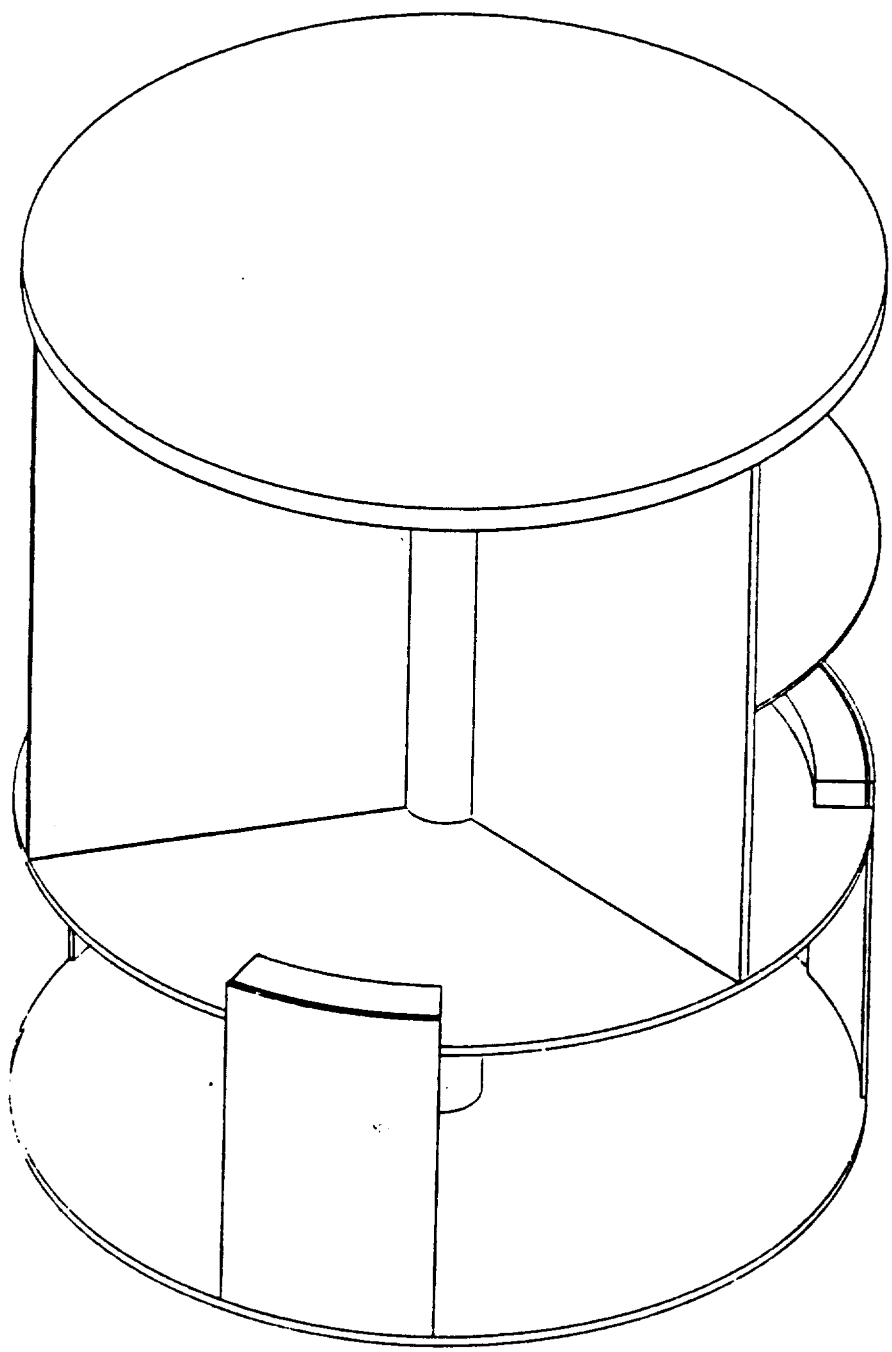


FIGURE - 3.1.0

bottom of this plate. Drawings of the mounting plate also showed that the support structure would be screwed into the plate. The previous design appeared to have the support structure welded entirely to the mounting plate and this discovery quickly lead for a need to redesign the top of the support structure.

In order to redesign the top of the support structure, the major concern was to do so without altering the space already designated for the IPPE and micro-gravity combustion experiments. Since it was established that the experiment mounting plate should not have been included in the design, this gave the height of the usable space an additional 5/8 inches. Clearance for both the IPPE and micro-gravity combustion was already sufficient and could only benefit from the additional height. With the exterior components of the IPPE, it was decided that the flanges could be altered such that the IPPE could have access to the entire diameter to allow them to run their electrical leads to the ion collector and antenna. As this idea materialized, it was also discovered that the previous group had not designed the venting mechanism for the battery. From the outset it was known that the venting would be done through the centerpost. However, just how this venting would mate with the experiment mounting plate had not been established.

Further research showed that the venting of the battery had to be mated inside a plumbing circle of the design of the mounting plate. This plumbing circle could be oriented at any angle around the diameter and therefore would be oriented above one of the three compartments. An immediate concern was to then determine how the venting would get from the centerpost to this plumbing circle.

Taking both the venting and mounting to the mounting plate into account, the top of the support structure was then redesigned. The flanges and centerpost were reduced by three inches. This three inch clearance would allow venting to exit the centerpost and be directed to the venting apparatus inside the plumbing circle. It would also allow the IPPE to reach their exterior components anywhere along the diameter. The next change and design modification was then the mounting of the support structure. Review into the mounting of GAScan I showed the use of mounting brackets. Since our can utilized the same three flange design, it was decided that the mounting of GAScan II could be the same as GAScan I (see figure 3.3.7).

The next design consideration was to address the supports around the rotational flow experiment. The experiment group found it necessary to utilize the entire diameter of the canister. Therefore it was decided that the supports of the old design could be removed and replaced by bumpers above or below the rotational area which would give the same support that the previous design would give.

Further review of GAScan I showed that the batteries and battery box had a weight of 98.6 lbs. This weight was much different than the weight that the previous MQP had allotted. Since the power requirements had not yet been determined, the weight of the batteries of GAScan I would be used to get a measure for GAScan II. In the 1988 MQP, they used the weight of the batteries as 42.55 lbs. Each experiment then had the hardware weight and battery weight for its purpose and still remained under the 200 lb. limit. With the discovery of the actual weight, many design aspects of GAScan II had to be immediately reviewed. With the battery box and the rotational flow beneath the first circular plate, there would be a substantial amount of weight being supported solely by the centerpost. With this substantial amount of weight also the farthest from the fixed end, the frequency of the entire structure would be low, possibly below the 51 hertz designated by NASA. To solve this problem the battery box was switched with the rotational flow. This idea would then move the bulk of the weight up the cantilevered structure, enlarging the frequencies and giving a firmer mounting orientation. This mounting orientation could be designed to be similar to GAScan I since the same three flange design would mate with the battery box area. The battery box could be slotted to slip over the centerpost and be firmly bolted around the entire diameter of the centerplate. To give the battery box some support at the centerpost, a support ring with a set screw is welded into place. This ring will also serve as a rigid support to have the rotational flow bearing mounts firmly assembled to.

Bumpers were then the next concern to stabilize the support structure. It was decided that the bumpers could be positioned above the battery box at the ends of the flanges and an additional set could be installed beneath the rotational flow platform and above the bottom plate.(see figure 3.3.7)

3.2 STRUCTURE DRAWINGS

This section contains the drawings of each component which makes up the internal support structure of GAScan II. The list of all components is the following:

3 mounting brackets

3 flanges

1 centerpost

1 middle plate

6 bumpers (3 of one size and 3 of another size)

1 support ring

1 bottom plate

1 battery box (preliminary design)

The bolts and holes for bolts are only temporary designs. The next group will have to take this projects ANSYS results and make a finer mesh around the bolt areas to size the bolts properly.

Drawing 3.1.3 -Mounting Bracket-The mounting bracket design was made in a similar fashion to the bracket used on GAScan I. The three holes on the mounting surface must accept 10-32 UNF machine screws to mount to the experimental mounting plate. The three holes which join the bracket and the flange need to be sized with a fine ANSYS mesh analysis. The three inches between the mounting surface and the start of the flange is for the venting of the battery box and the electrical leads of the IPPE.

Drawing 3.1.4 - Centerpost-The centerpost has three grooves for the flanges to be welded into, and holes for the support ring set screw and the rotational flow slip ring assembly. The bottom of the post must be further designed to include the threads for the rotational flow bolt and the mounting of the bottom plate.

3.1.5 -Flange-The flanges have the three holes for the mounting brackets and two holes for the bumper assembly. All of these holes must be sized using the fine mesh technique. The screws along the bottom surface of the flange are designed to have 15 screws for mounting with the middle plate. These screws can be omitted and the flange/plate assembly can be welded if the middle plate need not be removed.

3.1.6 -Shelf- The shelf is to hold the IPPE controller box and can be attached to the flange structure using either angle irons or welding.

3.1.7 - Middle Plate- The middle plate has screw holes which mate with the flanges. As stated above, these holes can be omitted and the assembly can be welded. The square holes located 120 degrees apart are to allow passage to the bumpers; the size can be altered. The bolt holes around the circumference of the plate are to support the battery box.

3.1.8 -Support Ring-The support ring can be set screwed in or welded depending on whether or not it needs to be removed at any time. If it must be set screwed, then the number of set screws must be determined using a fine mesh.

3.1.9 - Bottom Plate- The large holes in the plate serve two purposes: weight reduction and passage to the bottom bumpers. The bottom bumpers are to be attached to this plate using yet to be determined screws.

3.1.10 - Large Bumpers-The large bumpers are designed similar to the bumpers used on GAScan I. The two parts are made of different materials so that when they are mated together they will not fuse together. The bolt which tightens the bumper assembly is also not yet sized.

3.1.11 - Small Bumpers-The bottom bumpers operate in a different fashion than the large bumpers. These have two screws which when tightened, push the exterior part against the canister wall. These screws must also be sized.

3.3 ASSEMBLY PROCEDURE

The major concern of GAScan II is simplicity in assembling and disassembling both the structure itself and the experiments housed within. Due to time constraints this project team was only able to determine the assembly and fastening of the support structure and will recommend that the next project group design the experiment fastening devices.

The starting point of the support structure is the centerpost.(see figure 3.3.1) The three flanges are then to be wedged into the slits on the centerpost and welded at this connection.(see figure 3.3.2) The centerplate is then slid over the centerpost up to the bottom edge of the flanges. This plate is screwed into the bottom of the flanges with yet to be determined screws.(see figure 3.3.3)

From this point the mounting brackets can be put on using properly sized nuts and bolts making sure that a good mating is attained with the experiment mounting plate holes. This completes the assembly of top of the support structure. (see figure 3.3.4)

The next component is the slip ring. It is slipped over the centerpost and set screwed at the designated position. It is then welded to the centerpost.(see figure 3.3.5) The next component is the bottom plate whose assembly has yet to be determined. This bottom plate however must be put on after the rotational platform is placed into position over the centerpost. This completes the assembly procedure of the support structure. The remaining areas of concern are the bumpers and the battery box.

The large set of bumpers are screwed into the flanges using properly sized nuts and bolts and the tightening bolt facing the bottom of the canister. (see figure 3.3.6) The smaller bumpers are to be attached between the rotational platform and the bottom plate. These bumpers should be attached to the bottom plate before the bottom plate is put onto the centerpost. (see figure 3.3.7) The next components to be put onto the internal support structure are the experiments themselves. A conceptual design for the battery box is shown in figure 3.1.9 and its attachment to the support structure is described in figure 3.1.10. This fully assembled GAScan is then slipped into the canister supplied by NASA. Once this is installed the bumpers must be adjusted to give a firm support against the inside walls of the canister. This can be done using a long screw driver and the proper orientation of the bottom plate and rotational platform. In order to see the screws on the large set of bumpers it may be necessary to spray paint this area with a neon color. To clear a path from the bottom of the canister, we recommend that the rotational platform have a hole somewhere on a far diameter which can be spun to the proper line of sight giving this long screw driver a clear passage to the bumper assembly.(see figure 3.3.8) The bottom set of bumpers can be adjusted by the screws located on the bottom plate which are easily accessible from the bottom of the canister.

Finally, the shelf for the IPPE experiment can be installed either with angle irons or welding. Both the shelf assembly and the middle plate/flange assembly will have to be reviewed by the next project group.(See recommendations section)

FIGURE 3.3.1

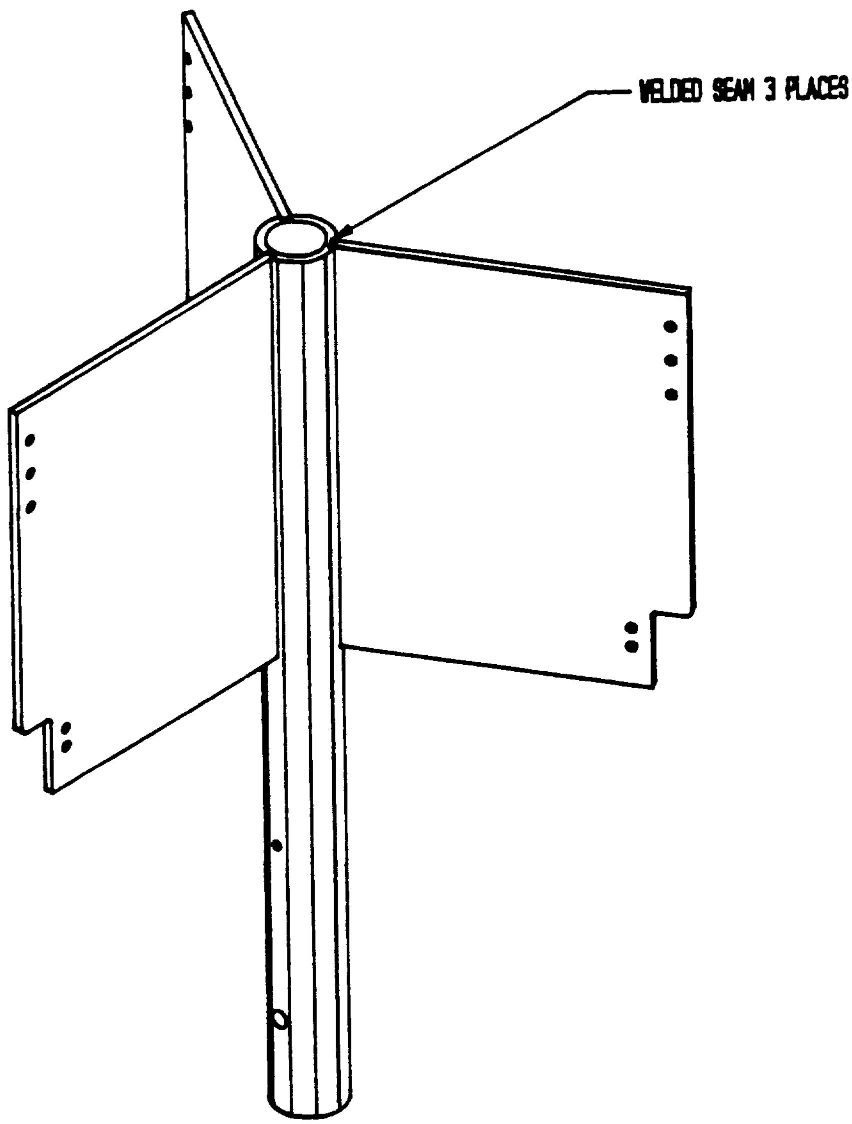


FIGURE 3.3.2

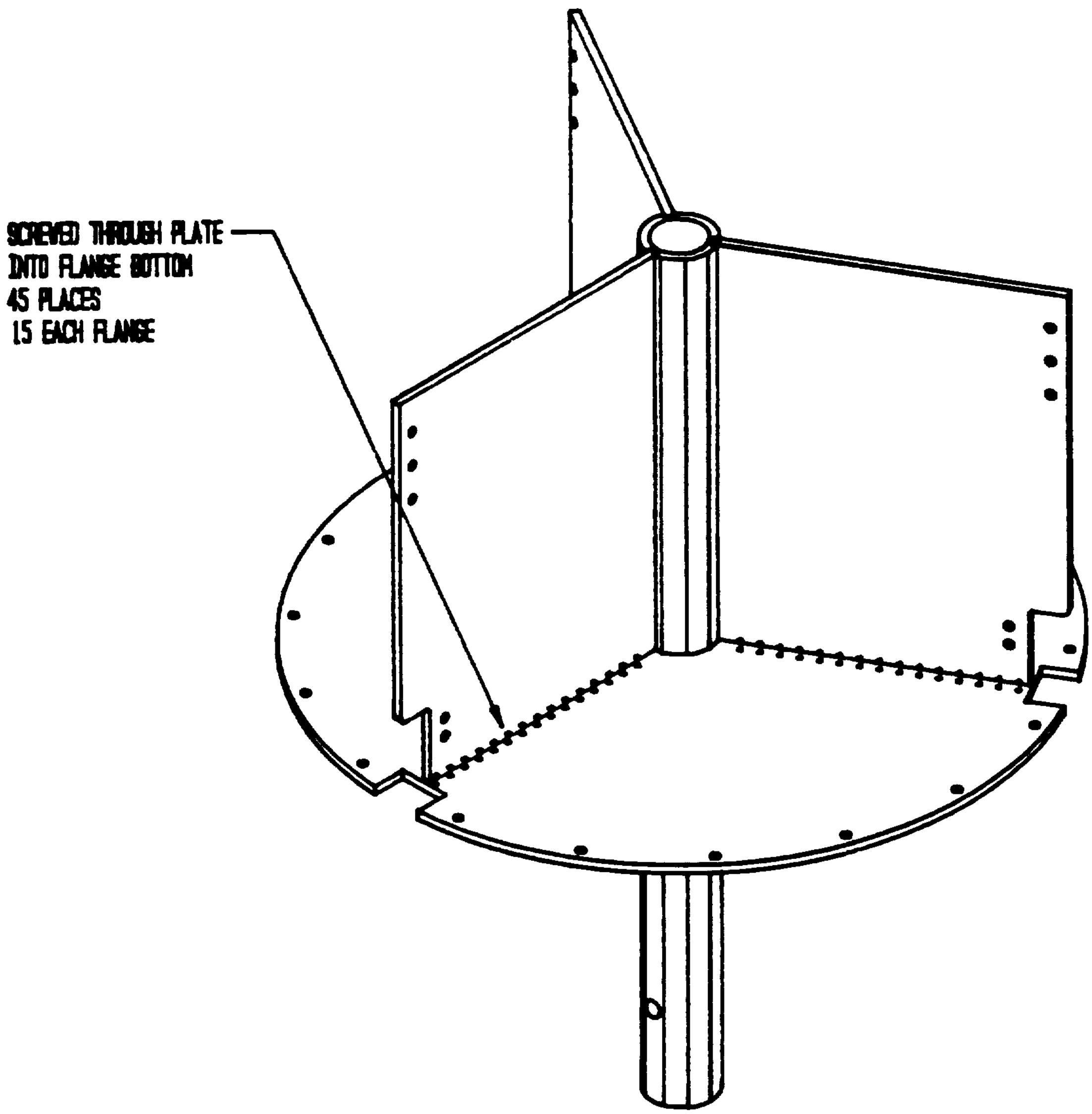

SCREWED THROUGH PLATE
INTO FLANGE BOTTOM
45 PLACES
15 EACH FLANGE

FIGURE 3.3.3

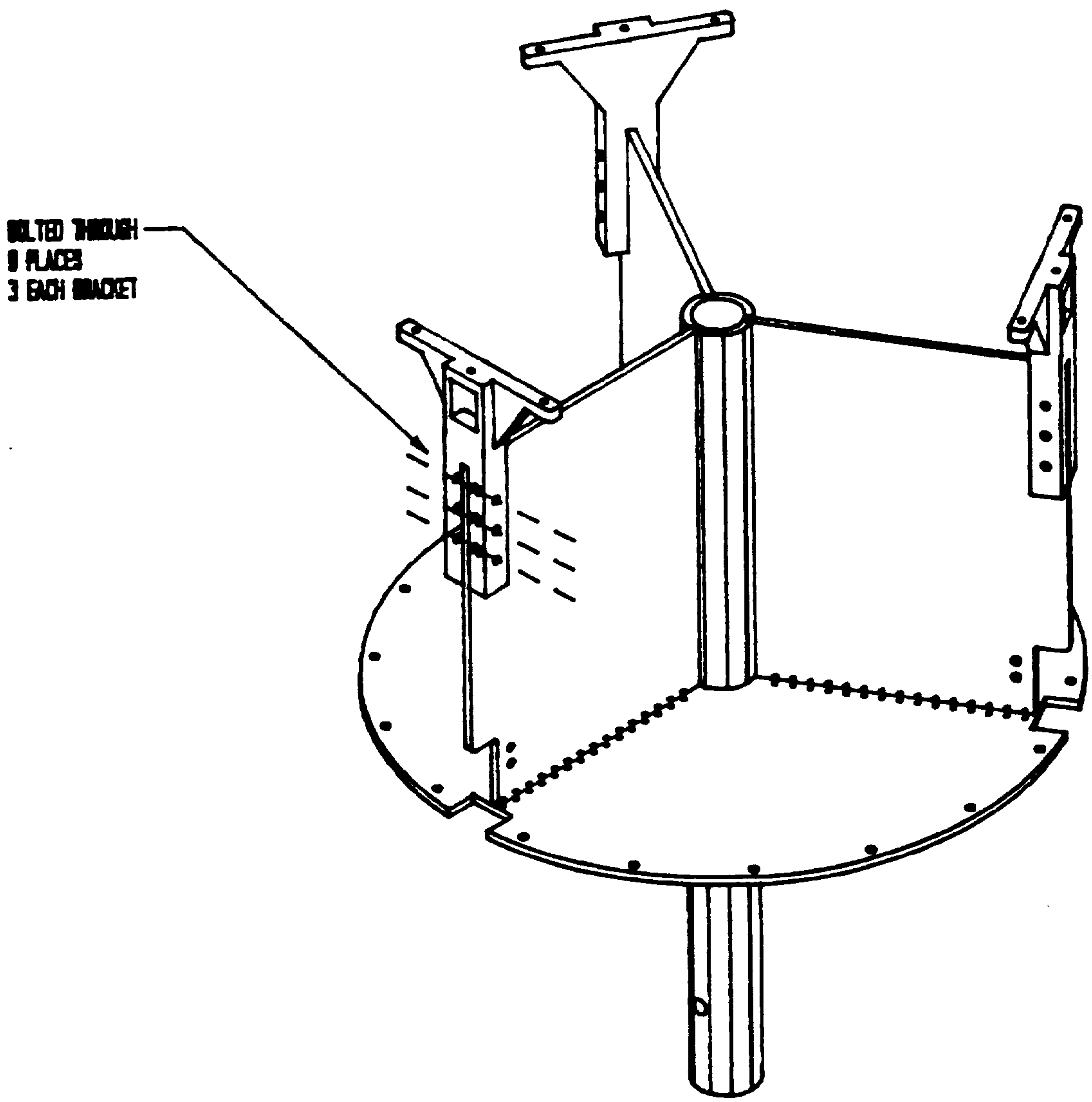


FIGURE 3.3.4

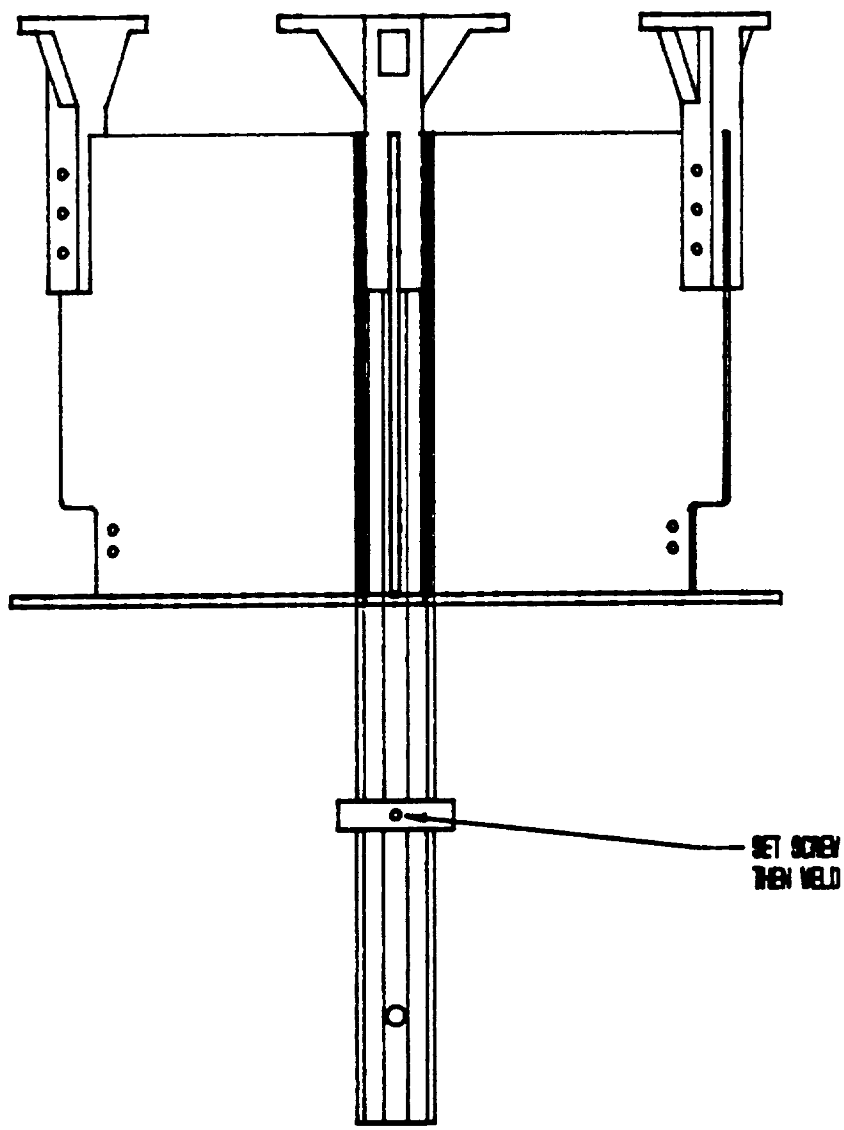


FIGURE 3.3.5

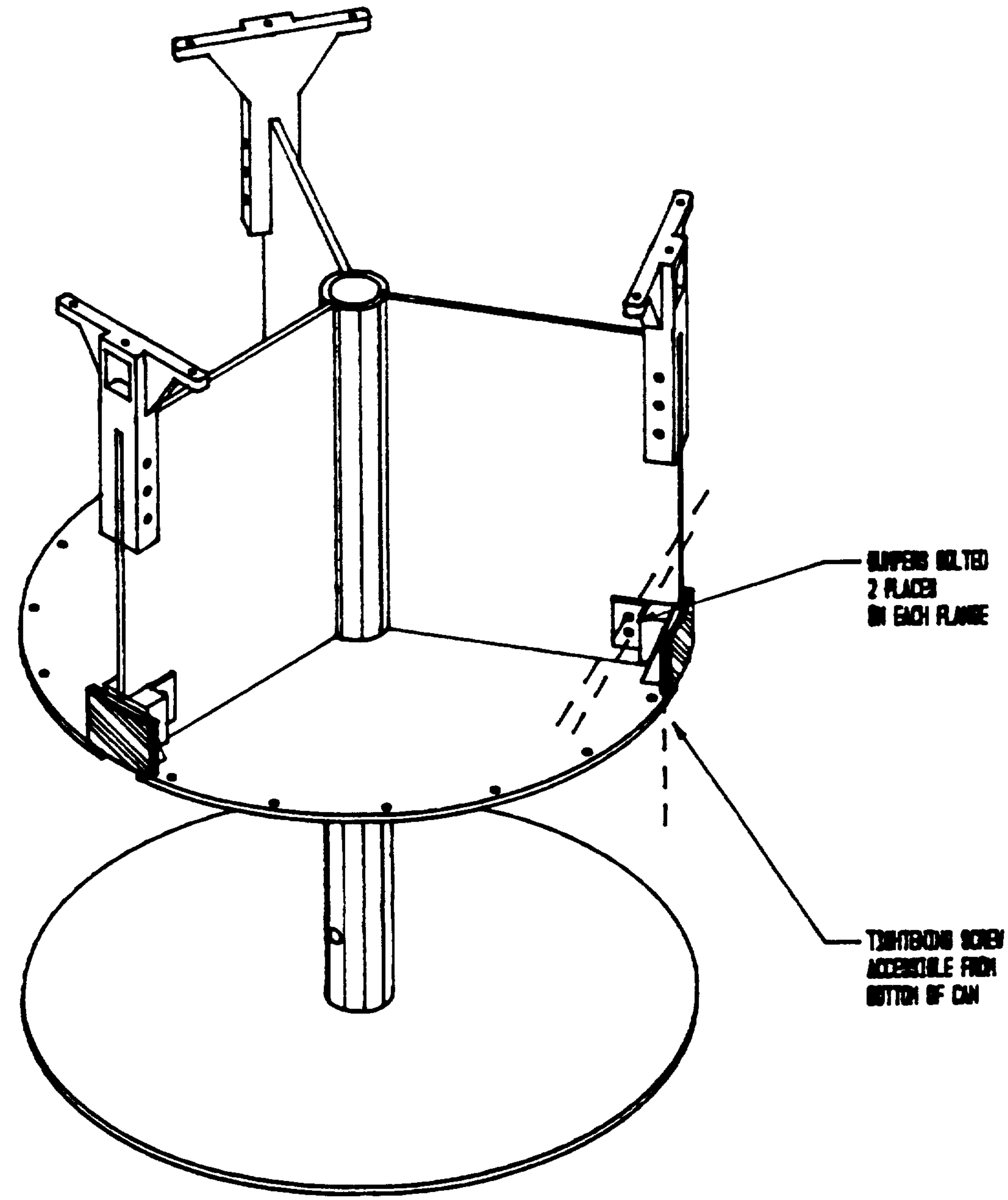


FIGURE 3.3.6

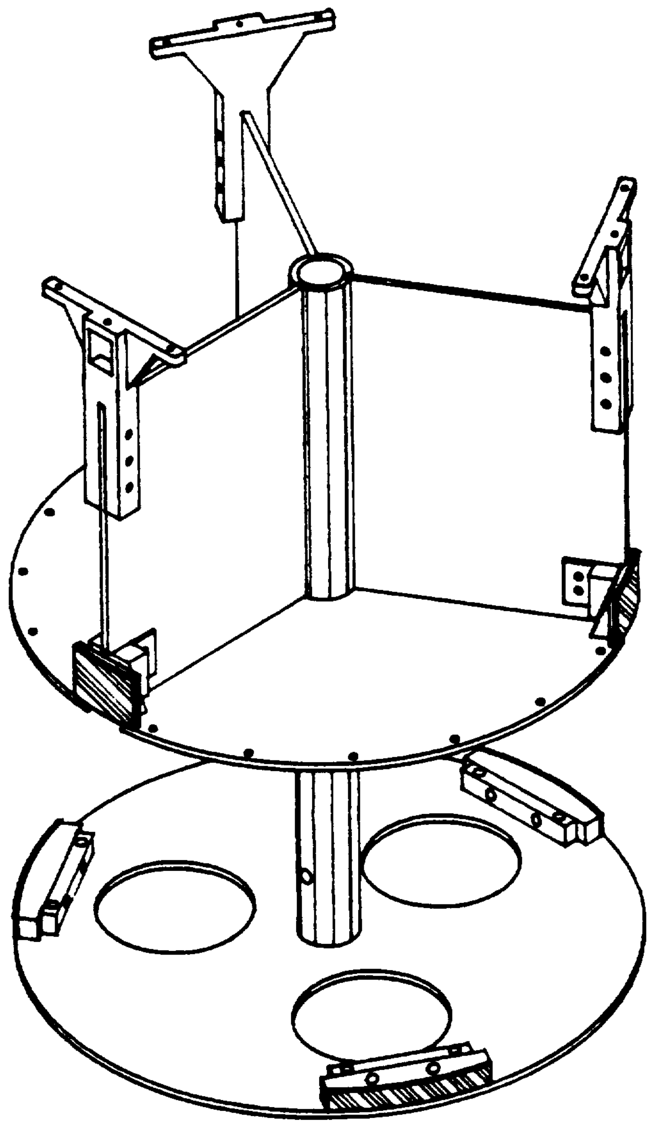


FIGURE 3.3.7

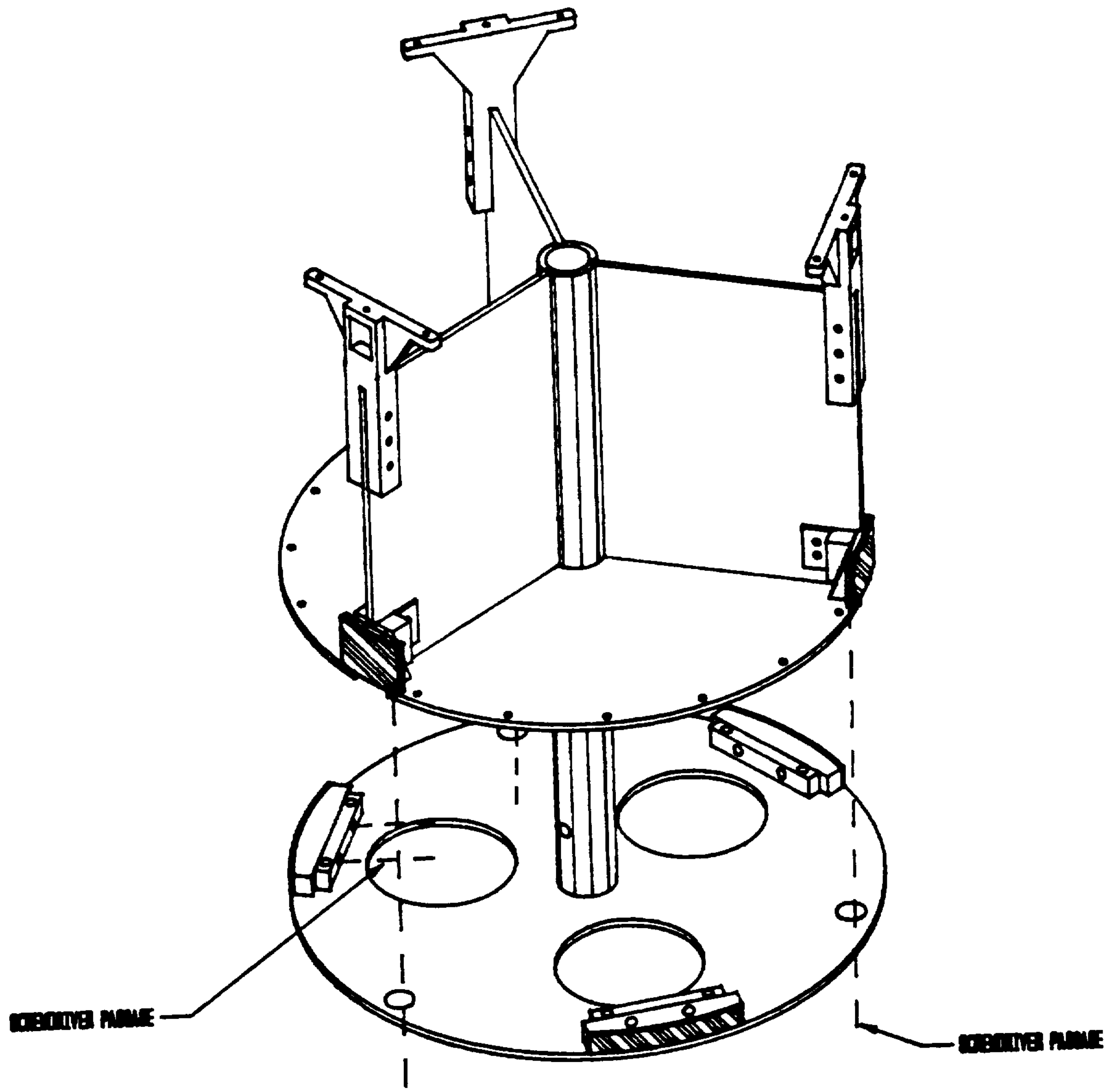


FIGURE 3.3.8

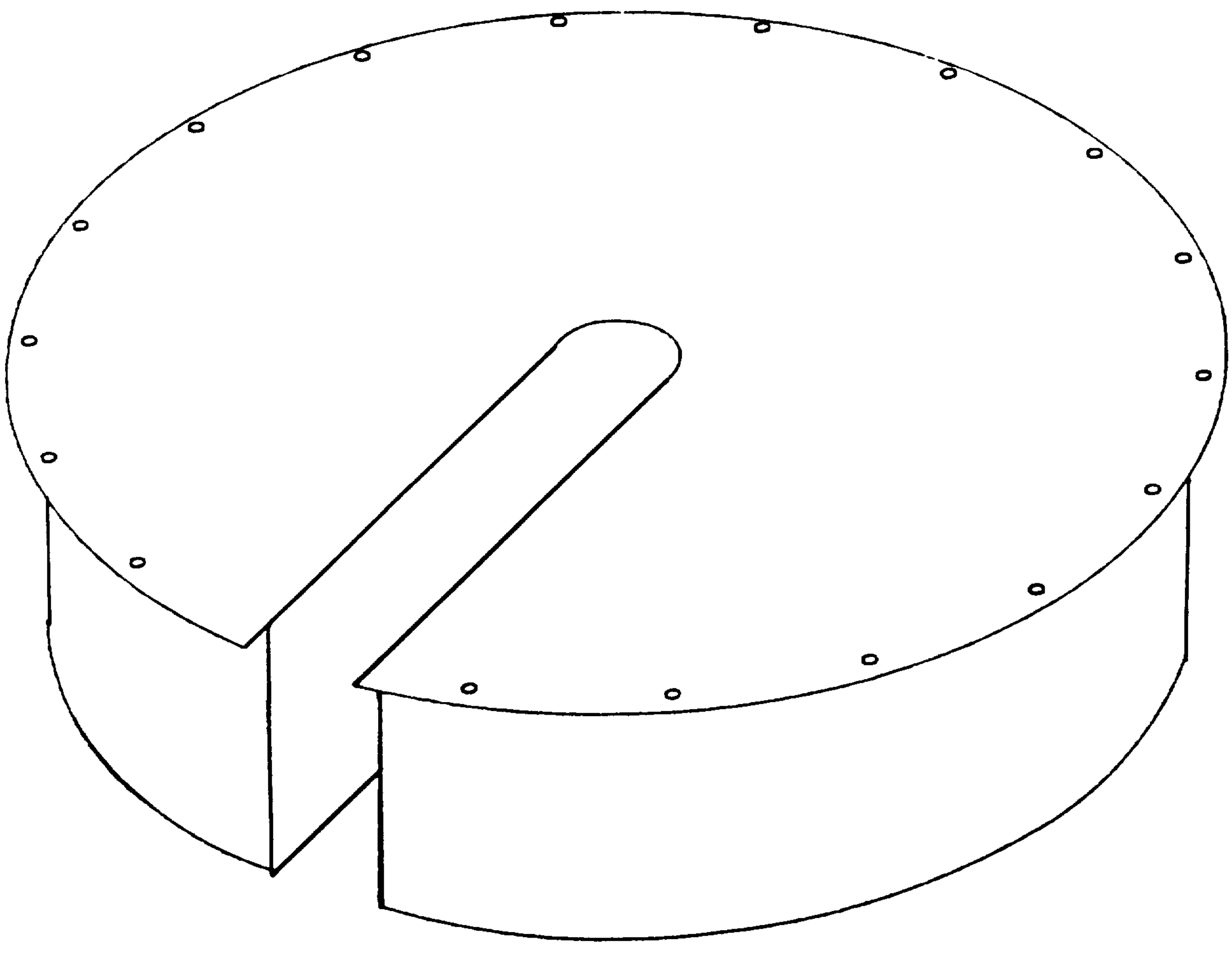


FIGURE 3.1.9

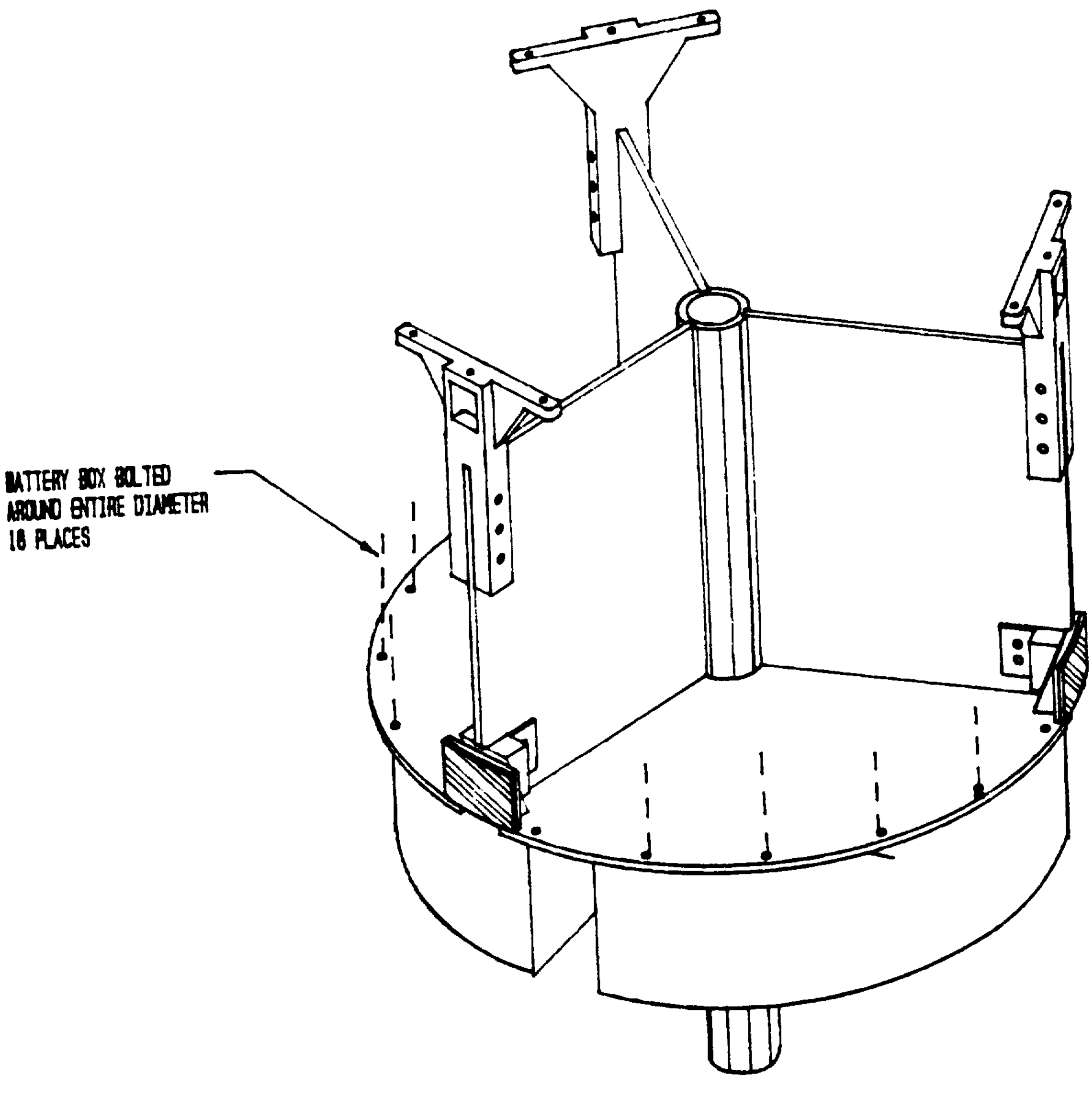


FIGURE 3.1.10

3.4 WEIGHTS AND VOLUMES

ITEM	TARGET WEIGHT	ACTUAL WEIGHT	VOLUME
ALUMINUM FRAME	35.79 LBS	35.79 LBS	—
IPPE	10 LBS	10 LBS	740 in^3
BATTERY WEIGHT		@ 16 LBS	
MICROGRAVITY IGNITION	30 LBS	30 LBS	2961
BATTERY WEIGHT		@ 32 LBS	
ROTATIONAL PLATFORM	35 LBS	35 LBS	2450
BATTERY WEIGHT		@ 24 LBS	
CABLING/CONNECTORS	**	7 LBS	—
BOLTS, CLAMPS ETC.	**	4 LBS	—
MISC.	**	5 LBS	—
BATTERY WEIGHT	50 LBS	(** ABOVE) (72 LBS)	—
BATTERY BOX	12 LBS	12 LBS	1531.77
PLUMBING	**	5 LBS	—
TOTAL	172.79 + **	215.79 LBS	7682.77

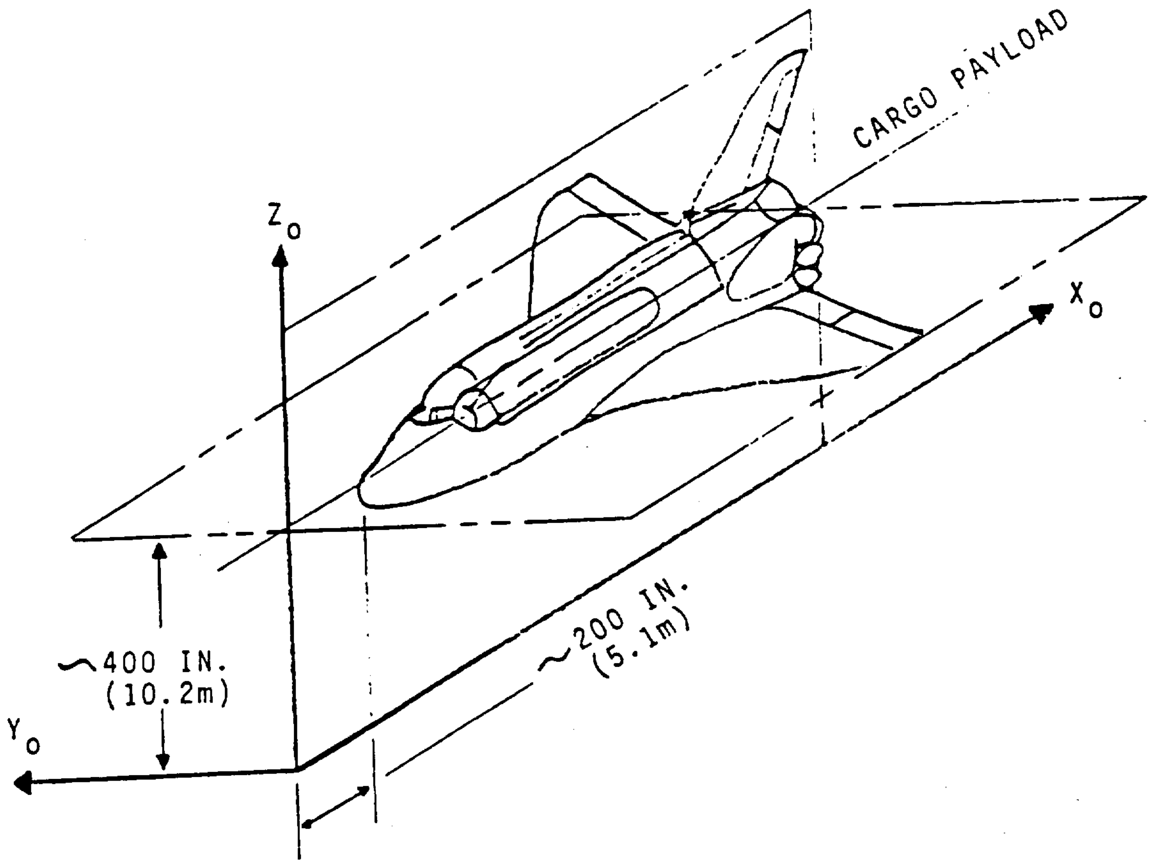
3.5 ANSYS

3.5.1 ANSYS INTRODUCTION

To insure structural integrity of GAScan II, a computer generated finite element model of GAScan II was developed. The computer package known as ANSYS was used to generate this model. ANSYS is used to predict if the structure will fail under the shuttle environment. This understanding begins with the orientation of the can with respect to the Space Shuttle. (see figure 3.5.1)[11]. It is on these axes that the worst possible loadings will be directed. These axes are consistent with the x,y,z axes used in the CAD simulation and ANSYS analysis.

The most important factor for design purposes are the loadings themselves. These loadings are split into three categories, limit, yield and ultimate loads. The limit loads are the worst possible loadings that actually may occur. The yield loads are used to insure that the design, within a specified margin of safety, will not undergo plastic deformations. The ultimate loadings are used to insure that the design will be safe when comparing actual loads with the ultimate allowable loads for the materials of the can.

For GAScan II to become space qualified, certain factor of safety requirements must be met. The factor of safety is the allowable stress divided by the applied stress. NASA requires that the GAScan II to meet a Yield F.S. =1.5 and an Ultimate F.S. = 2.0. In other words, one analysis must be done using the Yield loads. These loads will produce maximum stresses in GAScan II. The allowable stress divided by the calculated maximum stress in GAScan II will yield a ratio. This ratio



TYPE: ROTATING, ORBITER REFERENCED

ORIGIN: APPROXIMATELY 200 (5.1m) INCHES AHEAD OF THE NOSE AND APPROXIMATELY 400 INCHES (10.2m) BELOW THE CENTERLINE OF THE CARGO BAY

ORIENTATION AND LABELING:

THE X AXIS IS PARALLEL TO THE CENTERLINE OF THE CARGO BAY, NEGATIVE IN THE DIRECTION OF LAUNCH

THE Z AXIS IS POSITIVE UPWARD IN LANDING ATTITUDE

THE Y AXIS COMPLETES THE RIGHT-HANDED SYSTEM

THE STANDARD SUBSCRIPT IS 0

FIGURE - 3.5.1
Orbiter coordinate system

must be at least 1.5. Another analysis must be done using the Ultimate loads.(see table (3.5.1)[12]

TABLE 3.5.1.1 - LOAD VECTORS
ANALYSIS NOT VERIFIED BY TEST

Yield F.S. = 1.5
Ultimate F.S. = 2.0

DIR.	LIMIT LOAD (G,S)	YIELD LOAD (G,S)	ULTIMATE LOAD (G,S)
+X	6.0	9.0	12.0
-X	6.0	9.0	12.0
+Y	6.0	9.0	12.0
-Y	6.0	9.0	12.0
+Z	10.0	15.0	20.0
-Z	10.0	15.0	20.0

It should be noted that these loads are the combination of intense vibration and dynamic loads. (see figure 3.5.2)[13]

Our project is still within the initial stages of development. Therefore we will only include the Limit load spectrum in our analysis. A vibrational analysis will be used only for finding the natural frequency of GAScan II. ANSYS will be the computer software package that will be used for these analyses. Hand calculations will be used to verify some ANSYS results. These calculations consist of simple models generated on ANSYS and verified by hand and center of gravity calculations by hand (see Appendix 1) to see if they match those obtained by ANSYS.

GET AWAY SPECIAL
SMALL SELF-CONTAINED PAYLOADS

SHUTTLE ENVIRONMENT

ACCELERATIONS:
QUASI-STEADY STATE
LIMIT LOAD FACTORS

ACROSS CONTAINER = ± **6.0 g's**
AXIS (ALL DIRECTIONS)

ALONG CONTAINER = ± **10.0 g's**
AXIS

OVERALL ROOT MEAN SQUARED RANDOM VIBRATION LEVEL IS
12.9 g's

RANDOM VIBRATION

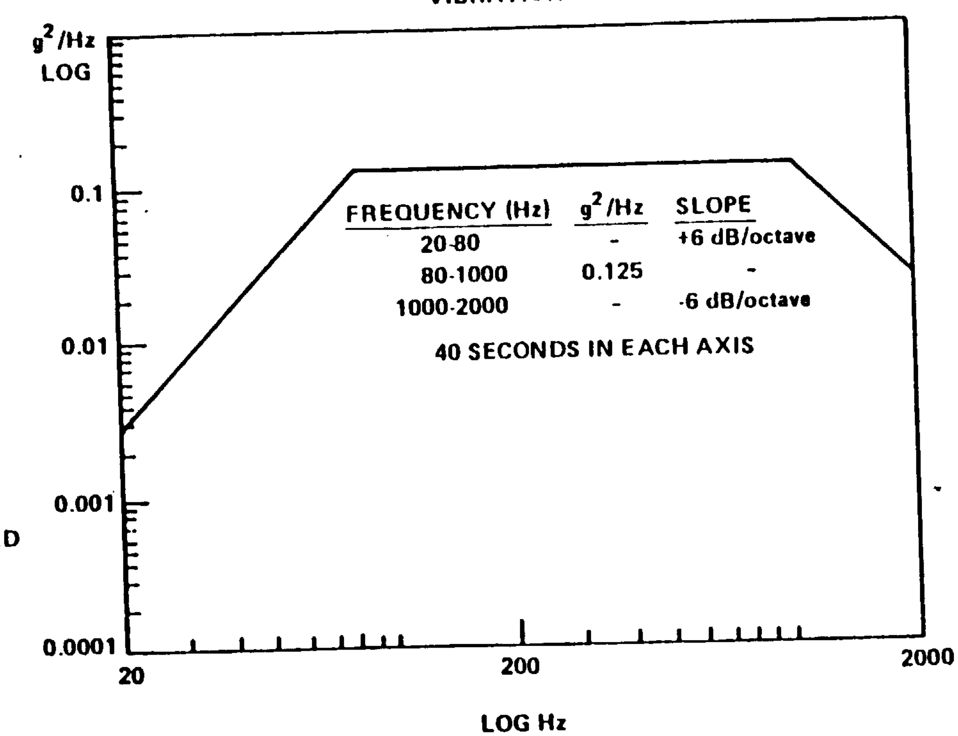


FIGURE - 3.5.2

3.5.2 ELEMENT SELECTION

A finite element model consists of defining points around the model and connecting these points, or nodes, with elements. Throughout the ANSYS analyses three element types will be used. These elements were chosen to represent various parts of the GAScan II model. Each element can be described by its name, or STIF#, number of nodes needed, degrees of freedom per node, real constants, material properties and certain other characteristics unique to it.

The first element is the elastic quadrilateral shell, STIF63, as shown in figure 3.5.3[14]. The shell element requires 4 nodes, in some cases the fourth node is the same as the third node resulting in a triangle. The shell element has six degrees of freedom at each node, translations in the nodal x,y,and z directions and rotations about the nodal x,y,and z axes. The shell element has six real constants, thickness at the four nodes, elastic foundation stiffness (EFS), and material direction angle (theta). The shell element has seven material properties; modulus of elasticity in the x and y directions, thermal constants in the x and y directions, Poissons ratio, density and shear modulus. The shell element will be used to represent the plates, the flanges, and the shelf. The output from the shell element are sx, sy, sxy, si, sig1, sig2, sig3, and sigE, as shown in figure 3.5.4.[15]

The next element is the 3-D elastic beam, STIF4, as shown in figure 3.5.5.[16] The beam element is normally defined by two nodes, one at each end. The beam element has six degrees of freedom per

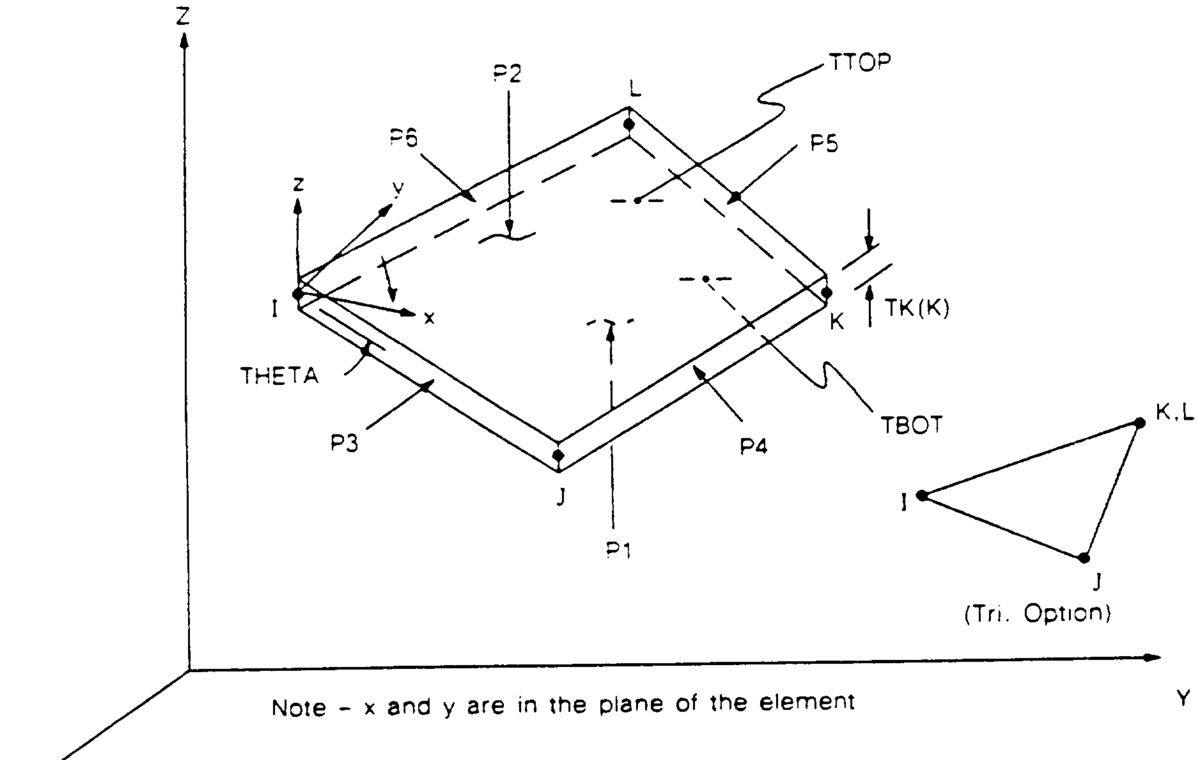


FIGURE - 3.5.3 Quadrilateral Shell

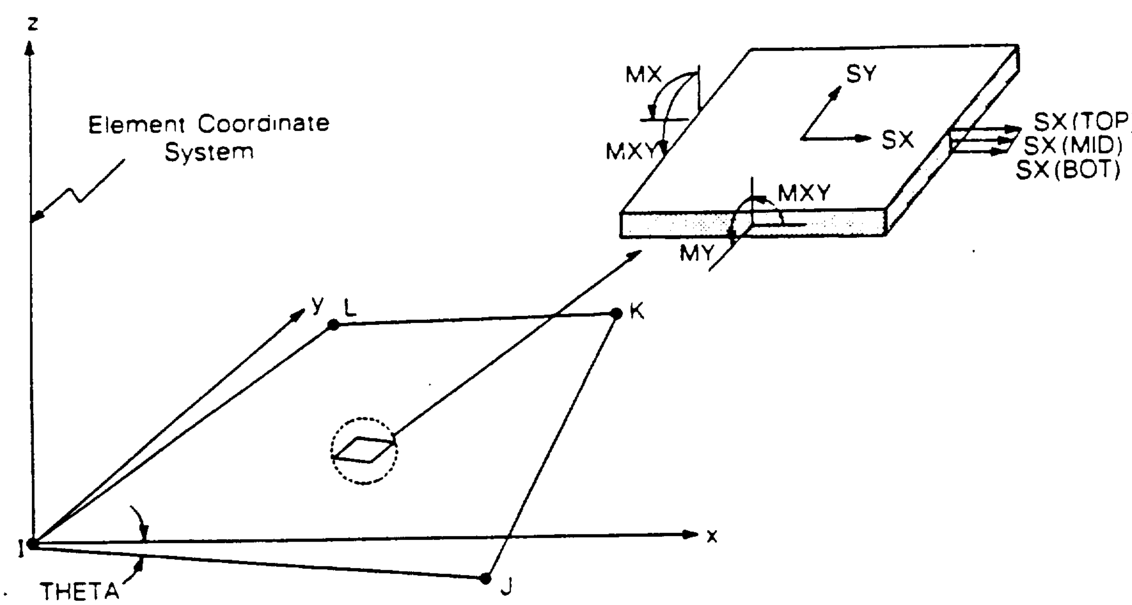


FIGURE - 3.5.4 Quadrilateral Shell Output

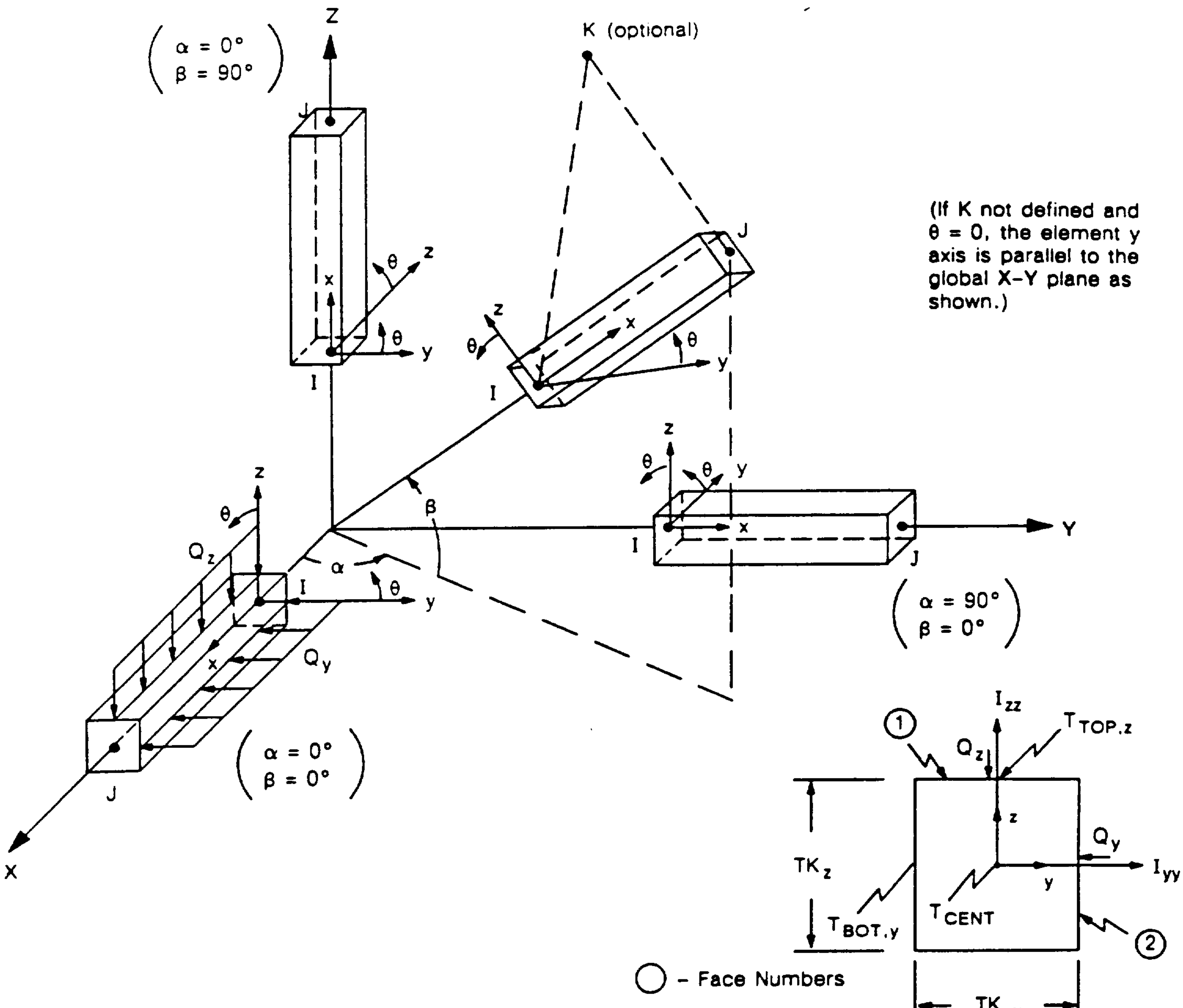


FIGURE - 3.5.5. Three-Dimensional Beam

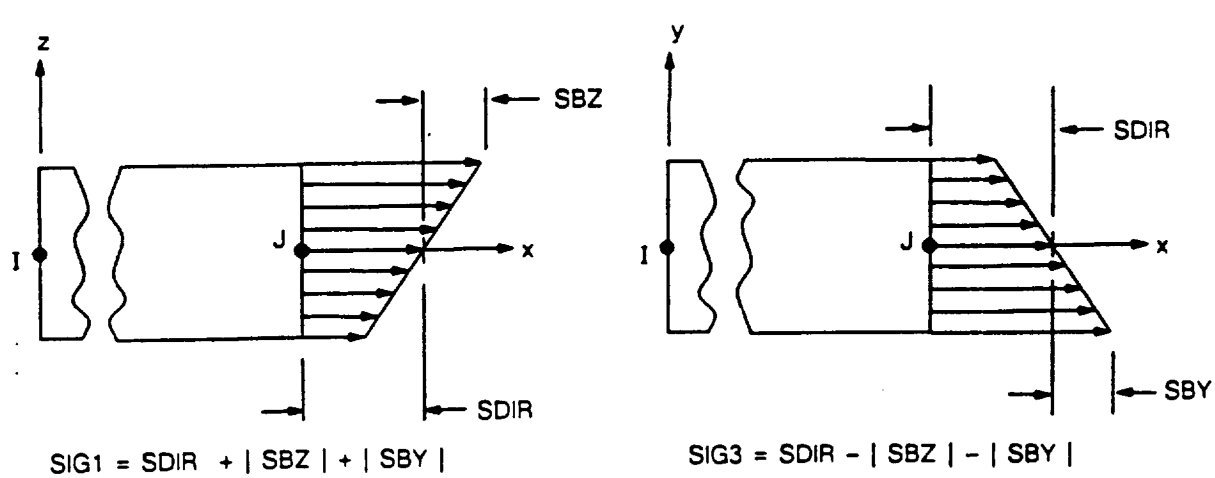


FIGURE - 3.5.6 Three-Dimensional Beam Output node, translations in the x, y and z directions and rotations about x, y and z nodal axes. The beam can have up to ten real constants, area, moments of inertia about the x, y and z axes, thickness in the y and z directions, theta, initial strain, and shear deflections in the x and y. The beam element has four material properties, modulus of elasticity in the x direction, thermal constant in the x direction, Poissons ratio, and density. The beam element output are sdir, sbz, sby, sig1 and sig3, as shown in figure 3.5.6.[17]

The last element used is the mass element, STIF21, as shown in figure 3.5.7.[18] The mass element requires one node to be defined. It has six degrees of freedom, translations in the nodal x,y, and z directions and rotations about the nodal x,y, and z axes. The mass element has six real constants, mass in the x, y and z directions and moments of inertia about the x, y and z axes. The mass element has no material properties and there is no output from this element type.

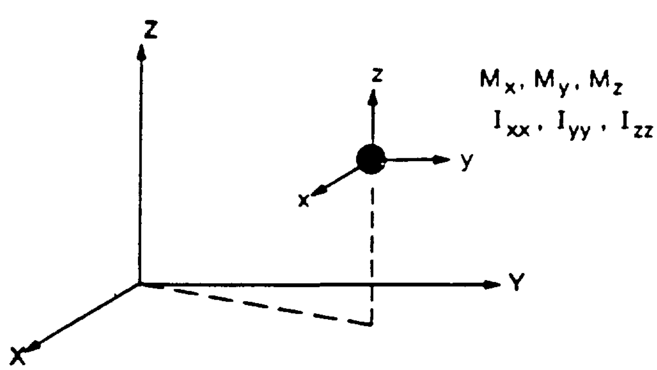


FIGURE -3.5.7 Generalized Mass

3.5.3 ANSYS ANALYSIS

3.5.3.1 ANALYSIS METHOD

In past experiences, there has been rough transitions in continuing projects, especially with the learning of the ANSYS computer package. The purpose of this section is to eliminate any confusion by outlining the method of our analysis. The following table explains this method.

TABLE - 3.5.2 METHODOLOGY

SECTION	HEADING	REASONING FOR SECTION
3.5.3.A	ANALYSIS TITLE -	This will show the name of the analysis to follow. The letter A is the analysis number (starting with number two).
3.5.3.A.1	PURPOSE -	This section will explain why we are doing the analysis and what we hope to find.
3.5.3.A.2	NODAL CONSTRUCTION -	This section explains the assumptions and procedures in generating the model. A nodal plot will be included.

3.5.3.A.3 ELEMENT CONSTRUCTION - This section explains which elements are to be used in the analysis. All assumptions will be included. An element plot is included.

3.5.3.A.4 BOUNDARY CONDITIONS - This section explains the constraints that the model are subjected to. A plot is included.

3.5.3.A.5 APPLYING FORCES - This section explains the loads and acceleration that the model will experience. A plot is included.

3.5.3.A.6 PREP7 INPUT COMMANDS - This section allows the reader direct access to the commands used on ANSYS to generate the model.

3.5.3.A.7 RESULTS - This section will give the maximum displacements, component stresses, and principle stresses. Pictures and plots will be included if they are available. Hand calculations will also be included in the appropriate sections.

3.5.3.2 CANTILEVER BEAM

3.5.3.2.1 PURPOSE

The purpose of this analysis was to test the beam element. The beam element was given all the geometric and material properties of the central shaft of GAScan II. A load was applied to the end of the beam and a deflection was calculated. Stresses, reaction forces and moments were also obtained. This analysis showed that the central shaft could be modeled with this element.

3.5.3.2.2 NODAL CONSTRUCTION

The nodal construction of the beam was completed in three commands. There are only two key nodes that are of importance. The first node (node #1) was the node that was constrained in all directions and the second key node (node #10) was the node on which the force was applied. All other nodes filled between these two nodes.(see figure 3.5.8)

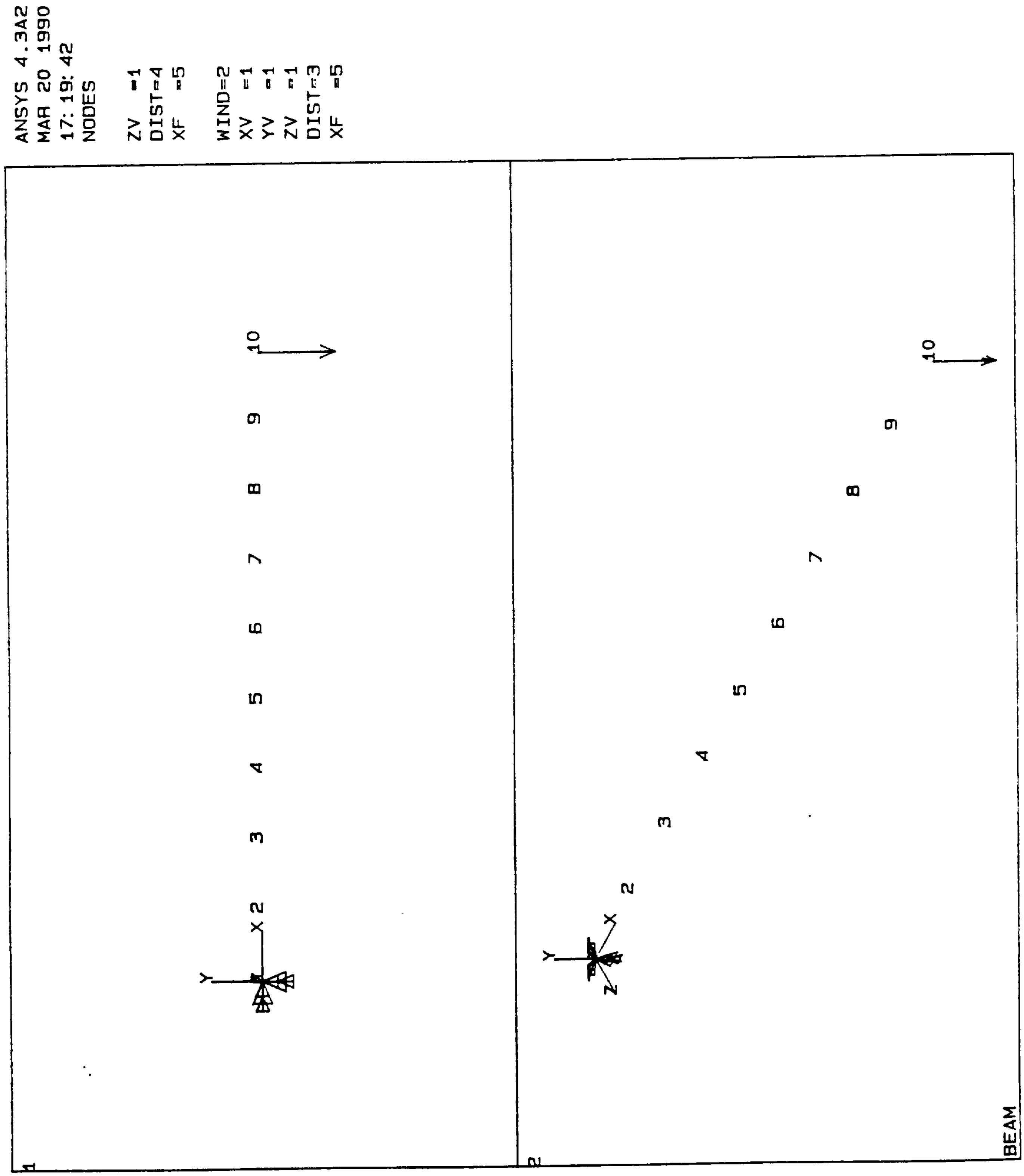

ANSYS 4.3A2
MAR 20 1990
17:19:42
NODES
ZV =1
DIST=4
XF =5
WIND=2
XV =1
YV =1
ZV =1
DIST=3
XF =5
BEAM
1
2
3
4
5
6
7
8
9
10
X
Y
Z

FIGURE - 3.5.8

3.5.3.2.3 ELEMENT CONSTRUCTION

The element selected for this analysis was the three dimensional elastic beam element. Five real constants had to be defined for ANSYS. Those constants are the area, moments of inertia about the Y and Z axes, and the thickness in the Y and the Z. The material properties for the central shaft were also input. The beam element is defined by two nodes which are connected as shown before in figure 3.5.5. Nine elements were used in the cantilever beam as shown in figure 3.5.9.

3.5.3.2.4 BOUNDARY CONSTRAINTS

The first node was fixed in all directions. This caused the cantilever beam to appear to be fixed into a wall. It was necessary to fix the beam like this to allow hand calculations to be easily computed.

3.5.3.2.5 APPLYING FORCES

The last node experienced a downward force. The force applied was 1000 lbs.

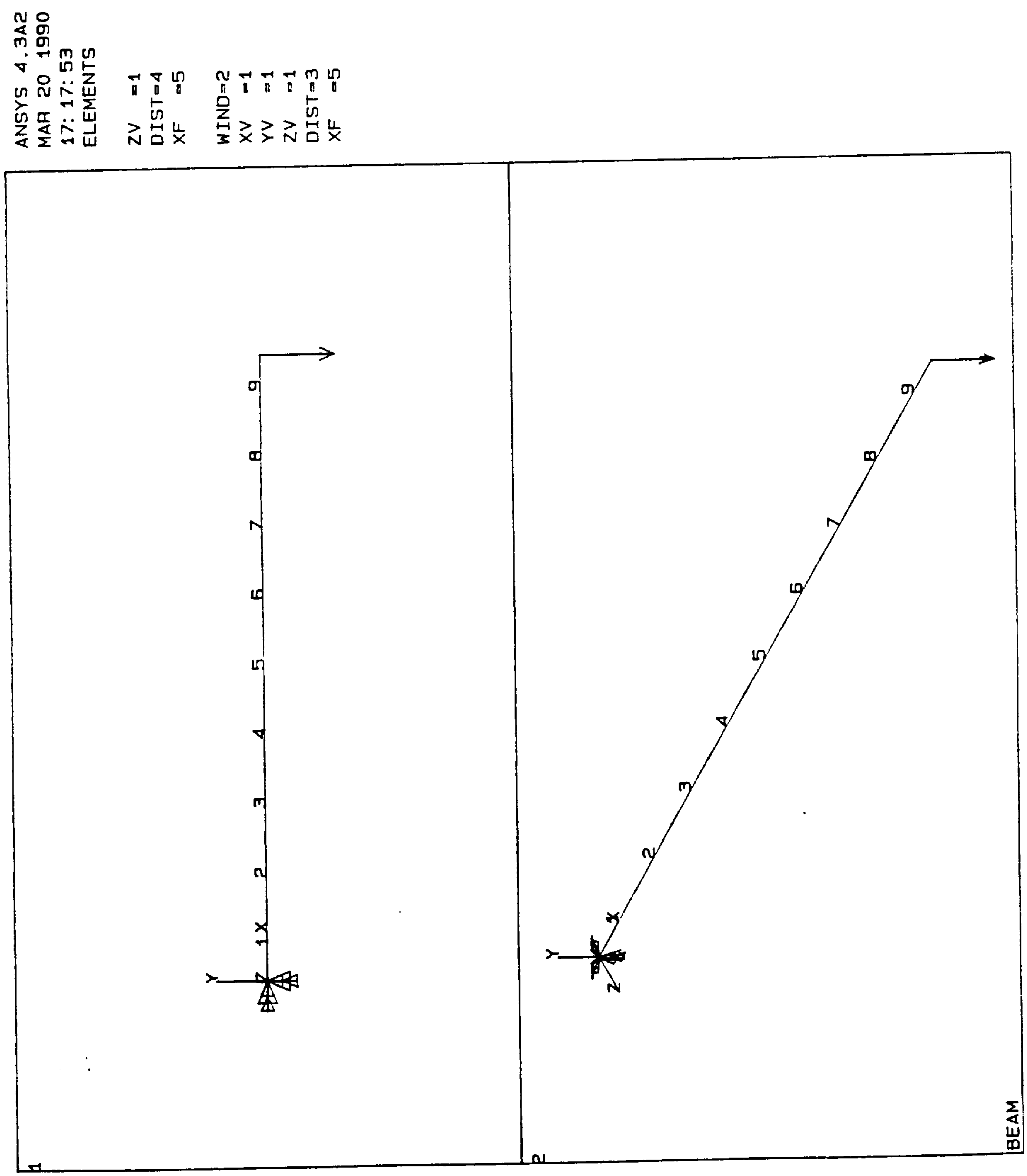

ANSYS 4.3A2
MAR 20 1990
17:17:53
ELEMENTS
ZV =1
DIST=4
XF =5
WIND=2
XV =1
YV =1
ZV =1
DIST=3
XF =5
BEAM

FIGURE - 3.5.9

3.5.3.1.6 PREP7 INPUT COMMANDS

The following PREP7 commands were used to do this analysis.

```
kan,0                                   STATIC ANALYSIS

r,1,.1.5708,.9817,.9817,2,2             REAL CONSTANTS
ex,1,10e6                               MATERIAL PROPERTIES
nuxy,1,.3
dens,1,.098

n,1                                     NODE GENERATION
n,10,10
fill

type,1                                  ELEMENT GENERATION
mat,1
real,1
e,1,2
egen,9,1,1,9,1

d,1,all,all                             BOUNDARY CONSTRAINTS

f,10,fy,-1000                           APPLYING FORCES

iter,1,1                                SET ITERATION TO ONE
/show,ega256                            SET UP GRAPHICS
/menu,yes
/pbc,all,1                              PRINT ALL BOUNDARY CONDITIONS
/title,beam                             TITLE
/view,1,1,1,1                           VIEW
eplo                                    ELEMENT PLOT
```

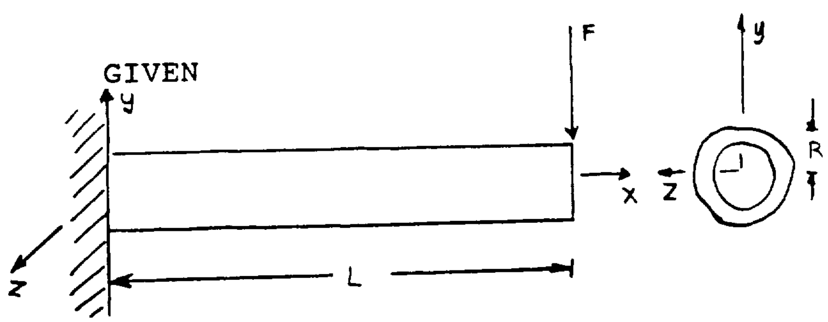
3.5.3.2.7 RESULTS

The shaft was subjected to a point load on the end. The ANSYS results are as follows and the displacement plot, figure 3.5.10, is shown on the following page.

TABLE 3.5.3 - BEAM RESULTS

FORCE	MAX DEFLECTION	MAX MOMENT	MAX STRESS
-1000 node# 10	-.03395 in node# 10	10,000 lb-in node# 1	±10,186 psi node# 1 (tension on top, and comp. on bottom)

The hand calculations are as follows:



L=10 in
F=1000 lbs
I_{zz}=.9817in^4
R=1 in

THE MAX MOMENT IS: M = LxF = 10in x 1,000lb = 10,000 lb-in

THE MAX STRESS IS: σ = My/I = 10,000 lb-in x 1 / .9817 in^4

σ = $\pm$10,186.4113 psi

THE MAX DEFLECTION IS: $\delta = FL^3/3EI$

δ = 1000 lbs x (10 in)^3 / 3 x 10e6 psi x .9817 in^4

δ = -.03395 in

As seen, the hand calculations match the ANSYS results. This proved that our method for modeling a beam are accurate.

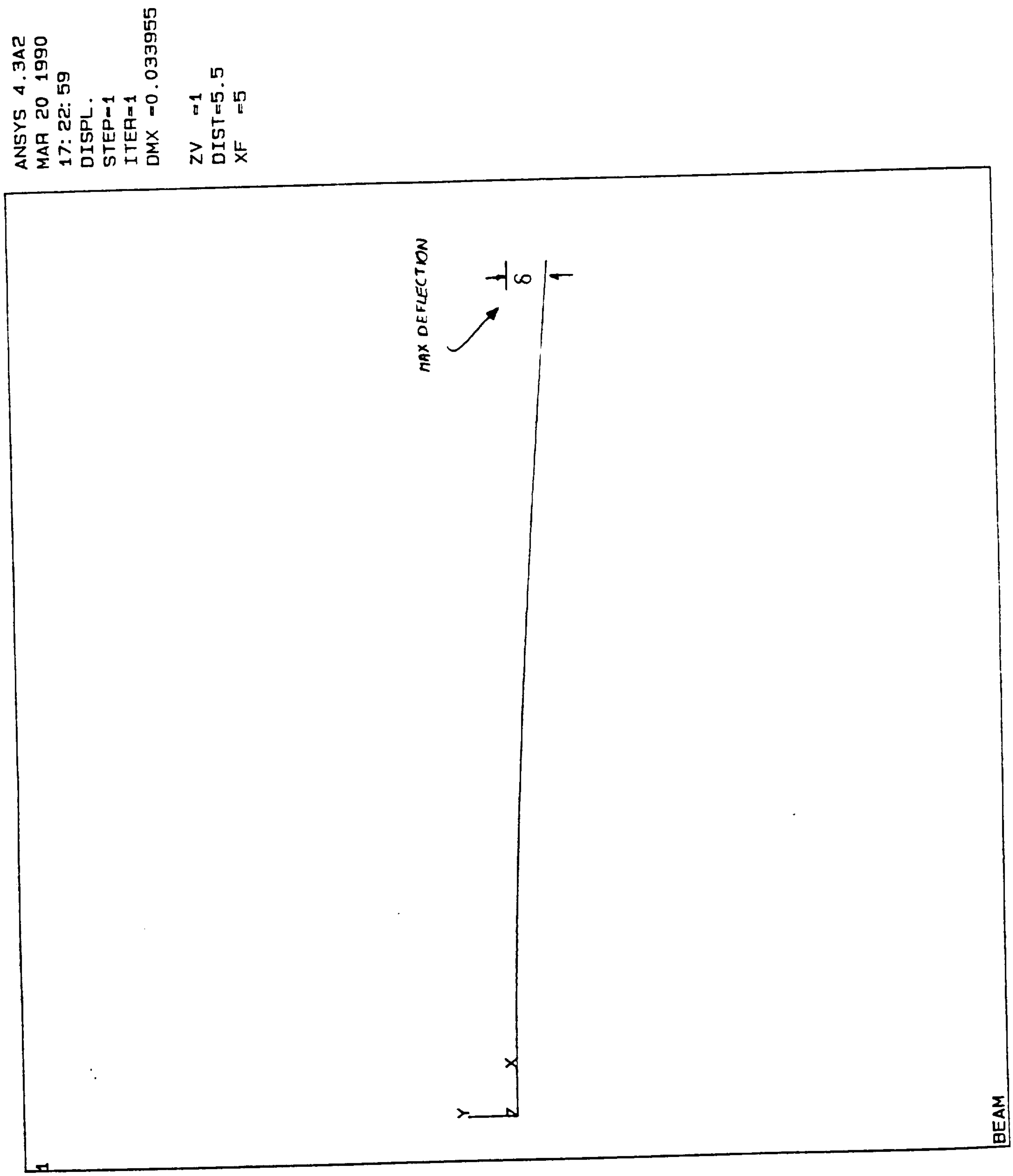

ANSYS 4.3A2
MAR 20 1990
17:22:59
DISPL.
STEP=1
ITER=1
DMX =0.033955
ZV =1
DIST=5.5
XF =5
MAX DEFLECTION
δ
X
Y
BEAM
1

FIGURE - 3.5.10

3.5.3.3 CIRCULAR PLATE

3.5.3.3.1 PURPOSE

Three plates were created to verify that the shell elements would be consistent with our analysis. The first plate consisted of 40 shell elements. We doubled the number of elements from the first plate created for the second plate and doubled that number of elements for the third plate. We did this to get a percentage of error in our modeling.

3.5.3.3.2 NODAL CONSTRUCTION

The plates were created by placing the first node in the center. For the 40 element plate, the second node was place along the x axis at a distance of ten inches from the center node. Four nodes were then equally spaced in between the first and second nodes. The set was then replicated seven times, rotated at an angle of 45 degrees between sets. The nodes for the 80 element plate were created the same way, except the set was replicated 15 times, rotated at an angle of 22.5 degrees between sets. The nodes for the 160 element plate were created the same way using the first and second nodes, and then placing 9 nodes equally spaced between them and then replicating the set 15 times, rotated at an angle of 22.5 degrees between sets.(see figure 3.5.11 through figure 3.5.13)

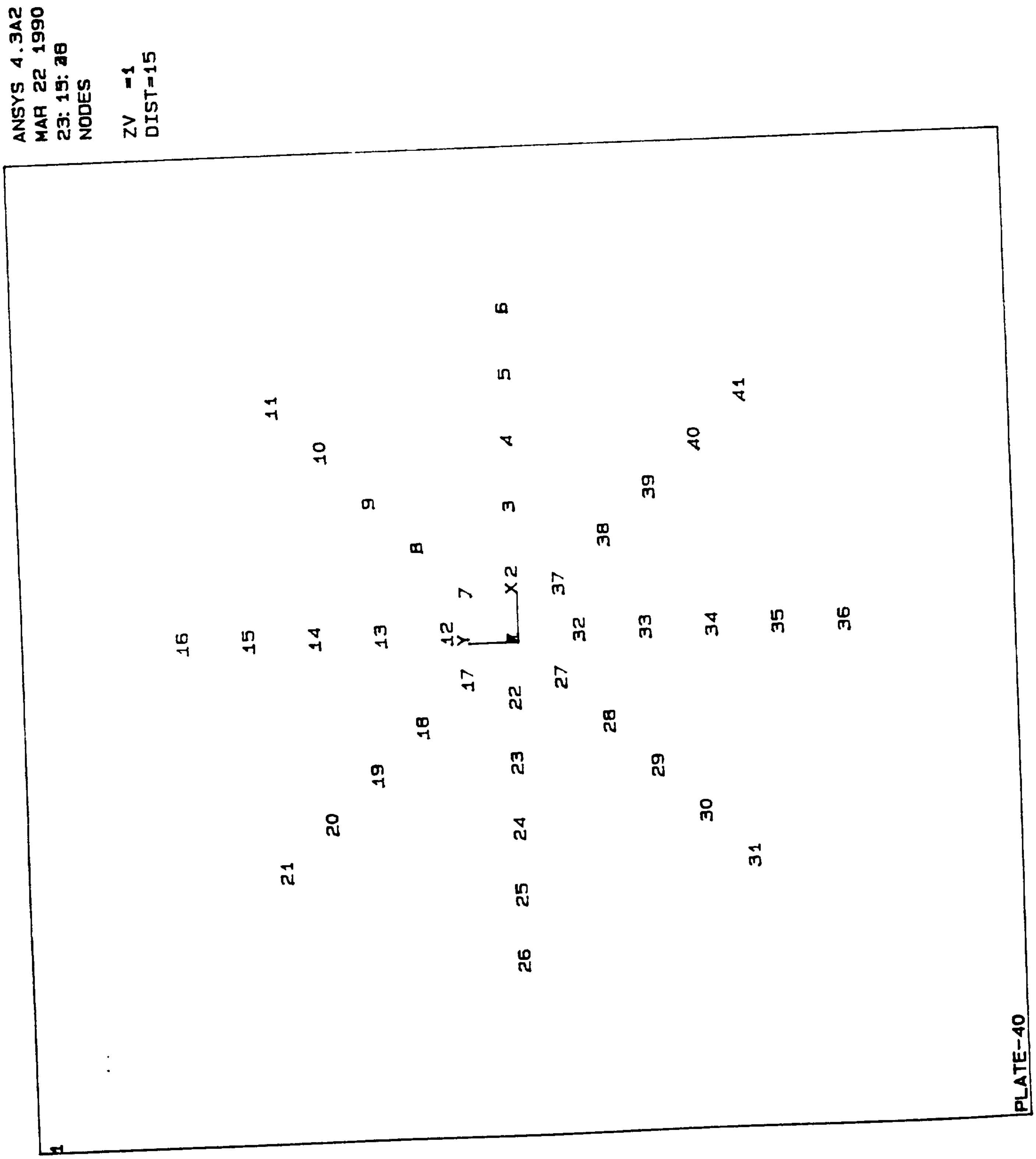


FIGURE - 3.5.11

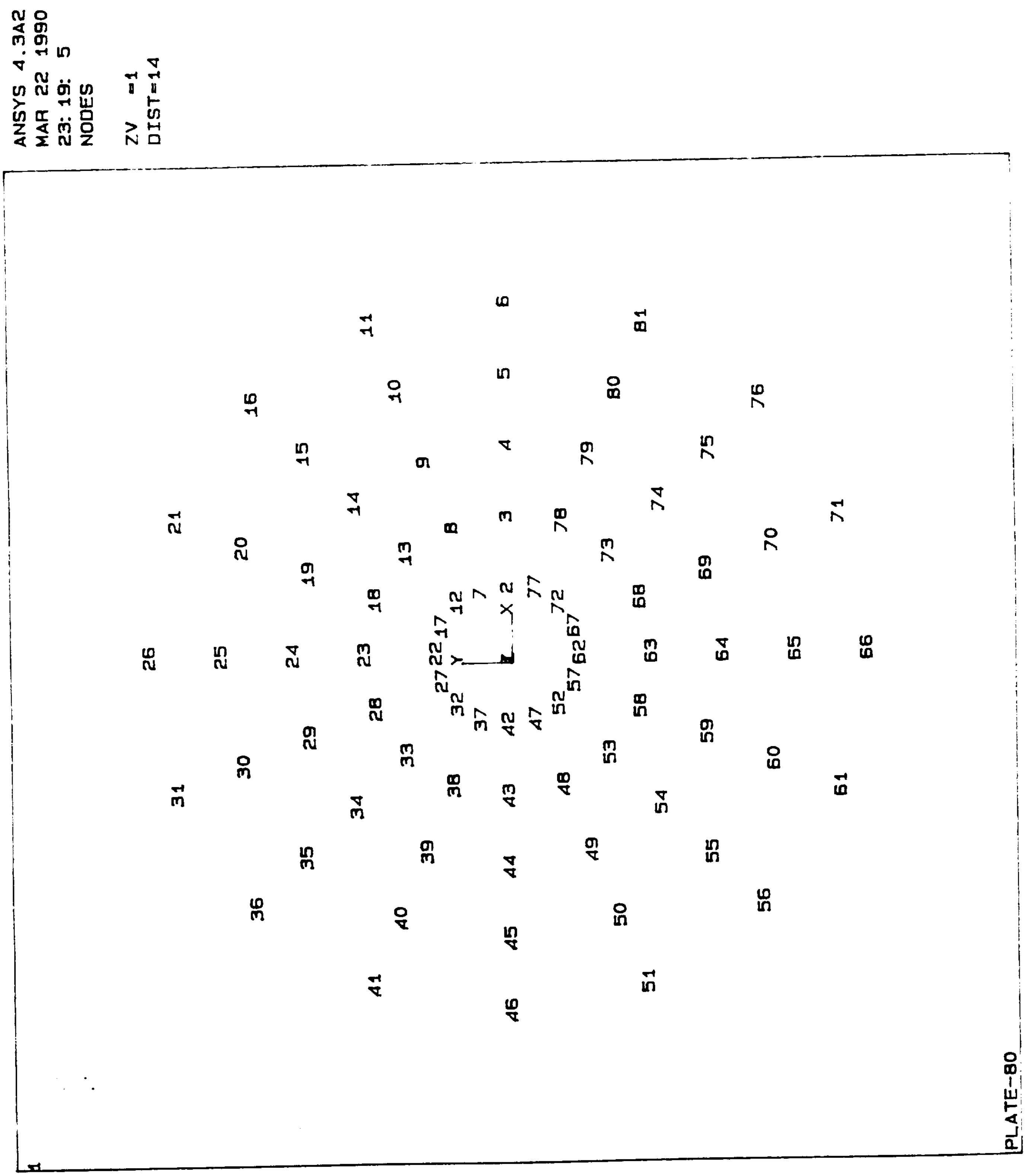


FIGURE - 3.5.12

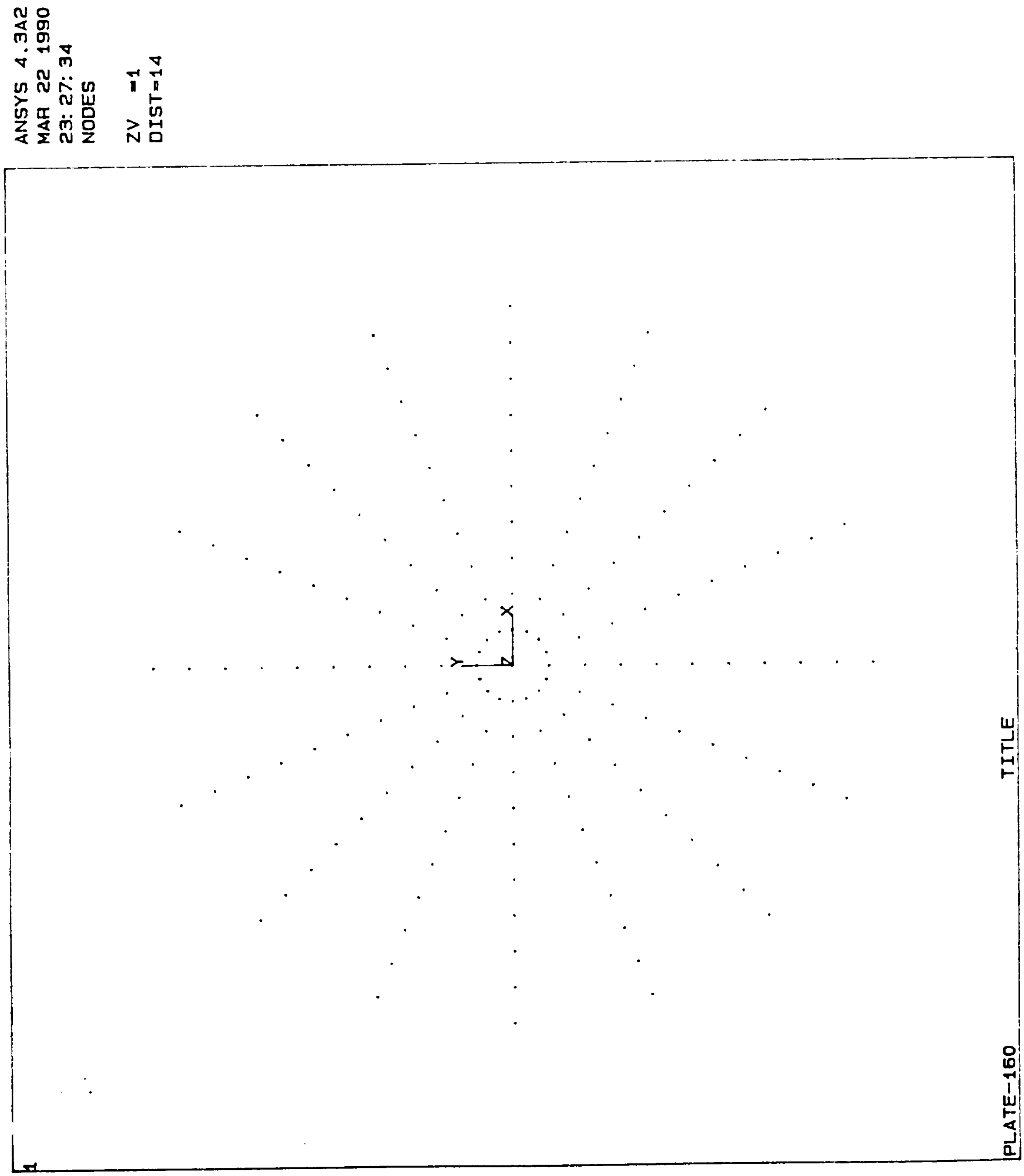

ANSYS 4.3A2
MAR 22 1990
23:27:34
NODES
ZV =1
DIST=14
X
Y
TITLE
PLATE-160

FIGURE - 3.5.13

3.5.3.3.3 ELEMENT CONSTRUCTION

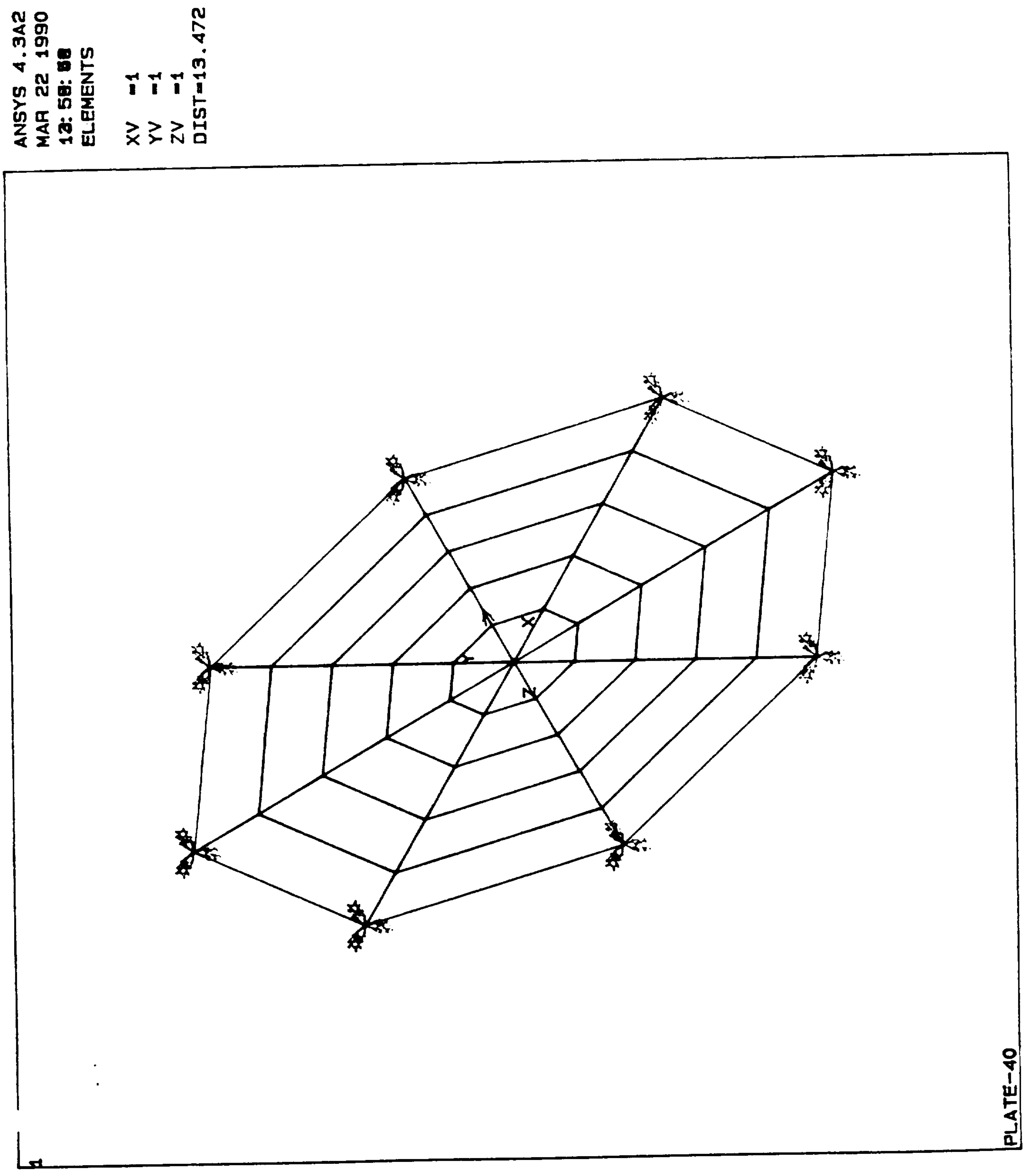
The element used for the plate was the shell element with a thickness of 0.25 inches and material properties of aluminum. The elements were created by connecting nodes in a counter clockwise manner. This had to be kept consistent througout the element generating sequence in order to get an accurate model. For all the elements using node one in the center of the plate, there is only three nodes to connect to so the last node is repeated. For the four cornered elements they are connected in a normal fashion. (see figure 3.5.14 though figure 3.5.16)

3.5.3.3.4 BOUNDARY CONDITIONS

The boundary conditions for the plates are all nodes at the edge fixed in all directions. This does not allow any displacements or deflections. These fixed nodes can be noticed in the element plots.

3.5.3.3.5 APPLYING FORCES

A force was then applied, to the center of the plates, of 100 pounds. The force was applied at that location for ease of computation. The single force is plotted on the element plot.



ANSYS 4.3A2
MAR 22 1990
ELEMENTS
XV =1
YV =1
ZV =1
DIST=13.472
PLATE-40

FIGURE - 3.5.14

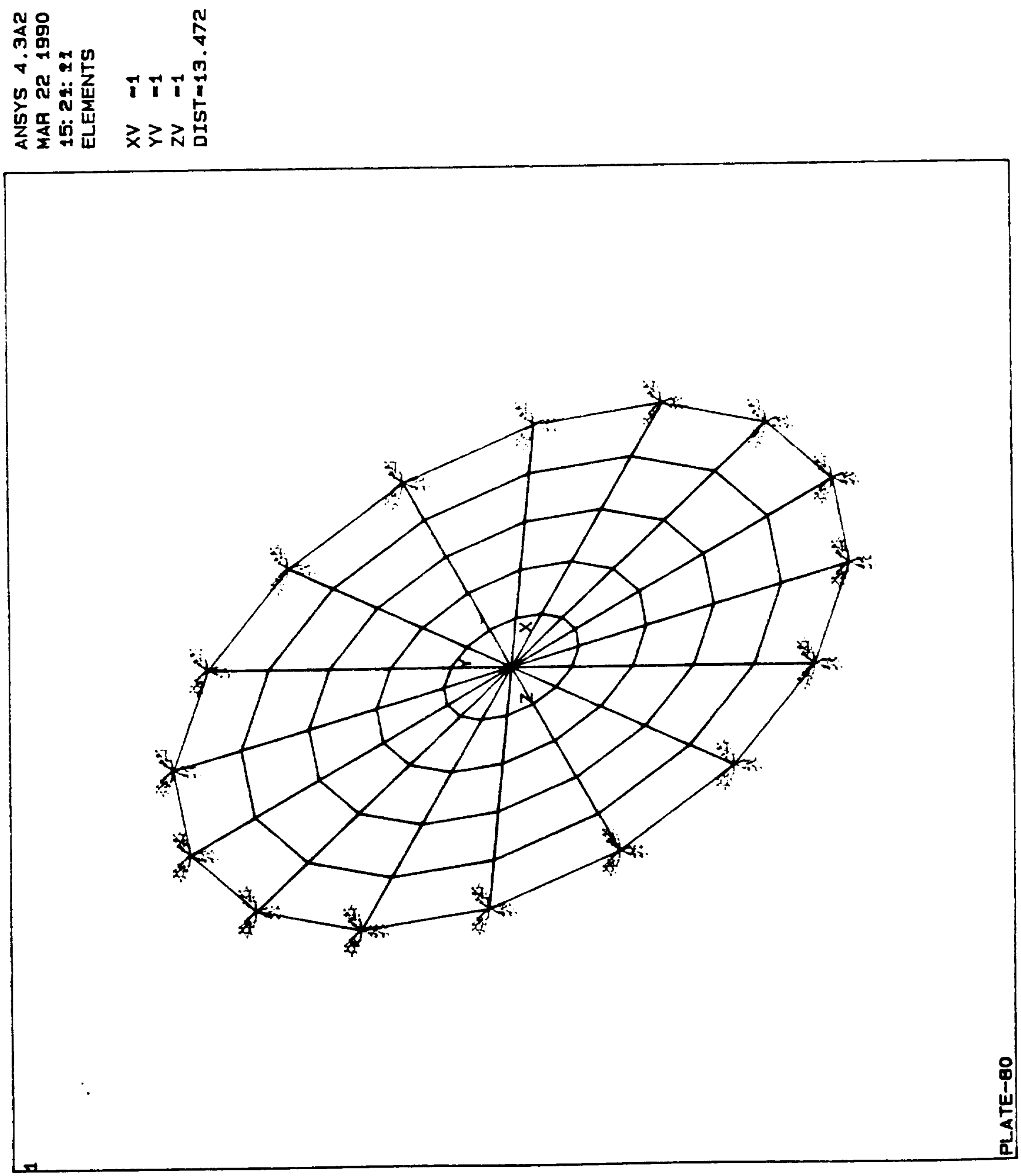

ANSYS 4.3A2
MAR 22 1990
15: 21: 11
ELEMENTS
XV =1
YV =1
ZV =1
DIST=13.472
PLATE-80

FIGURE - 3.5.15

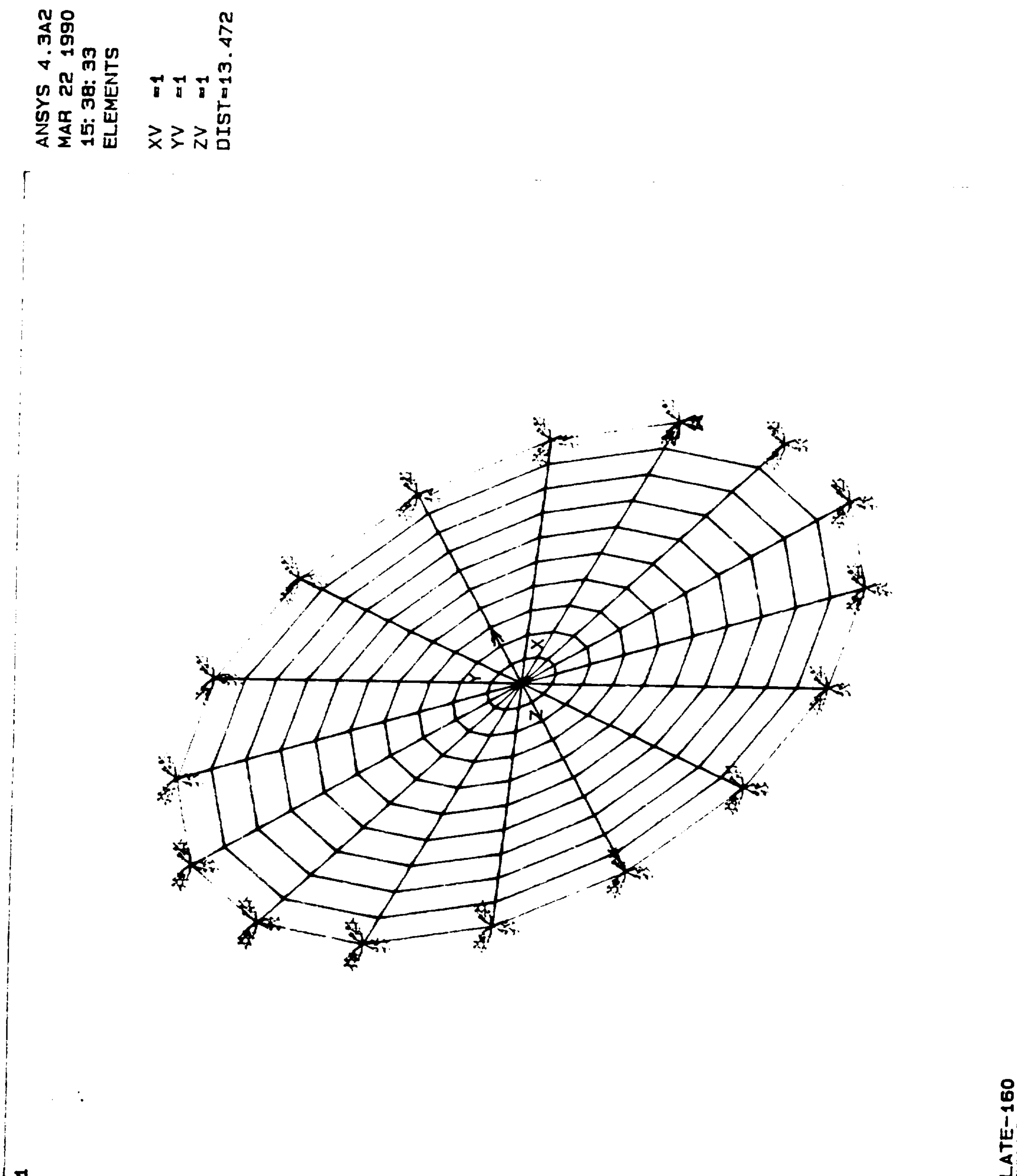

ANSYS 4.3A2
MAR 22 1990
15:38:33
ELEMENTS
XV =1
YV =1
ZV =1
DIST=13.472
PLATE-160

FIGURE - 3.5.16

3.5.3.3.6 PREP7 INPUT COMMANDS

The following are the commands used to generate PLATE-40.

```
                                      STATIC ANALYIS
kan,0

                                      QUAD. SHELL ELEMENTS
et,1,63                               REAL CONSTANTS
r,1,.25,.25,.25,.25                   MATERIAL PROPERTIES
ex,1,1e7
ey,1,1e7
nuxy,1,.3
dens,1,.00026

                                      CYLINDRICAL COORDINATES
csys,1

                                      NODAL CONSTRUCTION

n,1
n,6,10,0,0 <---- number of nodes per set = 6
fill
ngen,8,5,2,6,1,0,45 <---- angle between sets of nodes
                                      ELEMENT CONSTRUCTION
type,1
mat,1
real,1
e,1,2,7,7
e,1,7,12,12
e,1,12,17,17
e,1,17,22,22
e,1,22,27,27
e,1,27,32,32
e,1,32,37,37
e,1,37,2,2
e,2,3,8,7
egen,4,1,9,12,1
egen,7,5,9,36,1
e,37,38,3,2
egen,4,1,37,40,1

                                      BOUNDARY CONSTRAINTS
d,6,all
d,11,all
d,16,all
d,21,all
d,26,all
d,31,all
d,36,all
d,41,all

                                      APPLYING FORCES
f,1,fz,-100

                                      TITLE
/title,PLATE-40                       PRINT ALL BOUNDARY CONDITIONS
/pbc,all,1                            SET ITERATION TO ONE
iter,1,1
```

The changes made for increasing the elements to eighty required changing the angle between sets of nodes from 45 degrees to 22.5 degrees.

NODAL CONSTRUCTION

```
n,1
n,6,10,0,0  <---- number of nodes per set = 6
fill
ngen,16,5,2,6,1,0,22.5 <---- angle between sets of nodes
```

For the one hundred and sixty element plate the number of nodes from the center to the perimeter was double that of the eighty element plate.

NODAL CONSTUCTION

```
n,1
n,11,10 <---- number of nodes per set = 11
fill
ngen,16,10,2,11,1,0,22.5 <---- angle between sets of nodes
```

3.5.3.3.7 RESULTS

For the three models the ANSYS calculated displacements are shown in column one of table 3.5.4. The hand calculated results are in column two. The formula used for the hand calculated results was taken from <u>Advanced Mechanics of Materials</u> by A.P. Buresi and O.M. Sidebottom,[19] and is as follows:

$$w_{max} = \frac{3(1-v^2)Pa^2}{4\pi Eh^3}$$

w = displacement
a = radius of plate
v = Poissons ratio
P = load
h = thickness of plate
E = modulus of elasticity

TABLE 3.5.4 - PLATE RESULTS

ANSYS	HAND CALC
40 element plate, w = 0.0145"	10" radius plate, w = 0.0139"
80 element plate, w = 0.0138"	
160 element plate w = 0.0140"	

displacement Calculation:

$$w = \frac{3(1-\nu^2)Pa^2}{4\pi E h^3} = \frac{3(1-.3^2)(100\,lbs)(10\,in)^2}{4\pi(1\times10^7\,lbs/in)(0.25\,in)^3} = 0.0139\,in$$

ERROR CALCULATION:

40 ELEMENT PLATE $\frac{0.0145-0.0139}{0.0139} \times 100$ 4.3%

80 ELEMENT PLATE $\frac{0.0138-0.0139}{0.0139} \times 100 = -0.71\%$

160 ELEMENT PLATE $\frac{0.0140-0.0139}{0.0139} \times 100 = 0.71\%$

The 40 element plate was within 5 percent of the actual answer and the 80 element plate and the 160 element plate were 7/10 of one percent off. We used 48 elements in GAScan II,s circular plates so it should be acceptable with only a small percentage error. All plots are shown in the following figures.

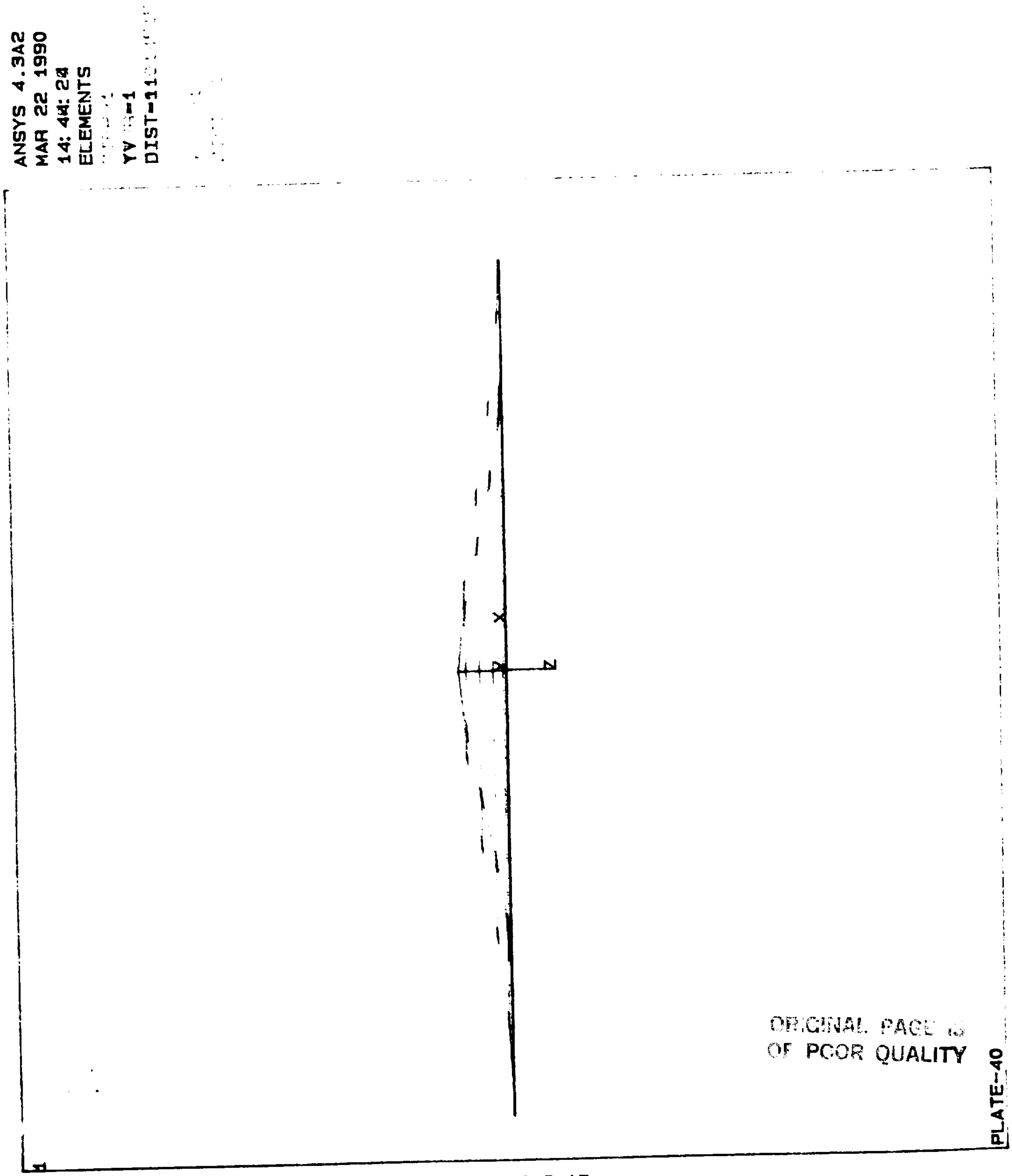


FIGURE - 3.5.17

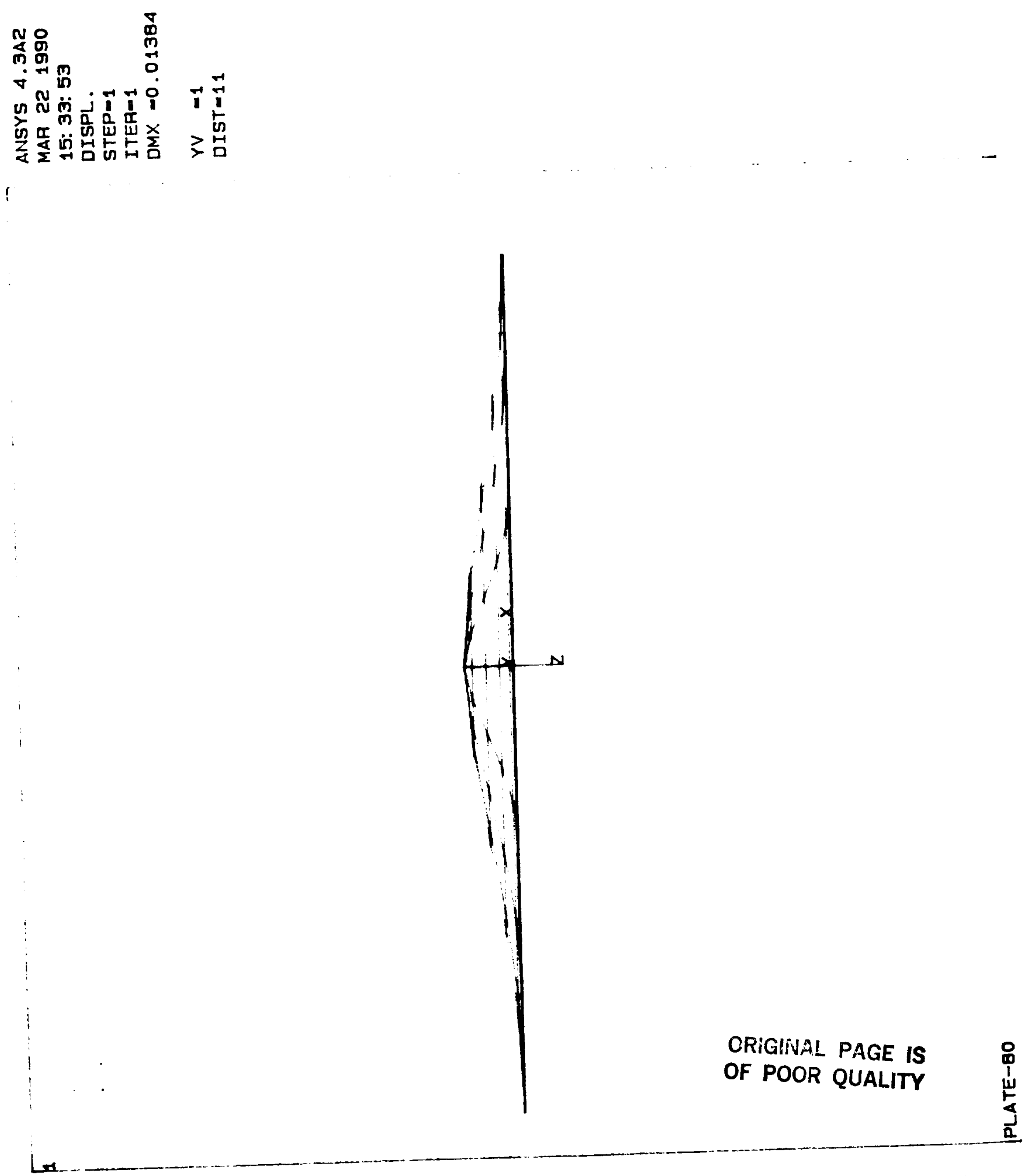

ANSYS 4.3A2
MAR 22 1990
15:33:53
DISPL.
STEP=1
ITER=1
DMX =0.01384
YV =1
DIST=11
X
Z
PLATE-80

FIGURE - 3.5.18

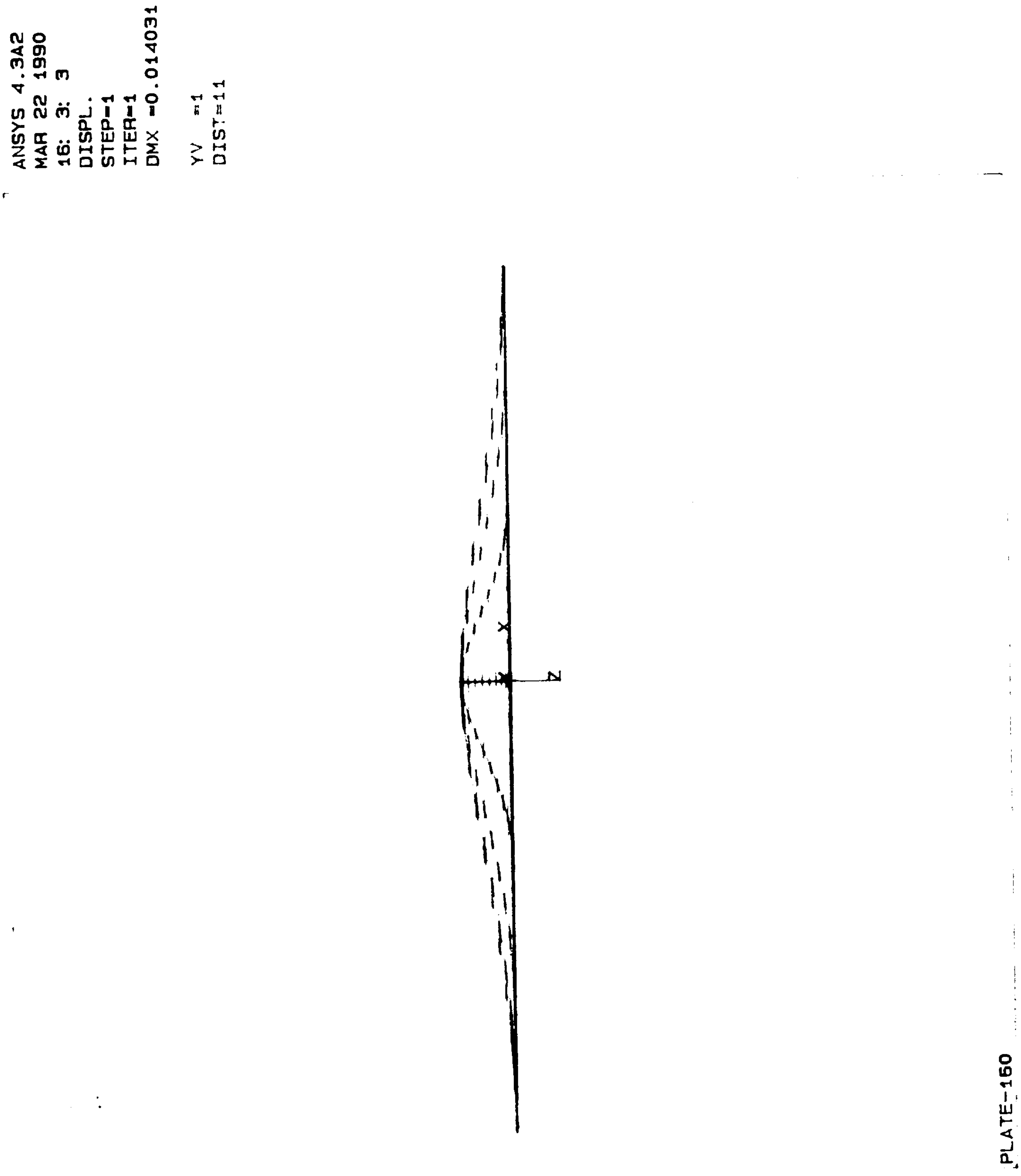

ANSYS 4.3A2
MAR 22 1990
16: 3: 3
DISPL.
STEP=1
ITER=1
DMX =0.014031
YV =1
DIST=11
X
Z
PLATE-160

FIGURE - 3.5.19

3.5.3.4 FOUR BEAM SUPPORT

3.5.3.4.1 PURPOSE

The purpose for this model was to insure that the beam elements could be mated with the quadrilateral shell elements. For our model we required that the microgravity combustion and IPPE experiments be represented by beams connected to a mass element that would have the mass of the experiment. The beams we used had a zero density and an infinite stiffness or modulus of elasticity. These beams would then not deflect under loading but would create a reactionary moment at the end where it was secured. They would not contribute to the weight of the experiment either. Our idea was that if the experiments would be secured to the can by four bolts and if little deflection occurred in the experiment, then all the forces would be directly transmitted to the plate and shelf.

3.5.3.4.2 NODAL CONSTRUCTION

This model was created by utilizing the 160 element plate and placing a node (node 162) ten inches directly above the center of the plate.

3.5.3.4.3 ELEMENT CONSTRUCTION

The elements of the model were also the same as those for the 160 element plate model with two exceptions. The first is that a mass element was place at node 162, with a mass value of 10 lbs. The second difference is that infinitely stiff, massless beams were used to secure the mass element to the plate. Four beams were used. Each one was attached to the mass element and then attached to nodes five inches from the center, at nodes 45, 135, 225, and 315 degrees respectively. The plot of the mass/beam structure is shown in figure 3.5.20 and the plot with the plate attached to this structure is shown in figure 3.5.21.

3.5.3.4.4 BOUNDARY CONSTRAINTS

The model was constrained in six directions, ux, uy, ux, rotx, roty, rotz, at each node on the edge of the plate. These constraints can be viewed on the element plot.

3.5.3.4.5 APPLYING FOCES

After constraining the model at the edges, it was accelerated twelve g's in the x direction. This was to cause a deflection of the mass element resulting in moments at the plate.

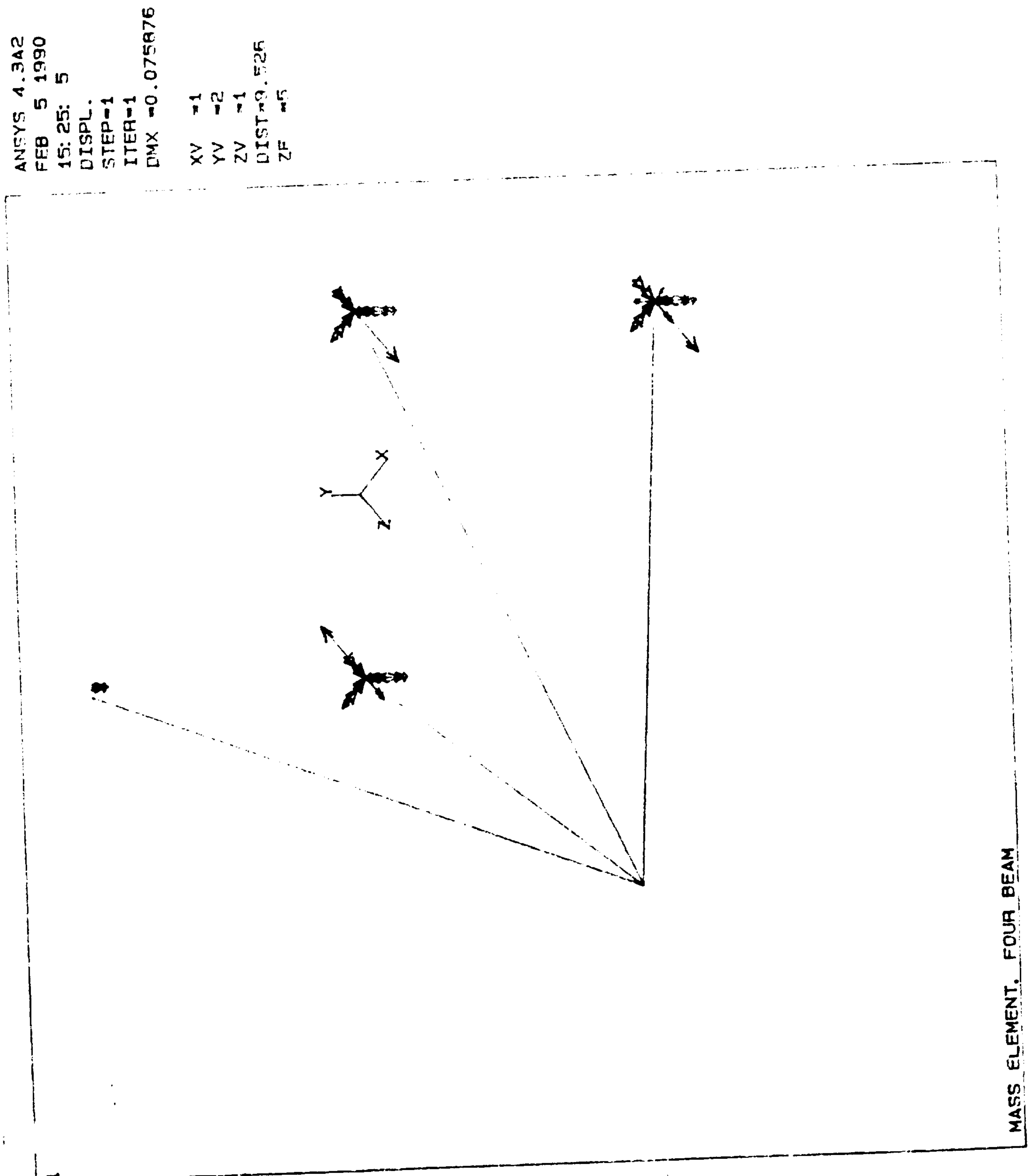

ANSYS 4.3A2
FEB 5 1990
15:25: 5
DISPL.
STEP=1
ITER=1
DMX =0.075876
XV =1
YV =2
ZV =1
ZF =5
X
Y
Z
MASS ELEMENT, FOUR BEAM

FIGURE - 3.5.20

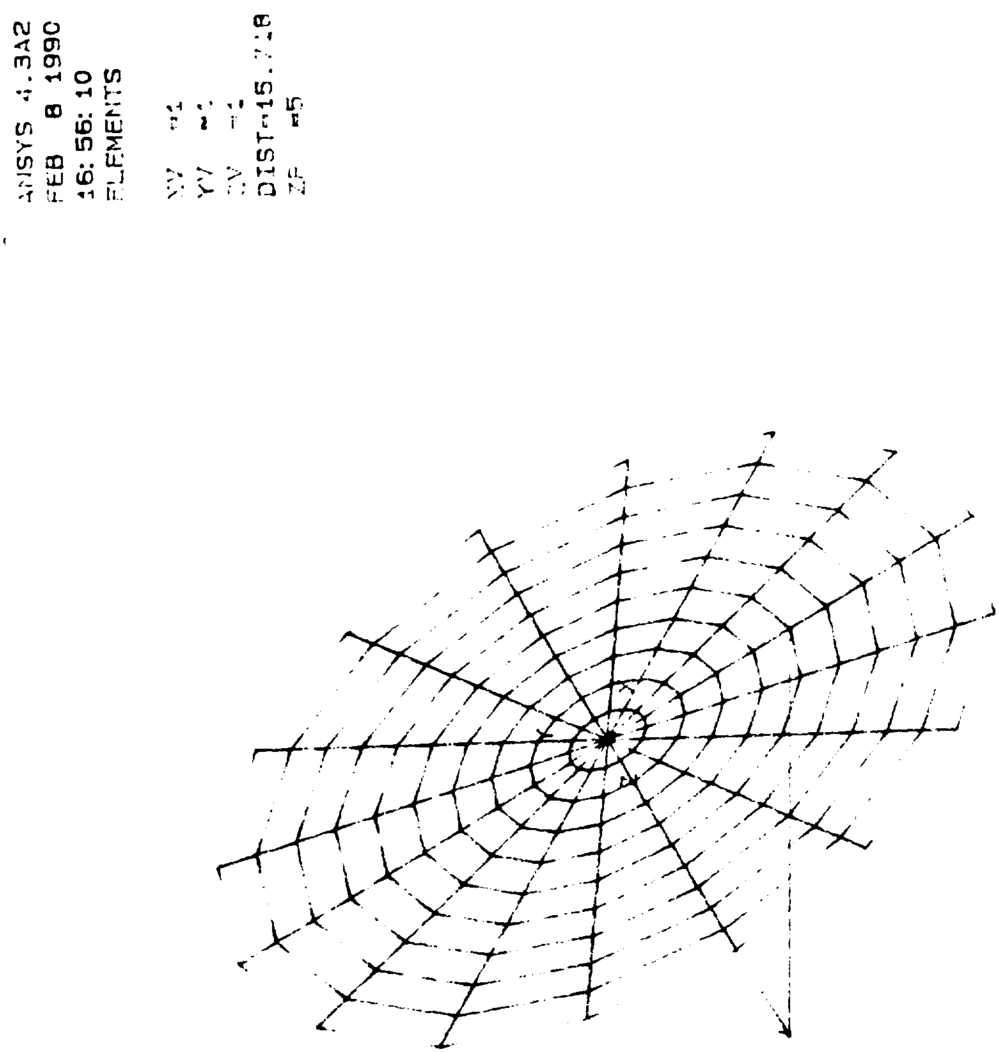


PLATE-160

FIGURE - 3.5.21

ORIGINAL PAGE IS
OF POOR QUALITY

3.5.3.4.6 PREP7 COMMANDS

These are the commands necessary to generate the plate/mass/beam model.

```
kan,0                                   STATIC ANALYSIS

et,1,63                                 QUADRILATERAL SHELL
r,1,.25,.25,.25,.25                     REAL CONSTANTS
ex,1,1e7
ey,1,1e7                                MATERIAL PROPERTIES
nuxy,1,.3                               FOR ALLUMINUM
dens,1,.098

et,2,4                                  3-D ELASTIC BEAM
r,2,.01,8.33e-10,8.33e-10               REAL CONSTANTS
ex,2,1e11                               MATERIAL PROPERTIES
dens,2,.0001

et,3,21                                 MASS ELEMENT
r,3,10                                  REAL CONSTANTS

csys,1                                  CYLINDRICAL COORDINATES

                                        NODE GENERATION
n,1
n,11,10
fill
ngen,16,10,2,11,1,0,22.5

n,162,0,0,10

                                        ELEMENT GENERATION
                                         - circular plate
type,1
real,1
mat,1
e,1,2,12,12
e,1,12,22,22
e,1,22,32,32
e,1,32,42,42
e,1,42,52,52
e,1,52,62,62
e,1,62,72,72
e,1,72,82,82
e,1,82,92,92
e,1,92,102,102
e,1,102,112,112
e,1,112,122,122
e,1,122,132,132
e,1,132,142,142
e,1,142,152,152
```

```
e,1,152,2,2
e,2,3,13,12
egen,9,1,17,25,1
egen,15,10,17,151,1
e,152,153,3,2
egen,9,1,152,160,1
                                  - mass element
type,3
real,3
e,162
                                  - massless beams
type,2
real,2
mat,2
e,162,26
e,162,146
e,162,66
e,162,106
                                  BOUNDARY CONDITIONS

d,11,all
d,21,all
d,31,all
d,41,all
d,51,all
d,61,all
d,71,all
d,81,all
d,91,all
d,101,all
d,111,all
d,121,all
d,131,all
d,141,all
d,151,all
d,161,all
                                  APPLIED FORCES
acel,4636.8
                                  GRAPHIC COMMANDS
                                   - title
/title,PLATE-160                   - plot boundary conditions
/pbc,all,1
iter,1,1
```

3.5.3.4.7 RESULTS

There were three models run in this experiment. The first was a mass/beam set up accelerated in the x direction with the translational and rotational displacements fixed at the end of the beams. The second was a plate accelerated 12 g's in the x direction with all translational and rotational displacements fixed at the outer edge. The third was a plate, with the mass/beam setup attached to it, accelerated 12 g's in the x direction with all displacements fixed at the outer edge. From the ANSYS output of the first system it can be seen that reactionary forces result at ends of the beams when the mass/beam setup is accelerated. Likewise it is seen that when the plate is accelerated, stresses result. These stresses are relatively low throughout the plate and distributed evenly acrossed it. When the mass/beam setup is attached the resultant stresses in the plate are increased and and are highest in areas directly around the nodes where the beams attach. (see tables 3.5.5 to 3.5.7)

TABLE 3.5.5

REACTION FORCES OF MASS/BEAM

NODE	FX	FY	FZ	MX	MY	MZ
2	1.16E05	8.47E04	-2.60E05	3.39E04	2.36E05	6.32E04
3	1.16E05	-8.47E04	2.60E05	-3.39E04	2.36E05	6.32E04
4	1.16E05	8.47E04	2.60E05	3.39E04	2.36E05	-6.32E04
5	1.16E05	-8.47E04	-2.60E05	-3.39E04	2.36E05	-6.32E04

TABLE 3.5.6

STRESSES IN PLATE*

NODE	SX	SY	SZ	SI
26	3.376	0.539	0.0000	3.513
66	-2.562	-1.353	0.0000	3.513
106	-3.376	-0.539	0.0000	3.514
146	2.562	1.353	0.0000	3.513

*These are the stresses at nodes where the beams will be attached.

TABLE 3.5.7

STRESSES IN PLATE WITH MASS/BEAM ATTACHED

NODE	SX	SY	SZ	SI
26	4254	-4062	0.0000	0.2499E05
66	-3159	2967	0.0000	0.2499E05
106	-4254	4062	0.0000	0.2499E05
146	3159	-2967	0.0000	0.2499E05

3.5.3.5 GASCAN MODEL I

3.5.3.5.1 PURPOSE

In this analysis we were interested in finding trouble spots in the canister. At this time, the overall shape of GAScan II and mounting brackets was finalized after design changes to the previous MQP. GAScan II consisted of only the two plates, the flanges, the shelf and the center post, the bumpers had not yet been designed. This was also to give us some idea of where to focus for future ANSYS analyses.

3.5.3.5.2 NODAL CONSTRUCTION

Our first model consisted of one hundred and fifty two nodes. For this model we were interested in getting a rough idea of where the max stresses occurred. The first thing was the determination of where the key nodes had to be placed. These nodes had to be placed so forces could be applied where they would occur on GAScan II. The first node placed was node one and would be at the center of the bottom plate. Five nodes extended out from one radially over a distance of 9.875 inches. The rest of the bottom plate was created by replicating the five in a circle 15 degrees apart. The middle plate was created from copying the center node of the bottom plate and making it the center of the middle plate (node #50). Key nodes on the middle plate occurred where the micro-gravity canisters would be located. The locations of these nodes were R=5.5549 inches and theta=+22.5 degrees from flanges 1 and 3, and theta = -22.5 degrees from flanges 1 and 2 (nodes #56, #64, #72, #80). The middle plate was then generated by using these as references and generating radially from the center through these points and then around the plate in sections between the points. The center post was then created by placing three nodes in between the center nodes of the two plates. The remainder of the center post located above the middle plate was then created and also served as a base for the flanges. The flanges were created and a shelf in between two of them. A node was selected in the middle of the shelf for the IPPE (node #146). The last nodes were six nodes placed at the top of the flanges to represent mounting brackets. (see figure 3.5.22 though figure 3.5.26)

3.5.3.5.3 ELEMENT CONSTRUCTION

The element construction consisted of selecting appropriate elements and connecting nodes with these elements. The elements chosen were the quadrilateral shell and the 3-D elastic beam. The generation of the elements consisted of connecting nodes. For the quadrilateral shell, nodes are connected in a counterclockwise direction (I,J,K,L). For the 3-D elastic beam, elements are created between two nodes (I,J). The shell elements were used for the plates, flanges and shelf. The 3-D beam element was used to model the center post.(see figure 3.5.27)

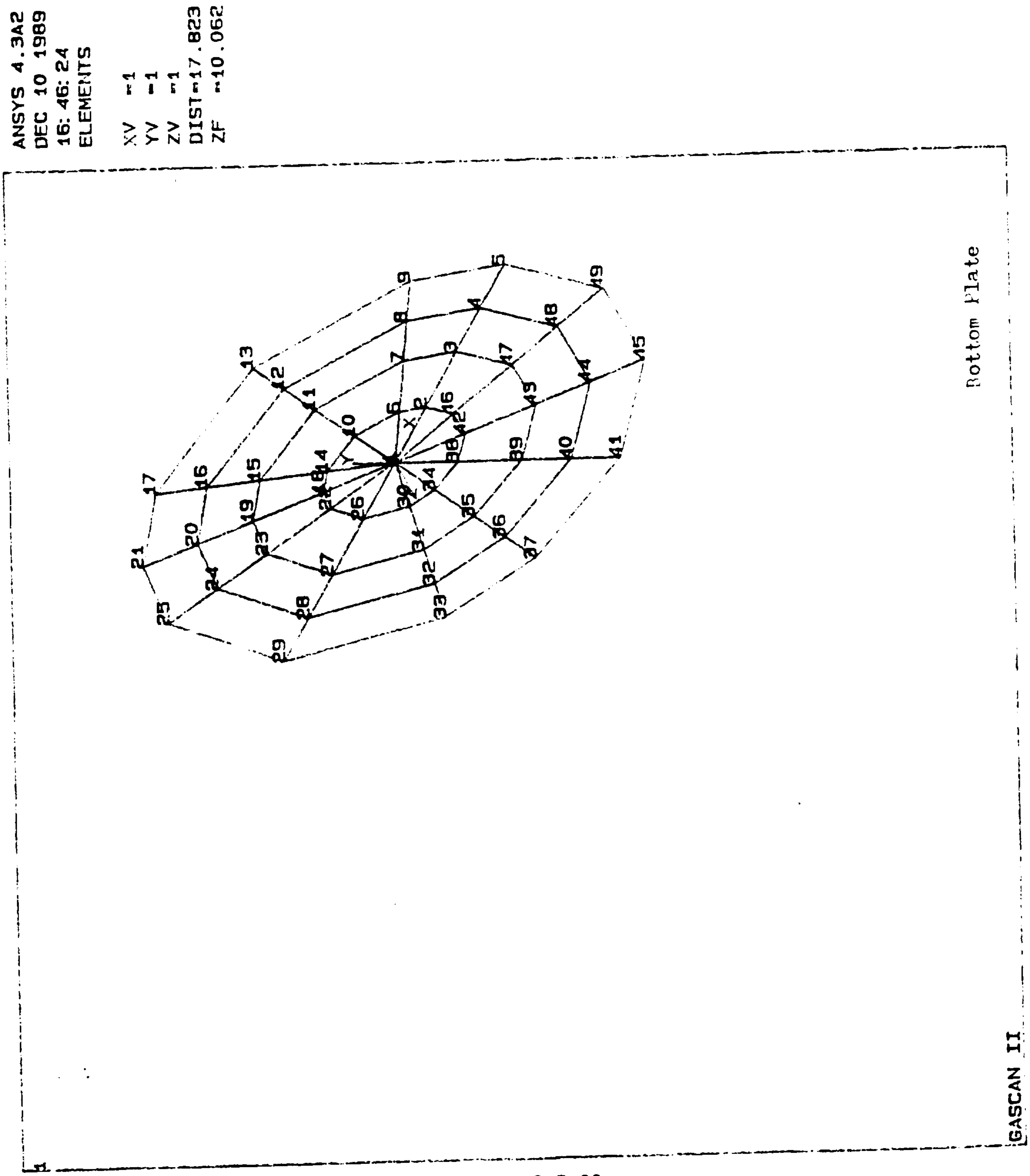

ANSYS 4.3A2
DEC 10 1989
16:46:24
ELEMENTS
XV =1
YV =1
ZV =1
DIST=17.823
ZF =10.062
Bottom Plate
GASCAN II

FIGURE - 3.5.22

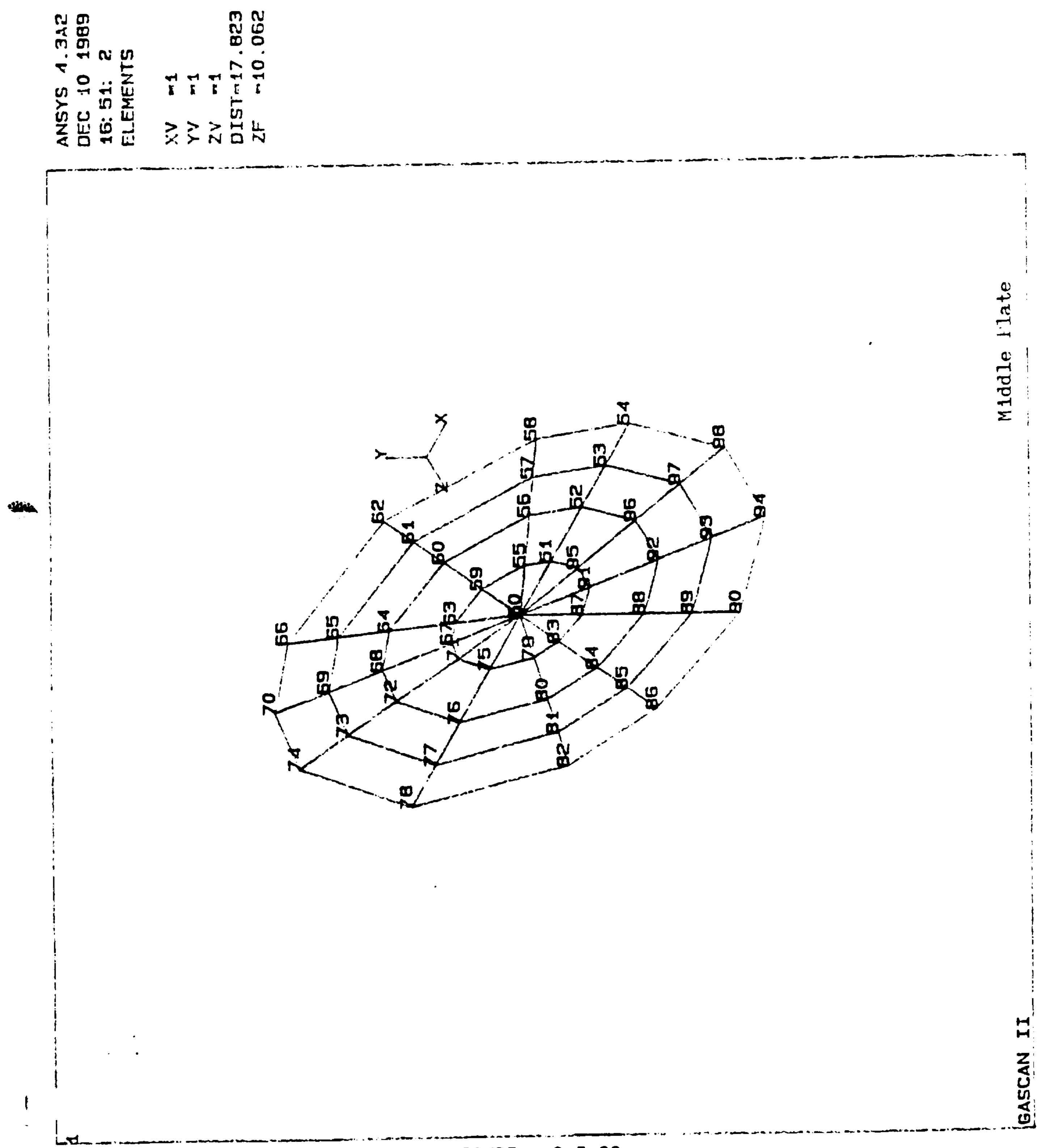

ANSYS 4.3A2
DEC 10 1989
16:51: 2
ELEMENTS
XV =1
YV =1
ZV =1
DIST=17.823
ZF =10.062
Middle Plate
GASCAN II

FIGURE - 3.5.23

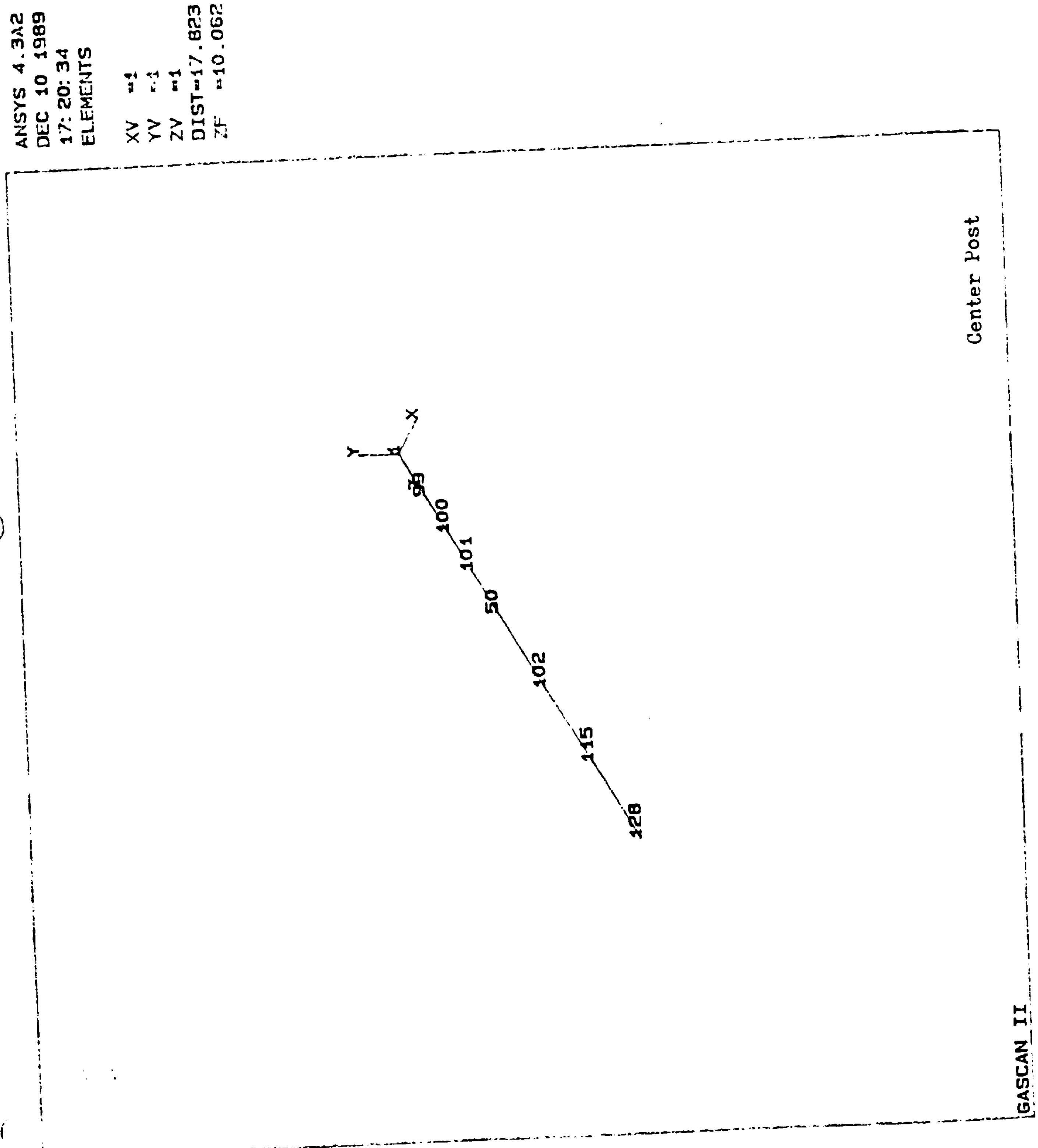

ANSYS 4.3A2
DEC 10 1989
17:20:34
ELEMENTS
XV =1
YV =1
ZV =1
DIST=17.823
ZF =10.062
Center Post
Y
X
100
101
50
102
115
128
GASCAN II

FIGURE - 3.5.24

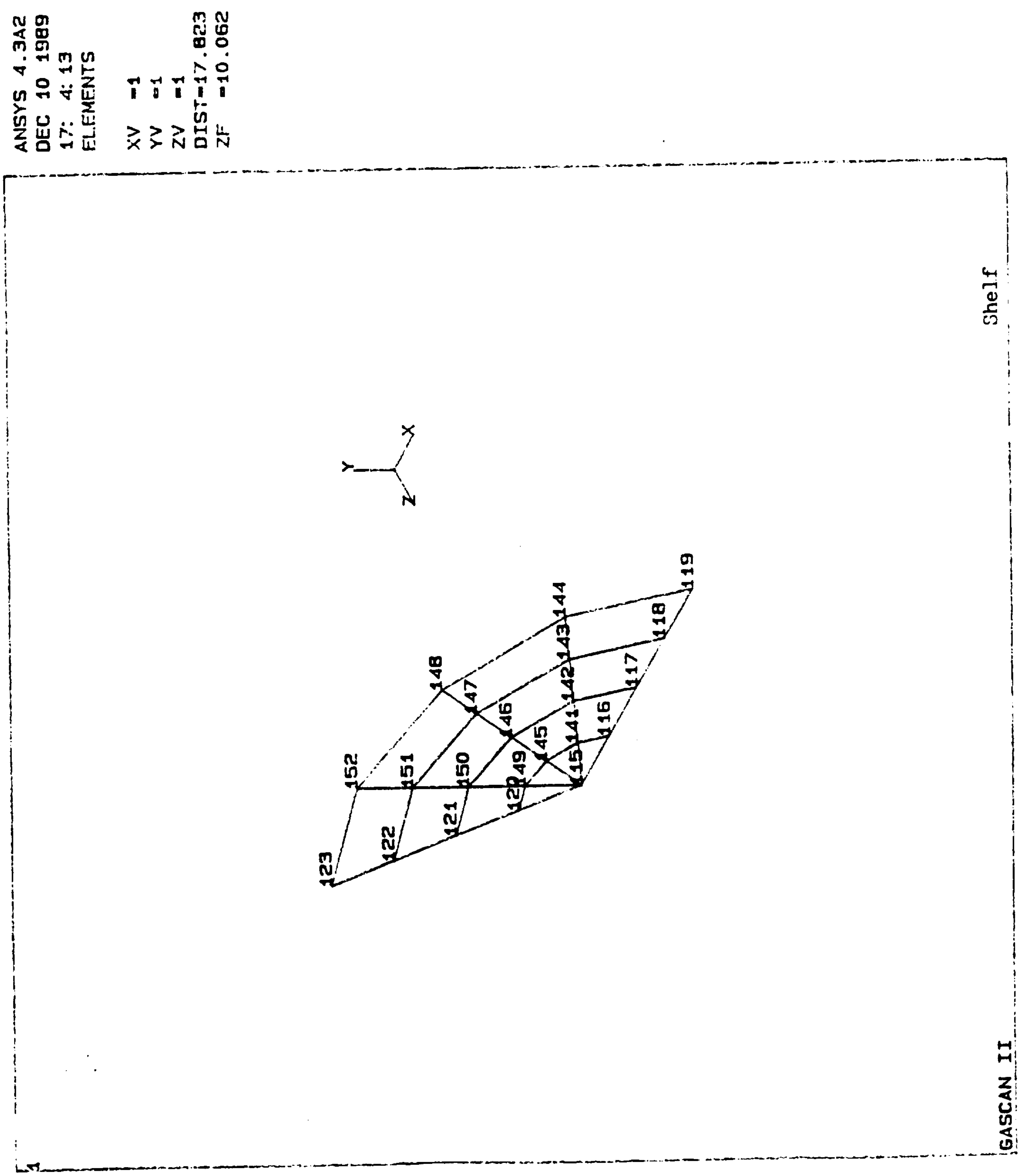

ANSYS 4.3A2
DEC 10 1989
17: 4:13
ELEMENTS
XV =1
YV =1
ZV =1
DIST=17.823
ZF =10.062
Shelf
GASCAN II

FIGURE - 3.5.25

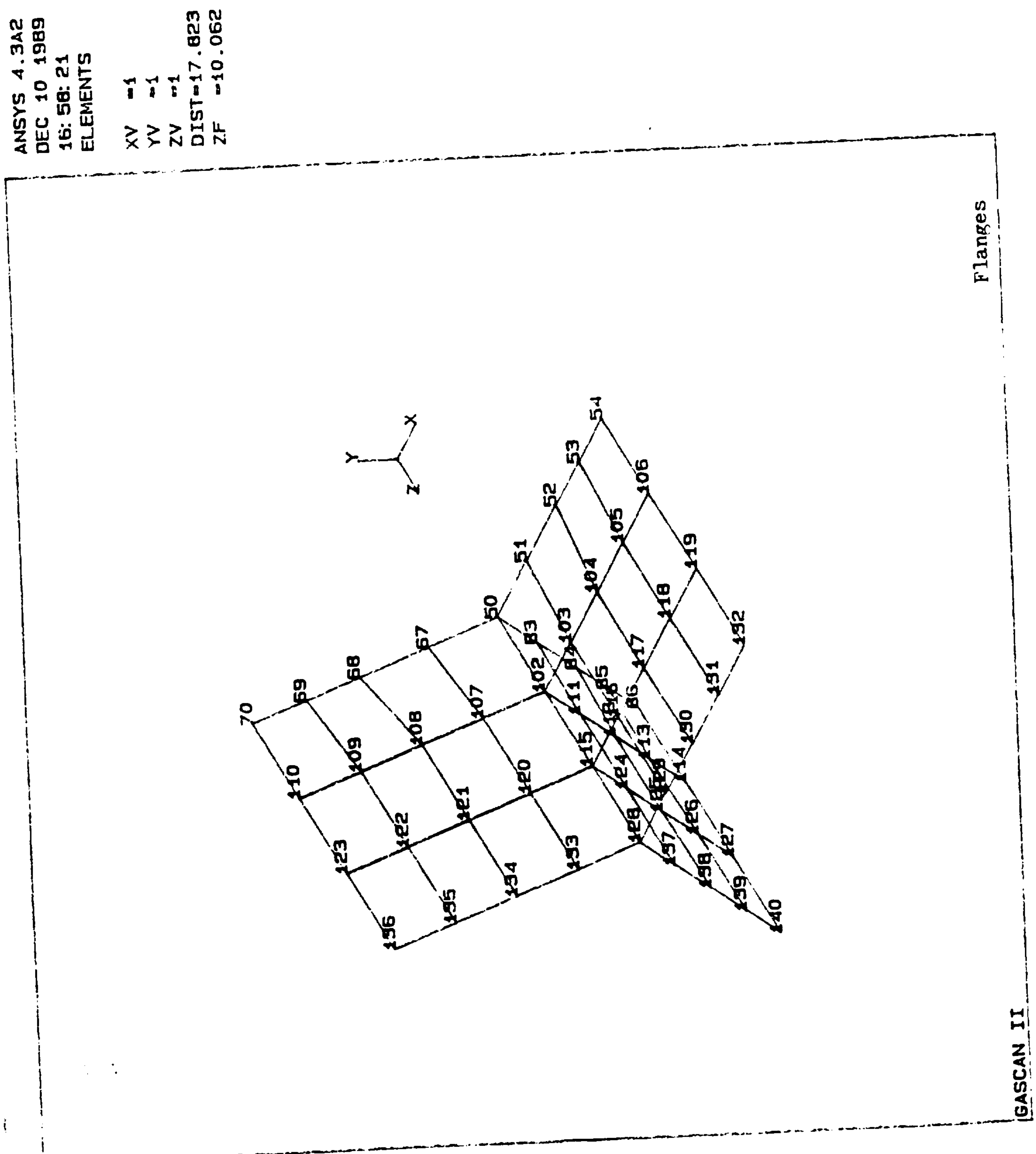

ANSYS 4.3A2
DEC 10 1989
16:58:21
ELEMENTS
XV =1
YV =1
ZV =1
DIST=17.823
ZF =10.062
Flanges
GASCAN II

FIGURE - 3.5.26

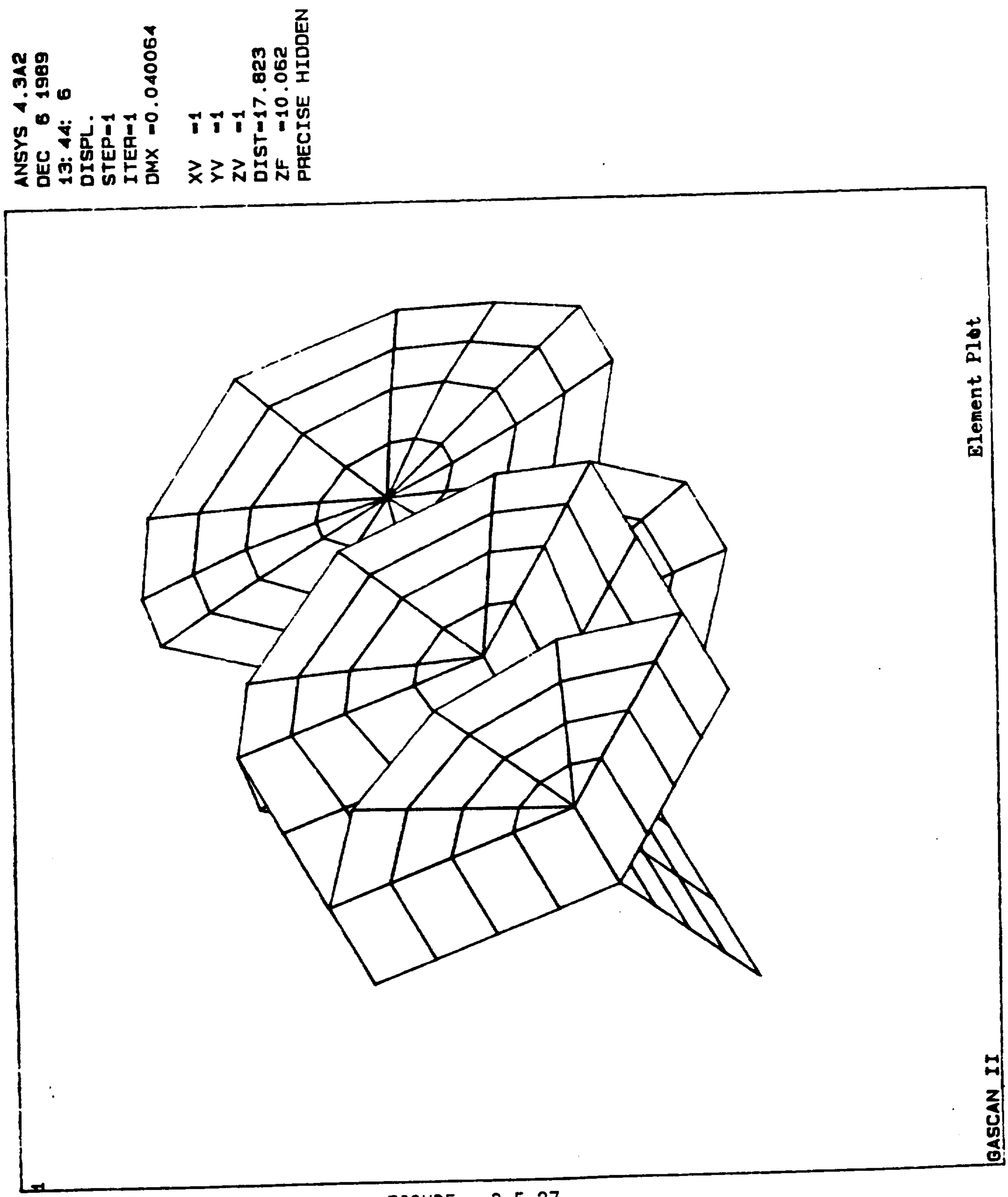

ANSYS 4.3A2
DEC 6 1989
13:44: 6
DISPL.
STEP=1
ITER=1
DMX =0.040064
XV =1
YV =1
ZV =1
DIST=17.823
ZF =10.062
PRECISE HIDDEN
Element Plot
GASCAN II

FIGURE - 3.5.27

3.5.3.5.4 BOUNDARY CONSTRAINTS

The next phase was the defining of boundary conditions. Assumptions had to be made insure accurate results. The first assumptions made was that the mounting brackets were stiff and would not break under any loading, this enabled the nodes at these points to be fixed so that there was no rotational or translational displacements. The second assumption made was that the bumpers would fix GAScan II into position. This enabled those nodes to also be fixed against translational and rotational displacements.

3.5.3.5.5 APPLYING FORCES

The fourth phase was applying forces at each node where there was an experiment. The mass of each experiment can be converted to a force by accelerating it; in this case and acceleration of 12 g's in the z-direction and 6 g's in the x,y-direction. After the force was calculated for each experiment they were applied to their corresponding nodes. Figure 3.5.28 shows all these specified forces along with the boundary constraints.

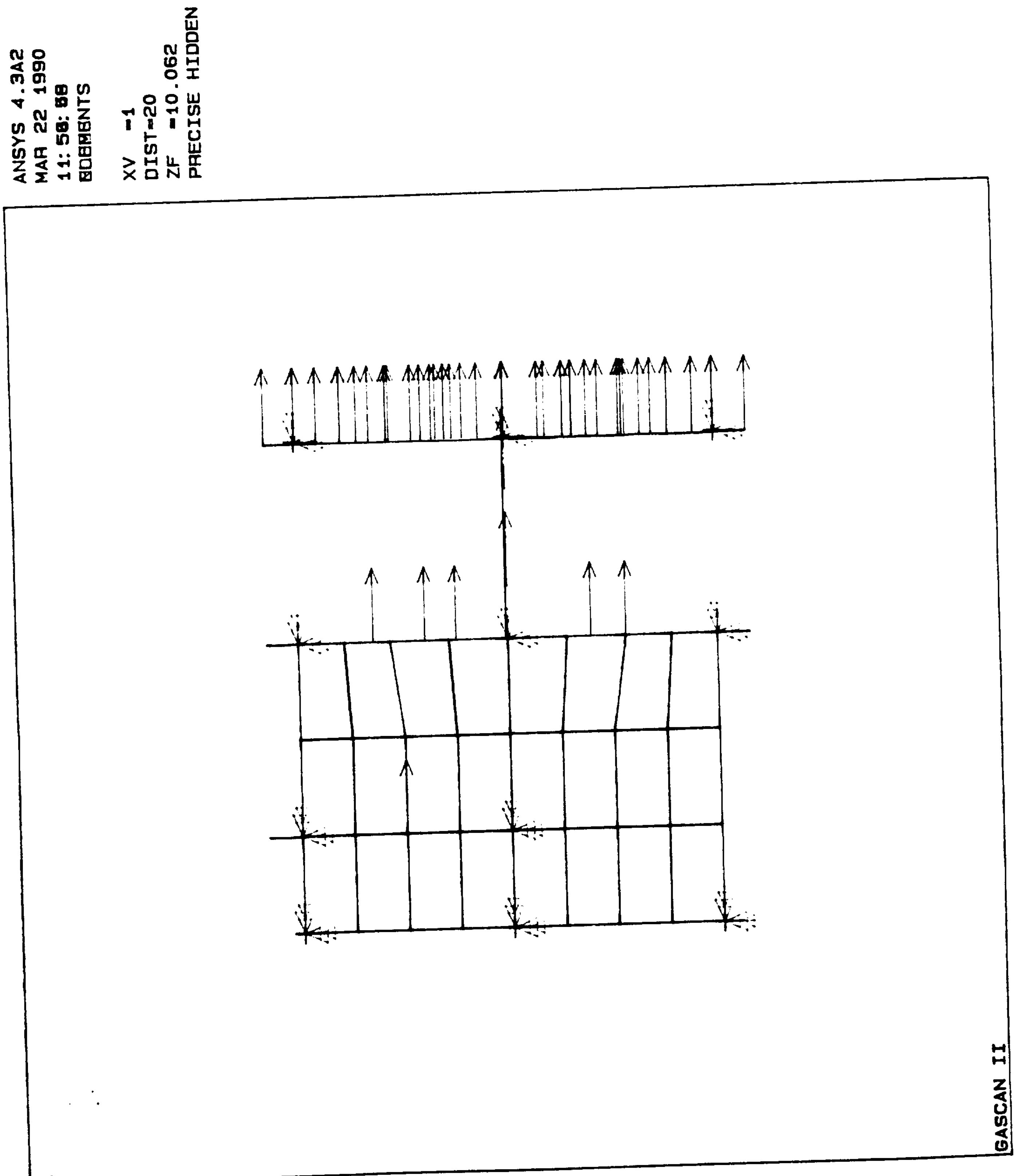

ANSYS 4.3A2
MAR 22 1990
XV =1
DIST=20
ZF =10.062
PRECISE HIDDEN
GASCAN II

FIGURE - 3.5.28

3.5.3.5.6 PREP7 INPUT

The following commands are all the commands needed to run the ANSYS model.

```
kan,0                                  STATIC ANALYSIS

et,1,63                                ELEMENT TYPE 1 = QUADRILATERAL SHELL
r,1,.25,.25,.25,.2                     REAL CONSTANTS
ex,1,1e7                               MATERIAL PROPERTIES
ey,1,1e7
nuxy,1,.3
dens,1,.00026

et,2,4                                 ELEMENT TYPE 2 = 3D-ELASTIC BEAM
r,2,1.3745,.00307,.00307               REAL CONSTANTS
ex,2,1e7                               MATERIAL PROPERTIES
nuxy,,.3
dens,,.0006

csys,1                                 CYLINDRICAL COORDINATE SYSTEM

                                       NODE GENERATION
                                        - bottom plate
n,1
n,3,5.5549
fill
n,5,9.875
fill
ngen,2,4,2,5,1,0,22.5
ngen,3,4,6,9,1,0,37.5
ngen,3,4,14,17,1,0,22.5
ngen,3,4,22,25,1,0,37.5
ngen,2,4,30,33,1,0,22.5
ngen,4,4,34,37,1,0,30

ngen,2,49,1,49,1,0,0,8.25               - middle plate

                                        - post between plates
n,99,0,0,2.125
n,100,0,0,4.125
n,101,0,0,6.125

n,102,0,0,12.1875                        - flanges
n,106,9.875,0,12.1875
fill
ngen,3,4,103,106,1,0,120
ngen,2,13,102,114,1,0,0,3.9375
ngen,2,13,115,127,1,0,0,4

n,141,2.4688,30,16.125                   - shelf
```

```
n,144,9.875,30,16.125
fill
ngen,3,4,141,144,1,0,30
```

SHELL ELEMENT GENERATION
- bottom plate

```
type,1
mat,1
real,1
e,2,6,1,1
e,6,10,1,1
e,10,14,1,1
e,14,18,1,1
e,18,22,1,1
e,22,26,1,1
e,26,30,1,1
e,30,34,1,1
e,34,38,1,1
e,38,42,1,1
e,42,46,1,1
e,46,2,1,1
e,2,3,7,6
egen,3,1,13,15,1
egen,11,4,13,45,1
e,46,47,3,2
egen,3,1,46,48,1
```

- middle plate

```
egen,2,49,1,96,1
```

- flanges

```
e,50,51,103,102
egen,4,1,97,100,1
e,50,67,107,102
e,67,68,108,107
egen,3,1,102,104
e,50,83,111,102
e,83,84,112,111
egen,3,1,106,108,1
e,102,103,116,115
egen,4,1,109,112,1
e,102,107,120,115
e,107,108,121,120
egen,3,1,114,116,1
e,102,111,124,115
e,111,112,125,124
egen,3,1,118,120,1
e,115,116,129,128
egen,4,1,121,124,1
e,115,120,133,128
e,120,121,134,133
egen,3,1,126,128,1
e,115,124,137,128
e,124,125,138,137
egen,3,1,130,132,1
```

- shelf

```
e,116,141,115,115
e,116,117,142,141
egen,3,1,134,136,1
```

```
e,141,145,115,115
e,141,142,146,145
egen,3,1,138,140,1
e,145,149,115,115
e,145,146,150,149
egen,3,1,142,144,1
e,149,120,115
e,149,150,121,120
egen,3,1,146,148,1
                                   CENTER POST GENERATION

type,2
mat,2
real,2
e,1,99
e,99,100
e,100,101
e,101,50
e,50,102
e,102,115
e,115,128
                                   BOUNDARY CONDITIONS
d,132,all
d,136,all
d,140,all
d,119,all
d,123,all
d,140,all
d,54,all
d,70,all
d,86,all
d,5,all
d,21,all
d,37,all
                                   APPLIED FORCES
nrsel,node,1,49
f,all,fx,10.857
nall
f,99,fx,300
f,101,fx,300
f,56,fx,90
f,64,fx,90
f,72,fx,90
f,80,fx,90
f,92,fx,60
f,146,fx,24

/pbc,all,1                         PRINT BOUNDARY CONDITIONS
/title,GASCan II                   TITLE
eplo                               PRODUCE ELEMENT PLOT
```

3.5.3.5.7 RESULTS

GAScan II model was accelerated in 6 directions, once along the positive and negative of each axis. It was found that the results for accelerating along an axis, in the positive direction, was equal to accelerating along that axis in the negative direction. (except the component of stress was the negative of that for the original axis). Because of this result all future analyses will be only in the +x,y and +z-directions. The forces were applied in only the + x,y and z axes. A summary of results are as follows. The highest stress concentrations occurred at the mounting bracket and bumpers.

TABLE 3.5.7 MODEL I - RESULTS

FORCES	MAX DEFLECTION	MAX COMP STRESS(psi)	MAX PRIN. STRESS(psi)
X-DIR	.041"(node 100)	sx=-423.7(node 5)	si=524.78 (node 21)
Y-DIR	.041"(node 100)	sx=292.8 (node 37)	si=377.5 (node 37)
Z-DIR	.047"(node 45)	sy=573.2 (node140)	si=649 (node 140)

3.5.3.6 GASCAN MODEL II

3.5.3.6.1 PURPOSE

This model resulted from the work of the previous two terms and the CDR with Mitre in January. On completion of the CDR, recommendations were made to consider modeling GAScan II two ways. One way, which will be covered here, is with the battery box underneath the rotational fluid flow experiment. The second way is with the center shaft extended and the battery box mounted above the rotational fluid flow experiment.

3.5.3.6.2 NODAL CONSTRUCTION

This model was a revision of the first. Nodes were placed at the top corner of each flange so that the mounting brackets could be included in the model. This model also included nodes so that the experiments could be represented using beam and mass elements instead of forces. Actual geometries and weights were not obtainable from the experiment groups at the time of running the model. This meant that assumed weights, volumes and centers of gravity had to be used. The determination of these was from group projections as to what they might actually be. The assumed weights, volumes and centers of gravity were kept consistent throughout the analysis for ANSYS and hand calculations to insure accuracy.

The rotational fluid flow experiment was modeled by placing 12 nodes half way between the center plate and the bottom plate and half way between the center shaft and the outside edge of the experiment. The nodes for the battery box were placed half way between the bottom plate and the bottom of where the battery box is located. The nodes for the other experiments were placed at the assumed centroid of the experiment. One node was used for each experiment, reasons why should become clear in the next section. The microgravity combustion chambers nodes were placed seven inches above the center plate and directly above the node on the middle plate that was placed at the center of the microgravity combustion chamber. The IPPE node was placed three inches above the experiment shelf and above the node on the shelf placed at the center of the experiment. These are all the new nodes used in this model. The node numbers are printed on the element plots that are included in the next section.

3.5.3.6.3 ELEMENT CONSTRUCTION

The elements for the plates, flanges and center post are the same as those in the first model. The elements used to model all the experiments were the mass and beam elements. The rotational fluid flow and the battery box had their total mass divided by the total number of nodes used to represent them. That mass was than placed at each node. The masses, at each node, for the rotational fluid flow were then connected to both of its neighbors and the center shaft in two places, at the two bearings, nodes 99 and 101, by infinitely stiff massless beams. The battery box masses were connected to each other in the same manner and then connected to the bottom plate at the twelve nodes on the edge of the plate. Each microgravity combustion chamber and the IPPE was modeled by placing the mass of the canister at the node used to represent it and connecting it to the middle plate with a stiff massless beam. The mounting brackets were modeled with a series of beams. The mounting brackets consisted of five beams that were 0.875 inches thick in the y direction and ranged from 2.32 to 5.875 inches thick in the z direction. The first four beams from the bottom up were .46875 inches long and the fifth beam was .375 inches long. Figure 3.5.29 through 3.5.36 show each piece of GAScan II, in order, from the bottom to the top. This order begins with the battery box elements and ends with the shelf. Figure 3.5.37 shows the total assembly of GAScan II with the battery box on the bottom.

3.5.3.6.4 BOUNDARY CONSTRAINTS

The boundary conditions for the second model are for two cases. The first case is if the bumpers stay fixed and there is no slippage between the bumpers and the wall. The second case is if the bumpers release and they offer no resistance to movement of the can. In the case of no slippage the can will be fixed in all directions at the bumpers and at the mounting brackets. In the case where the can is free to move, the bumpers will be fixed in the x and y directions and free in the z direction and the mounting brackets will be fixed in all directions. Figure 3.5.38 shows these boundary constraints with respect to the nodes.

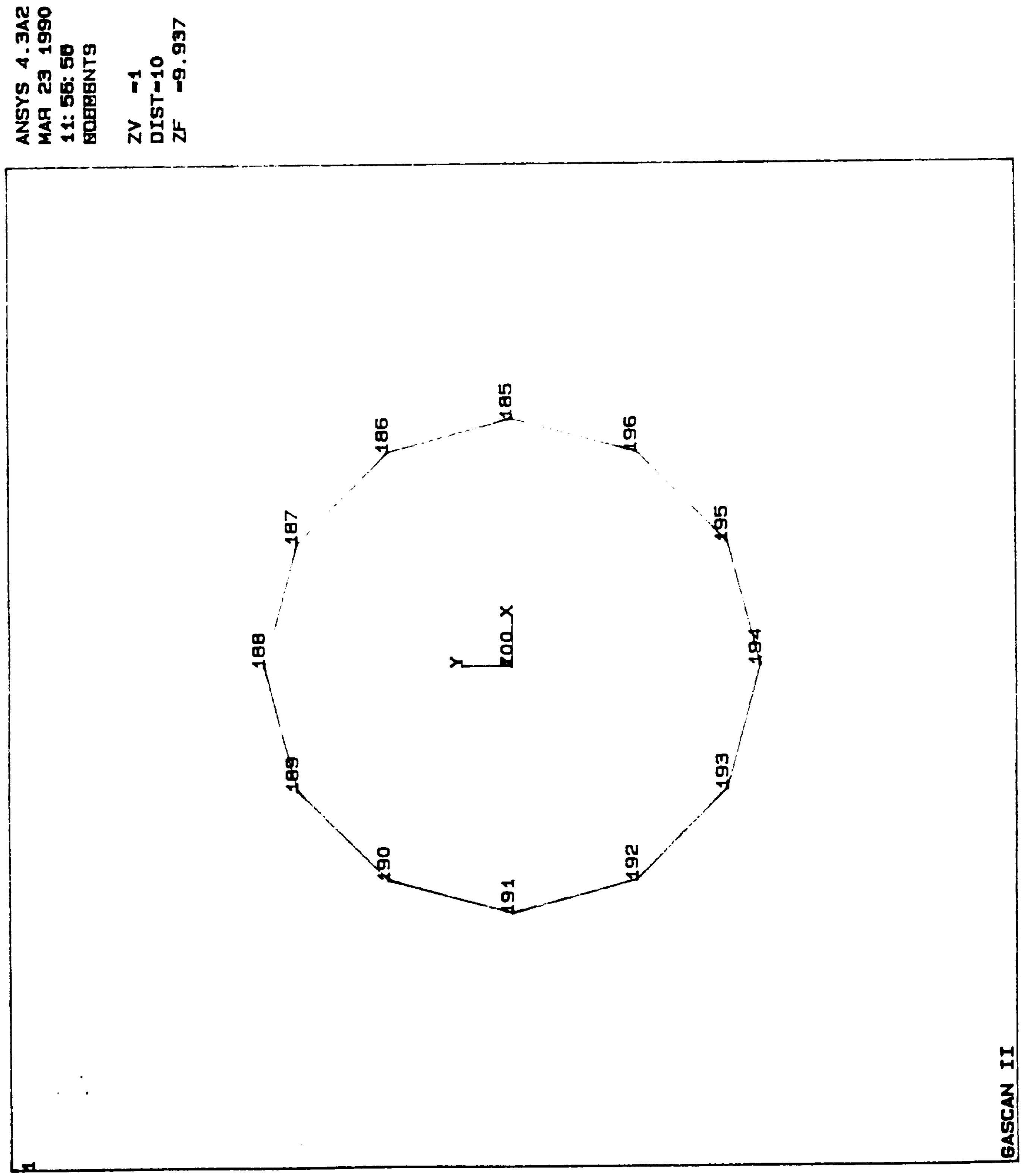

ANSYS 4.3A2
MAR 23 1990
11:56:58
ZV =1
DIST=10
ZF =9.937
185
186
187
188
189
190
191
192
193
194
195
196
Y
X
GASCAN II

FIGURE - 3.5.29

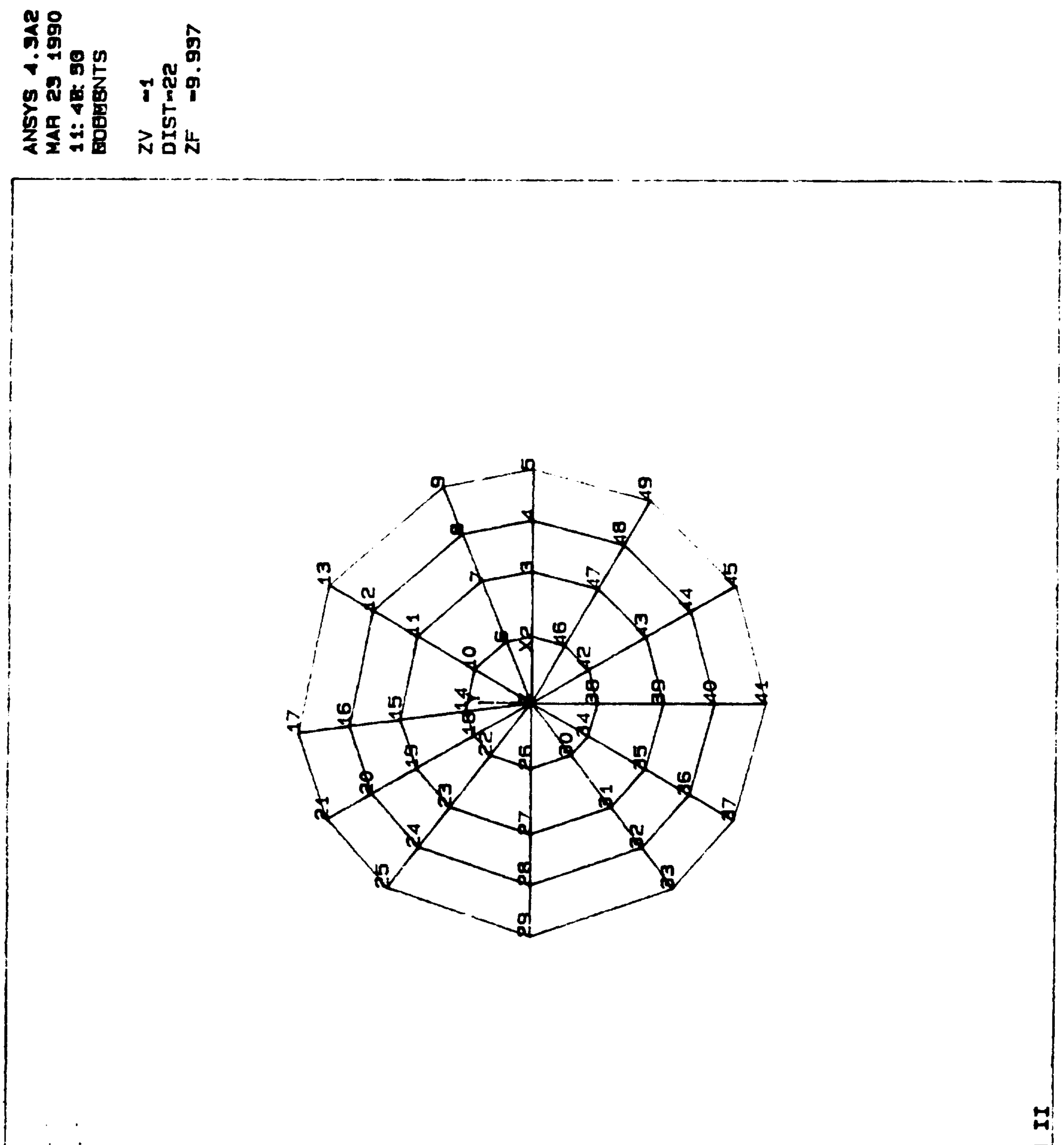


FIGURE - 3.5.30

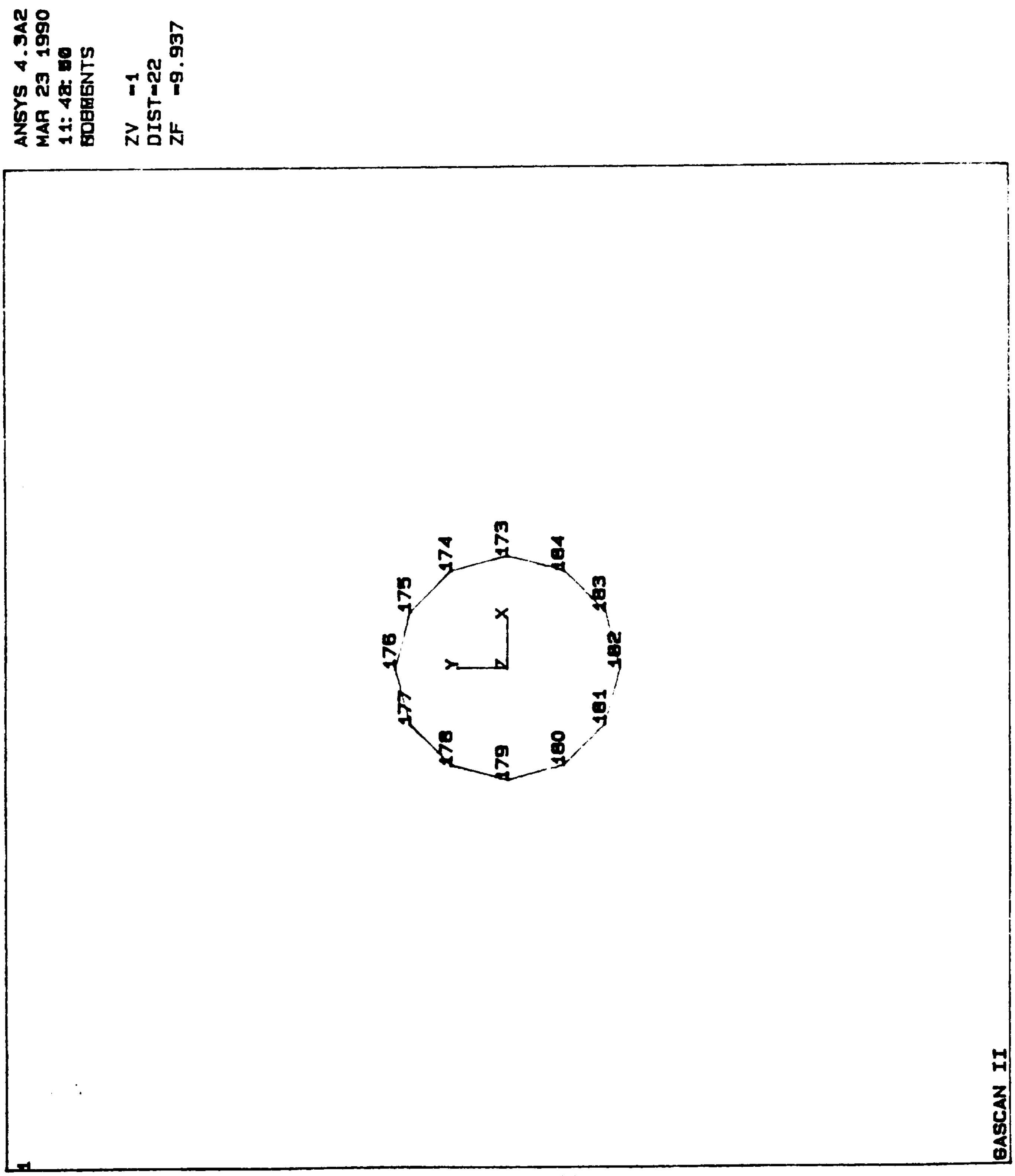

ANSYS 4.3A2
MAR 23 1990
ZV =1
DIST=22
ZF =9.937
173
174
175
176
177
178
179
180
181
182
183
184
X
Y
Z
BASCAN II

FIGURE - 3.5.31

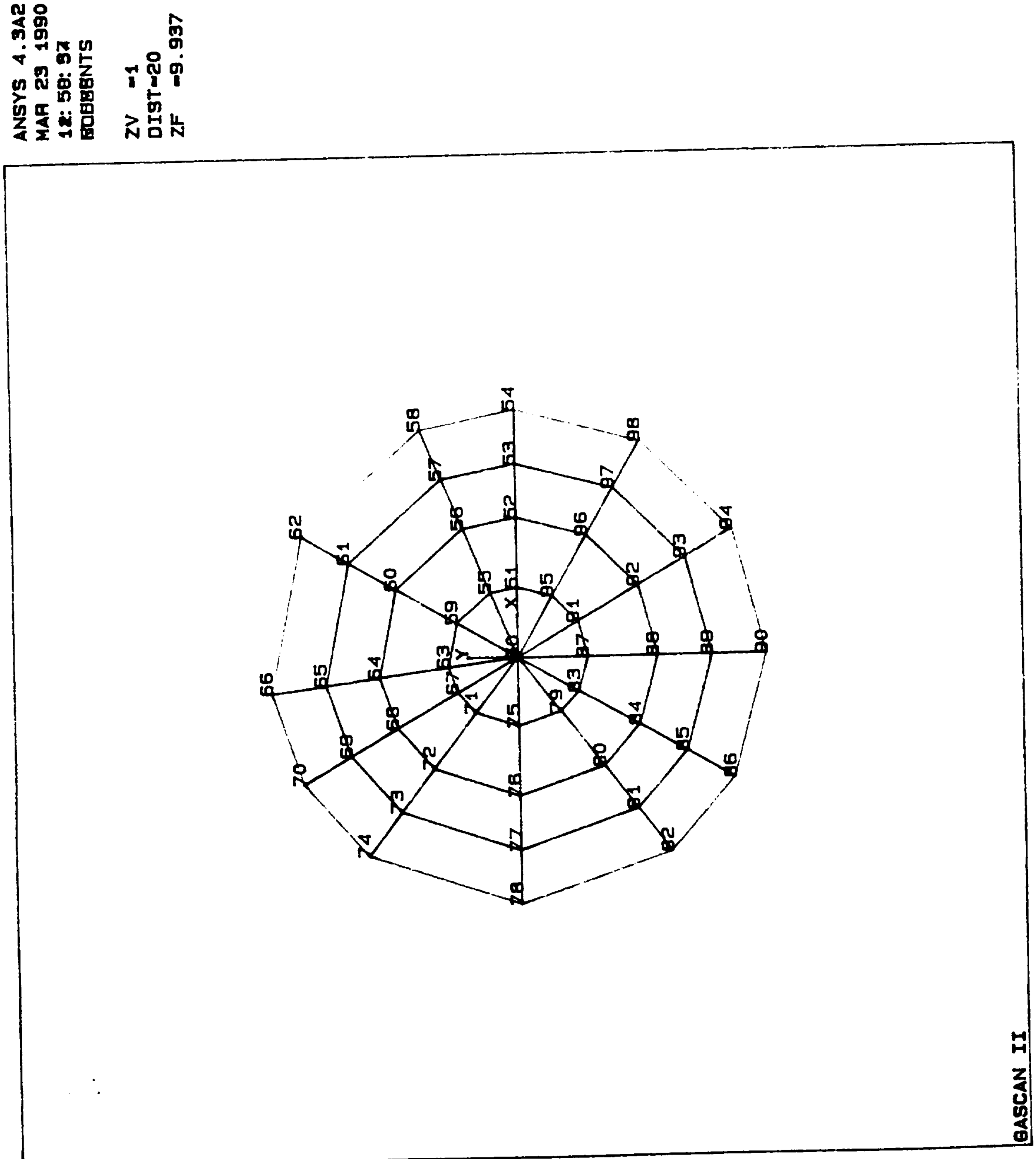


FIGURE - 3.5.32

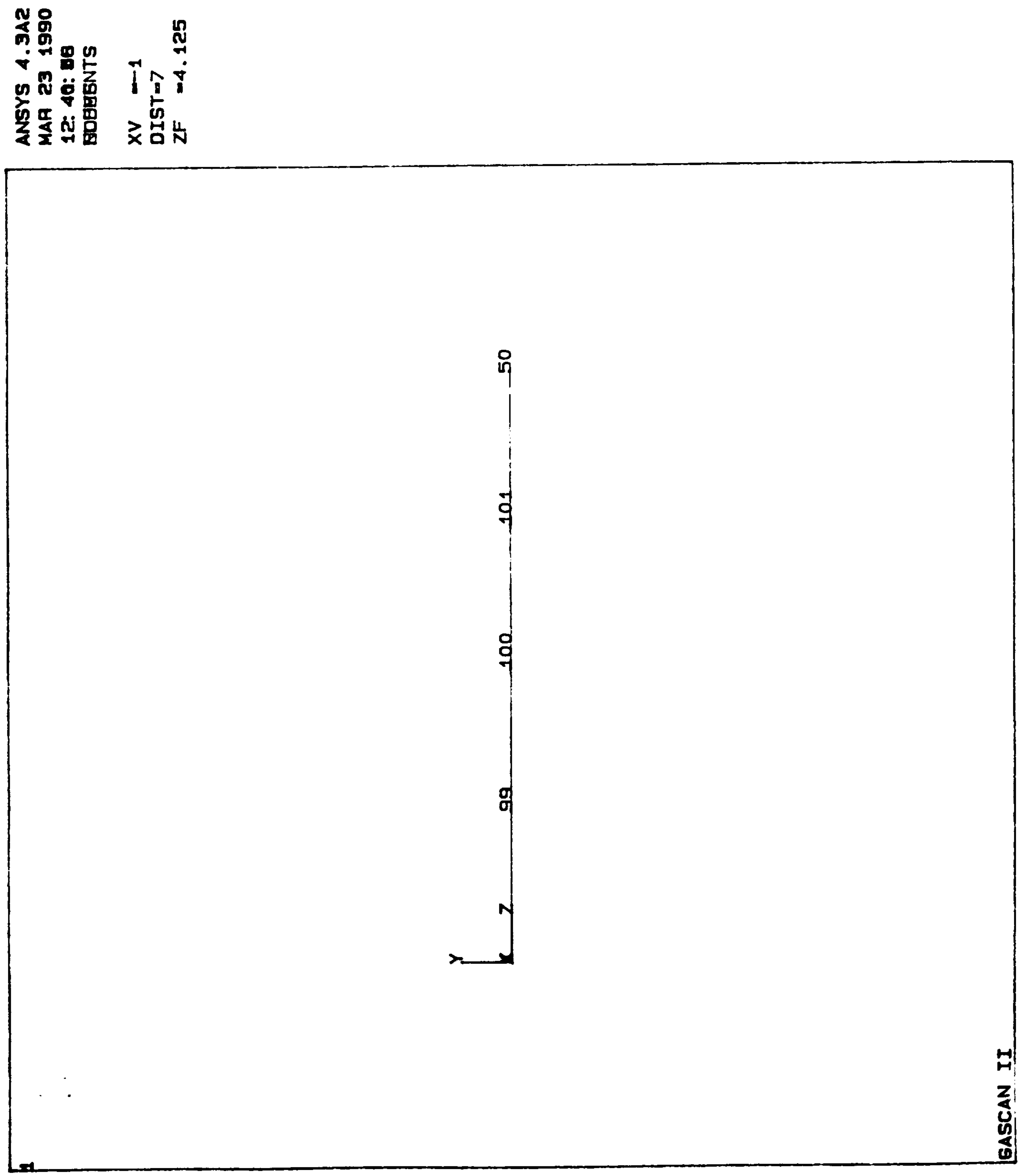

ANSYS 4.3A2
MAR 23 1990
XV =-1
DIST=7
ZF =4.125
50
101
100
99
7
Y
GASCAN II

FIGURE - 3.5.33

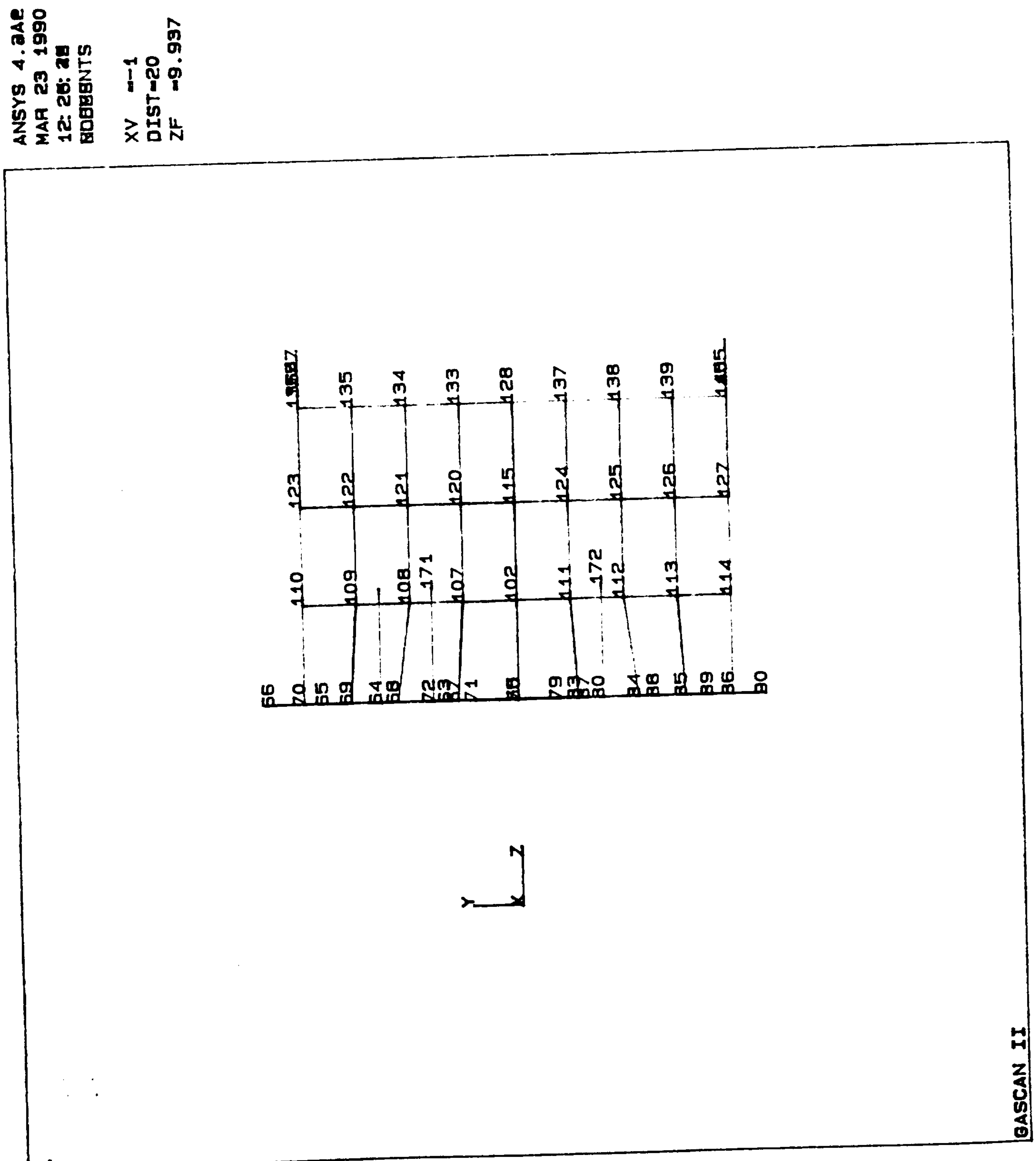
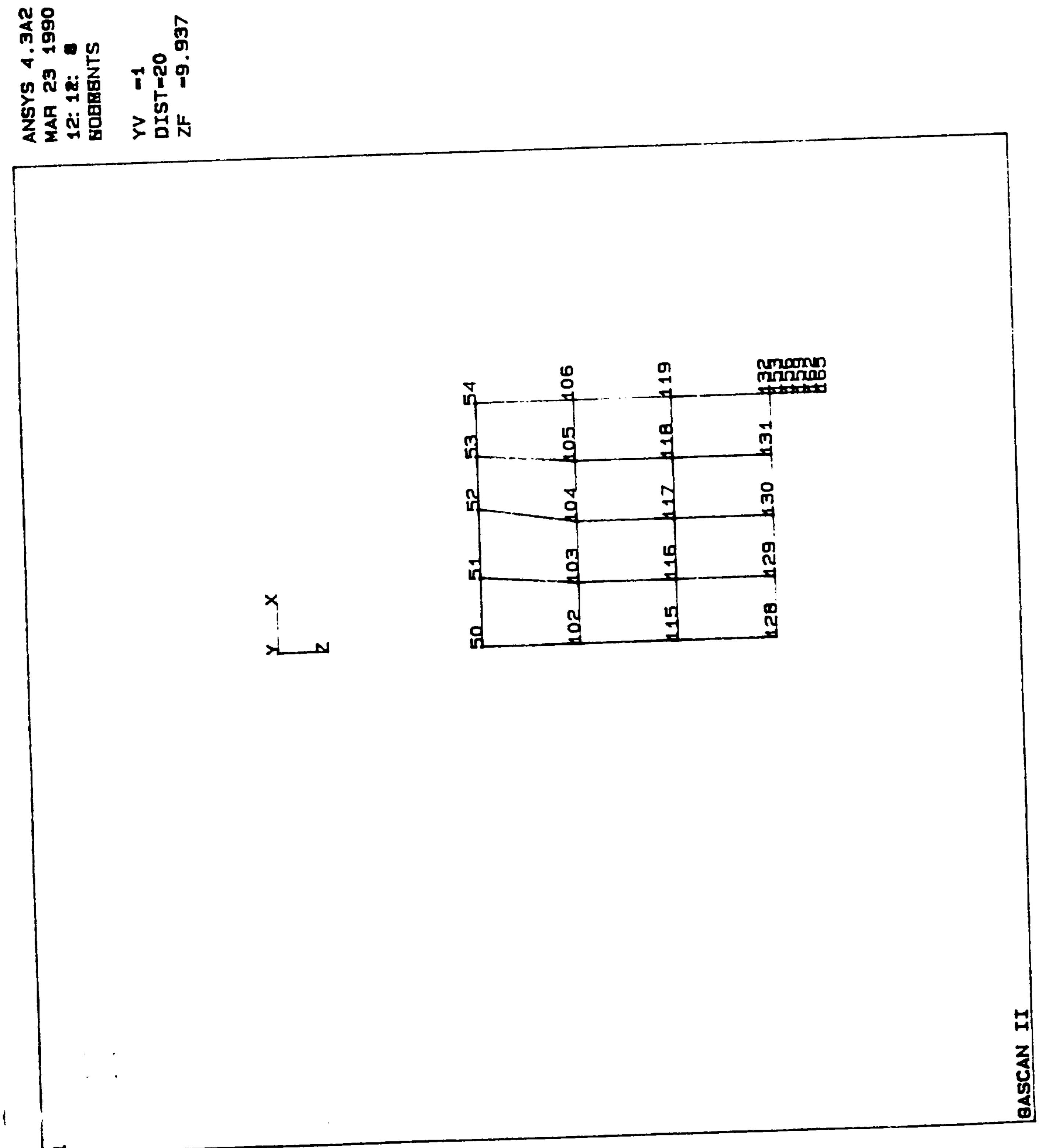


FIGURE 3.5.34



ANSYS 4.3A2
MAR 23 1990
YV =1
DIST=20
ZF =-9.937
X
Y
Z
50
51
52
53
54
102
103
104
105
106
115
116
117
118
119
128
129
130
131
BASCAN II

FIGURE - 3.5.35

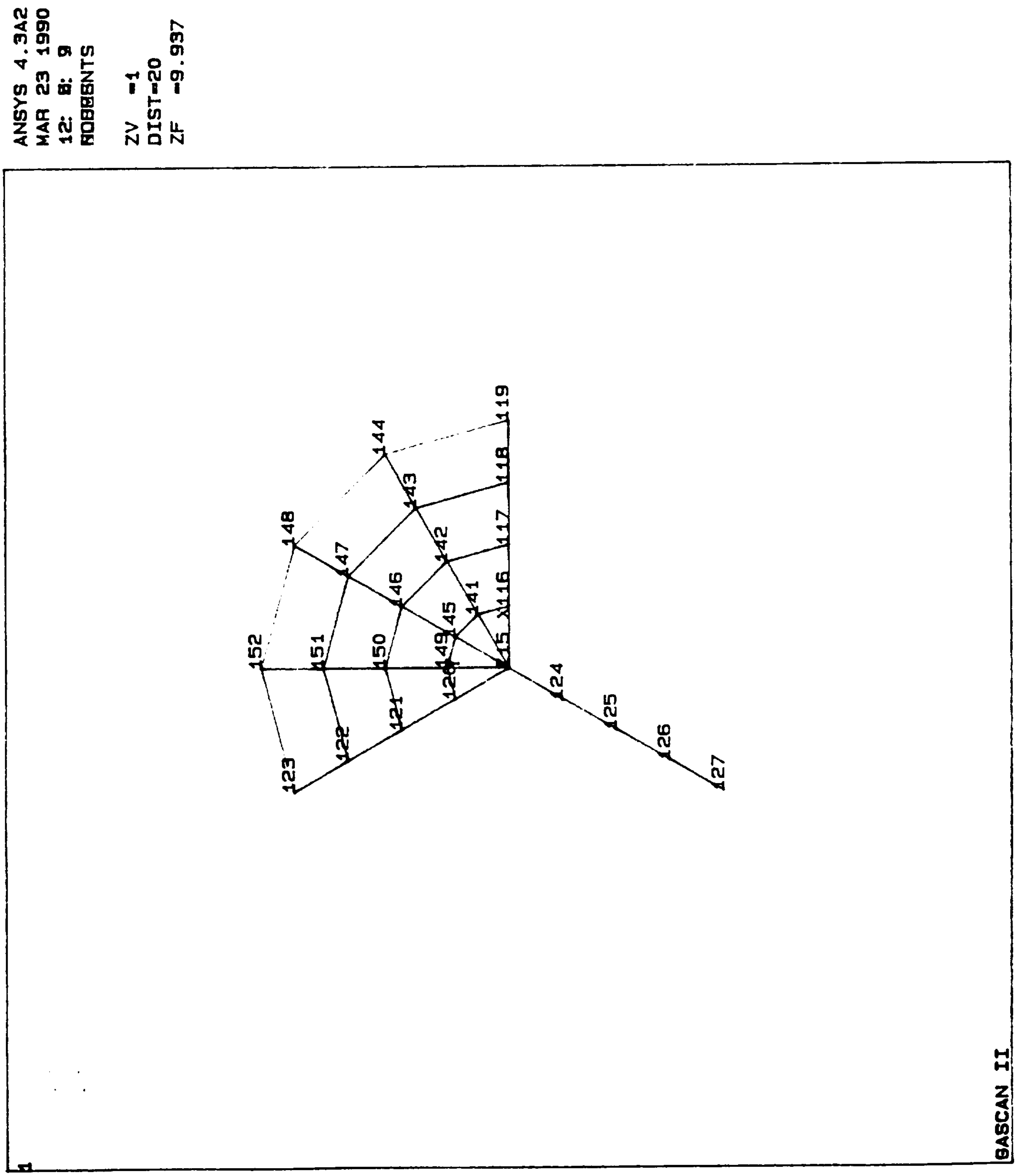

ANSYS 4.3A2
MAR 23 1990
12: 8: 9
NODES
ZV =1
DIST=20
ZF =9.937
119
118
117
116
115
144
143
142
141
148
147
146
145
152
151
150
149
120
121
122
123
124
125
126
127
BASCAN II

FIGURE - 3.5.36

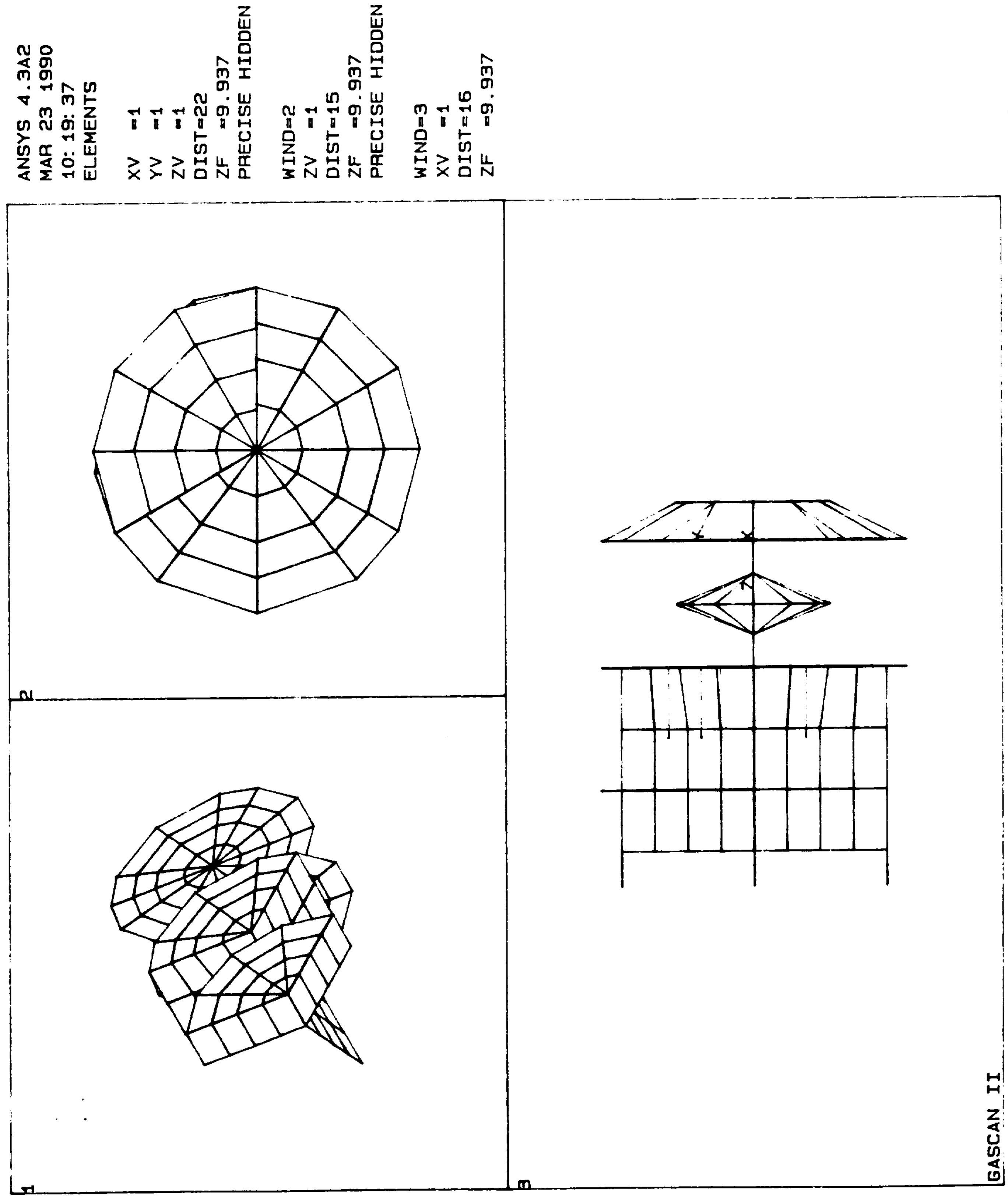

ANSYS 4.3A2
MAR 23 1990
10:19:37
ELEMENTS
XV =1
YV =1
ZV =1
DIST=22
ZF =9.937
PRECISE HIDDEN
WIND=2
ZV =1
DIST=15
ZF =9.937
PRECISE HIDDEN
WIND=3
XV =1
DIST=16
ZF =9.937
1
2
3
GASCAN II

FIGURE - 3.5.37

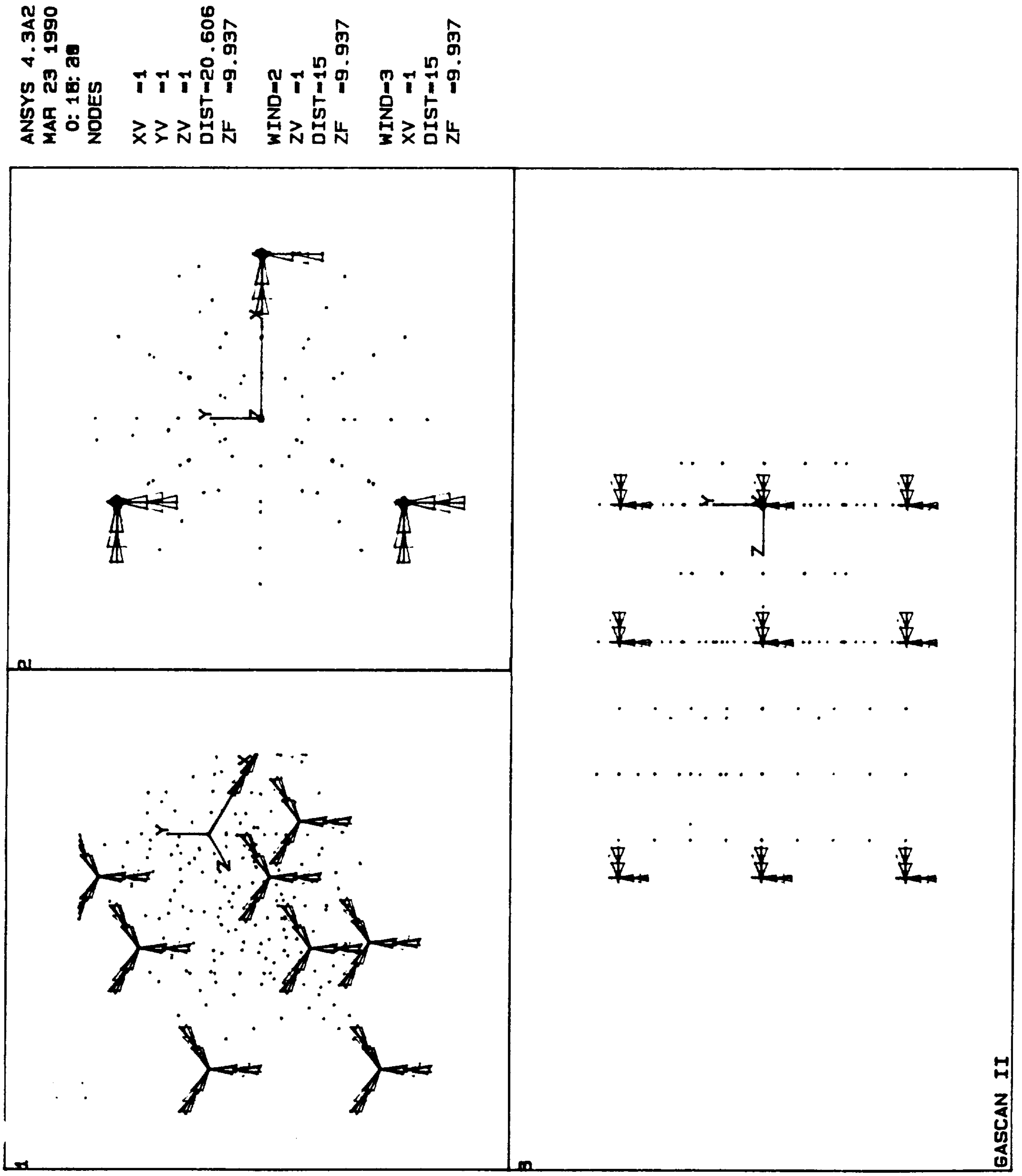

ANSYS 4.3A2
MAR 23 1990
0:18:38
NODES
XV =1
YV =1
ZV =1
DIST=20.606
ZF =9.937
WIND=2
ZV =1
DIST=15
ZF =9.937
WIND=3
XV =1
DIST=15
ZF =9.937
GASCAN II

FIGURE - 3.5.38

3.5.3.6.5 APPLYING FORCES

The second model was accelerated at six g's in the x and y directions and twelve g's in the z direction for both cases previously mentioned. These are the limit loads for the can in flight. These accelerations should give future structural groups an idea of problem areas to concentrate modeling.

3.5.3.6.6 PREP7 INPUT COMMANDS

The PREP7 commands are the commands used to construct the model of GAScan II. The descriptions do not go into detail explaining every command but they do give an idea of what each command did when constructing a model.

kan,0	STATIC ANALYSIS
et,1,63	QUADRILATERAL SHELL ELEMENT
r,1,.25,.25,.25,.25	REAL CONSTANTS
ex,1,1e7	
ey,1,1e7	MATERIAL PROPERTIES
nuxy,1,.3	FOR ALUMINUM
dens,1,.098	
et,2,4	3-D ELASTIC BEAM ELEMENT
r,2,1.5708,.9817,.9817,2,2	REAL CONSTANTS
ex,2,1e7	MATERIAL PROPERTIES
nuxy,2,.3	
dens,2,.098	
et,3,4	3-D ELASTIC BEAM ELEMENT
r,3,1.09375,.1424,.0698,.875,1.25	REAL CONSTANTS
ex,3,10e6	MATERIAL PROPERTIES
nuxy,3,.3	
dens,3,.098	
et,4,4	3-D ELASTIC BEAM ELEMENT
r,4,2.03,.91,.13,.875,2.32	REAL CONSTANTS

```
et,5,4                                   3-D ELASTIC BEAM ELEMENT
r,5,2.74,2.26,.175,.875,3.14             REAL CONSTANTS

et,6,4                                   3-D ELASTIC BEAM ELEMENT
r,6,3.465,4.53,.22,.875,3.96             REAL CONSTANTS

et,7,4                                   3-D ELASTIC BEAM ELEMENT
r,7,4.1825,7.96,.266,.875,4.78           REAL CONSTANTS

et,8,4                                   3-D ELASTIC BEAM ELEMENT
r,8,5.14,14.79,.328,.875,5.875           REAL CONSTANTS

et,9,4                                   3-D ELASTIC BEAM ELEMENT
r,9,1,1,1,1,1                            REAL CONSTANTS
ex,9,10e6                                MATERIAL PROPERTIES
dens,9,.00000000001
nuxy,9,.3

et,10,21                                 POINT MASS ELEMENT
r,10,9                                   REAL CONSTANTS

et,11,21                                 POINT MASS ELEMENT
r,11,5                                   REAL CONSTANTS

et,12,21                                 POINT MASS ELEMENT
r,12,2.92                                REAL CONSTANTS

et,13,21                                 POINT MASS ELEMENT
r,13,7.66                                REAL CONSTANTS


csys,1                                   CYLINDRICAL COORDINATE SYSTEM


n,1                                      NODE GENERATION
n,3,5.5549                                - bottom plate
fill
n,5,9.875
fill
ngen,2,4,2,5,1,0,22.5
ngen,3,4,6,9,1,0,37.5
ngen,3,4,14,17,1,0,22.5
ngen,3,4,22,25,1,0,37.5
ngen,2,4,30,33,1,0,22.5
ngen,4,4,34,37,1,0,30

ngen,2,49,1,49,1,0,0,8.25                 - middle plate

n,99,0,0,2.125                            - post between plates
n,100,0,0,4.125
n,101,0,0,6.125

n,102,0,0,12.1875                         - flanges
n,106,9.875,0,12.1875
fill
ngen,3,4,103,106,1,0,120
```

```
ngen,2,13,102,114,1,0,0,3.9375
ngen,2,13,115,127,1,0,0,4

n,141,2.4688,30,16.125                  - shelf
n,144,9.875,30,16.125
fill
ngen,3,4,141,144,1,0,30

n,153,9.875,0,20.594                    - mounting brackets
ngen,3,1,153,153,1,0,120
ngen,4,3,153,155,1,0,0,.46875
n,165,9.875,0,22.375
ngen,3,1,165,165,1,0,120

csys,0

n,168,2.4688,4.260,19.125               - IPPE experiment

n,169,5.1321,2.1258,12.75               - microgravity combustion
n,170,-.72506,5.5074,12.75
n,171,-4.407,3.3816,12.75
n,172,-4.407,-3.3816,12.75

csys,1

n,173,4.9375,0,-2.5                     - battery box
ngen,12,1,173,173,1,0,30

n,185,4.9375,0,4.125                    - rotational fluid flow
ngen,12,1,185,185,1,0,30

                                        SHELL ELEMENT GENERATION
type,1                                  - bottom plate
mat,1
real,1
e,2,6,1,1
e,6,10,1,1
e,10,14,1,1
e,14,18,1,1
e,18,22,1,1
e,22,26,1,1
e,26,30,1,1
e,30,34,1,1
e,34,38,1,1
e,38,42,1,1
e,42,46,1,1
e,46,2,1,1
e,2,3,7,6
egen,3,1,13,15,1
egen,11,4,13,45,1
e,46,47,3,2
egen,3,1,46,48,1

egen,2,49,1,96,1                        - middle plate

e,50,51,103,102                         - flanges
```

```
egen,4,1,97,100,1
e,50,67,107,102
e,67,68,108,107
egen,3,1,102,104
e,50,83,111,102
e,83,84,112,111
egen,3,1,106,108,1
e,102,103,116,115
egen,4,1,109,112,1
e,102,107,120,115
e,107,108,121,120
egen,3,1,114,116,1
e,102,111,124,115
e,111,112,125,124
egen,3,1,118,120,1
e,115,116,129,128
egen,4,1,121,124,1
e,115,120,133,128
e,120,121,134,133
egen,3,1,126,128,1
e,115,124,137,128
e,124,125,138,137
egen,3,1,130,132,1
```

- shelf

```
e,116,141,115,115
e,116,117,142,141
egen,3,1,134,136,1
e,141,145,115,115
e,141,142,146,145
egen,3,1,138,140,1
e,145,149,115,115
e,145,146,150,149
egen,3,1,142,144,1
e,149,120,115
e,149,150,121,120
egen,3,1,146,148,1
```

CENTER POST GENERATION

```
type,2
mat,2
real,2
e,1,99
e,99,100
e,100,101
e,101,50
e,50,102
e,102,115
e,115,128
```

MOUNTING BRACKET GENERATION
- first tier

```
type,3
real,3
mat,3
e,123,136
e,119,132
e,127,140
```

```
type,4                                - second tier
real,4
mat,3
e,132,153
e,136,154
e,140,155

type,5                                - third tier
real,5
mat,3
e,153,156
e,154,157
e,155,158

type,6                                - fourth tier
real,6
mat,3
e,156,159
e,157,160
e,158,161

type,7                                - fifth tier
real,7
mat,3
e,159,162
e,160,163
e,161,164

type,8                                - sixth tier
real,8
mat,3
e,162,165
e,163,166
e,164,167
                          IPPE AND ÌGRAVITY EXPERIMENT GENERATION

                                      MASS ELEMENT GENERATION
type,10                                - ippe
real,10
e,168

type,11                               - microgavity combustion
real,11
e,169
e,170
e,171
e,172

type,9                                MASSLESS BEAM GENERATION
real,9
mat,9

e,146,168                             - between ippe and shelf

e,169,56                              - between Ìg and middle plate
e,170,64
```

```
e,171,72
e,172,80
```

BATTERY BOX GENERATION

MASS ELEMENT GENERATION

```
type,13
real,13
e,173
e,174
e,175
e,176
e,177
e,178
e,179
e,180
e,181
e,182
e,183
e,184
```

MASSLESS BEAM GENERATION

```
type,9
real,9
mat,9
e,173,5
e,174,9
e,175,13
e,176,17
e,177,21
e,178,25
e,179,29
e,180,33
e,181,37
e,182,41
e,183,45
e,184,49
e,173,174
egen,11,1,208,218,1
e,184,173
```

ROTATIONAL FLUID FLOW GENERATION

MASS ELEMENT GENERATION

```
type,12
real,12
e,185
e,186
e,187
e,188
e,189
e,190
e,191
e,192
e,193
e,194
e,195
e,196
```

MASSLESS BEAM GENERATION

```
type,9
real,9
mat,9
e,185,99
e,186,99
e,187,99
e,188,99
e,189,99
e,190,99
e,191,99
e,192,99
e,193,99
e,194,99
e,195,99
e,196,99
e,185,101
e,186,101
e,187,101
e,188,101
e,189,101
e,190,101
e,191,101
e,192,101
e,193,101
e,194,101
e,195,101
e,196,101
e,185,186
egen,11,1,256,266,1
e,196,185
                                APPLIED FORCES
acel,2318.4,0,0
                                BOUNDARY CONDITIONS
d,165,all
d,166,all
d,167,all
d,62,all
d,78,all
d,94,all
d,5,all
d,21,all
d,37,all

iter,1,1                        SET ITERATION TO ONE
                                DISPLAY COMMANDS
/pbc,all,1                       - print all boundary cond.
/show,ega256                     - set up graphics
/menu,yes
/title,GASCan II                 - title model
/wind,1,ltop                     - set up screen
/wind,2,rtop
/wind,3,bot
/view,1,1,1,1                    - set up views
/view,2,0,0,1
/view,3,1,0,0
nplo                             - nodal plot
```

3.5.3.6.7 RESULTS

The results from the ANSYS are broken up into four tables. The first is the displacements and stresses for bumpers fixed. The second is displacements and stress for bumpers with freedom to slip in the z-direction. Two additional tables are added that summarize these into maximums by direction of acceleration. They give the maximum displacement and direction, the maximum stress and direction and the maximum average stress for acceleration along each axis.

TABLE 3.5.8 MAXIMUM DISPLACEMENTS AND STRESSES FOR BUMPERS FIXED

accelerated x direction

deflections	node	stresses	node
ux = - 3.753	172	sx=61680	132
uy= - 0.5850	168	sy=43580	17
uz= 2.948	148	sz=0	0
rotx= 0.5562	144	si=78590	21
roty= -1.172	168		
rotz= -1.583	168		

accelerated y direction

deflections	node	stresses	node
ux= 0.0627	125	sx= -16910	140
uy= -0.0786	105	sy= -6529	86
uz= -0.0892	94	sz= 0	0
rotx= 0.0197	53	si= 17430	140
roty= 0.0114	90		
rotz= 0.0186	124		

accelerated z direction

deflections	node	stresses	node
ux= -0.7840	171	sx= 16330	140
uy= 0.7875	169	sy= 16340	127
uz= -2.483	148	sz= 0	0
rotx= -0.4023	144	si= 36000	110
roty= 0.3643	152		
rotz= -0.0300	133		

TABLE 3.5.9 MAXIMUM DISPLACEMENTS AND STRESSES FOR BUMPERS FREE IN Z DIRECTION

accelerated x direction

deflections		node	stresses		node
ux=	-6.629	171	sx=	56380	132
uy=	-2.028	169	sy=	41400	106
uz=	-7.882	78	sz=	0	0
rotx=	0.844	74	si=	64000	54
roty=	-1.470	171			
rotz=	-1.582	168			

accelerated y direction

deflections		node	stresses		node
ux=	0.0613	125	sx=	-20360	140
uy=	-0.0801	105	sy=	-8799	110
uz=	-0.0914	94	sz=	0	0
rotx=	0.0196	53	si=	20660	140
roty=	0.0110	90			
rotz=	0.0182	124			

accelerated z direction

deflections		node	stresses		node
ux=	-1.307	171	sx=	50500	140
uy=	1.313	169	sy=	68000	127
uz=	-5.626	13	sz=	0	0
rotx=	0.8511	38	si=	100800	127
roty=	0.8532	2			
rotz=	-0.0510	133			

TABLE 3.5.10 SUMMARY OF MAXIMUM DISPLACEMENTS AND STRESSES FOR BUMPERS FIXED

ACCEL.	MAX DEFLECTION	MAX COMP. STRESS	MAX PRIN. STRESS
X-DIR	UX=-3.75"(n172)	SX= 61680psi(n132)	SI= 78590psi(n21)
Y-DIR	UZ=-0.089"(n94)	SX=-16910psi(n140)	SI= 17430psi(n140)
Z-DIR	UY= 0.788"(n169)	SY= 16340psi(n127)	SI= 36000psi(n110)

TABLE 3.5.11 SUMMARY OF MAXIMUM DISPLACEMENTS AND STRESSES FOR BUMPERS FREE IN Z-DIRECTION

ACCEL.	MAX DEFLECTION	MAX COMP. STRESS	MAX PRIN. STRESS
X-DIR	UZ=-7.882"(n169)	SX= 56380psi(n132)	SI= 64000psi(n54)
Y-DIR	UY=-0.091"(n94)	SX=-20360psi(n140)	SI= 20660psi(n140)
Z-DIR	UZ=-5.626"(n13)	SY= 68000psi(n127)	SI=100800psi(n127)

3.5.3.7 GASCAN MODEL III

3.5.3.7.1 PURPOSE

The purpose of this model was to examine the structural integrity of GAScan II, with the battery box positioned under the middle plate. This can was subjected to the same environment as the second model. This model was already proven superior due to the ease in the assembly procedure. The strength and frequency changes were found. An analysis with the bumpers totally fixed and free in the vertical direction was performed along with the corresponding vibrational analysis.

3.5.3.7.2 NODAL CONSTRUCTION

The nodal generation was exactly the same as the second model with the exception of a lengthened central shaft and the new location of the battery box. Refer to figure 3.5.39 for a nodal plot.

3.5.3.7.3 ELEMENT CONSTRUCTION

The element construction was also the same as the second model. All the node numbers had remained the same as before. This allows us to use the exact same ANSYS commands. An element plot is included in figure 3.5.40.

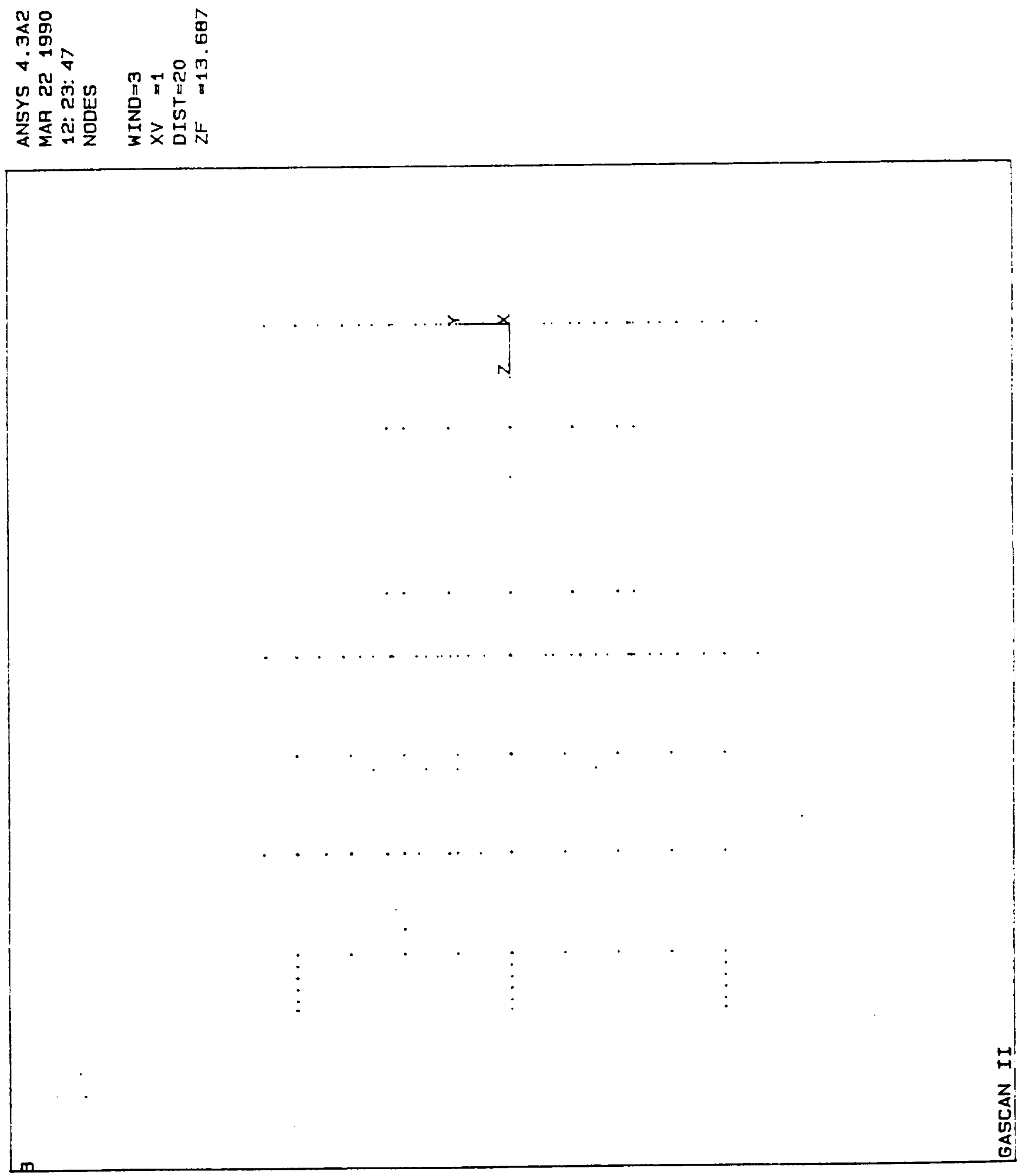


FIGURE - 3.5.39

ORIGINAL PAGE IS
OF POOR QUALITY

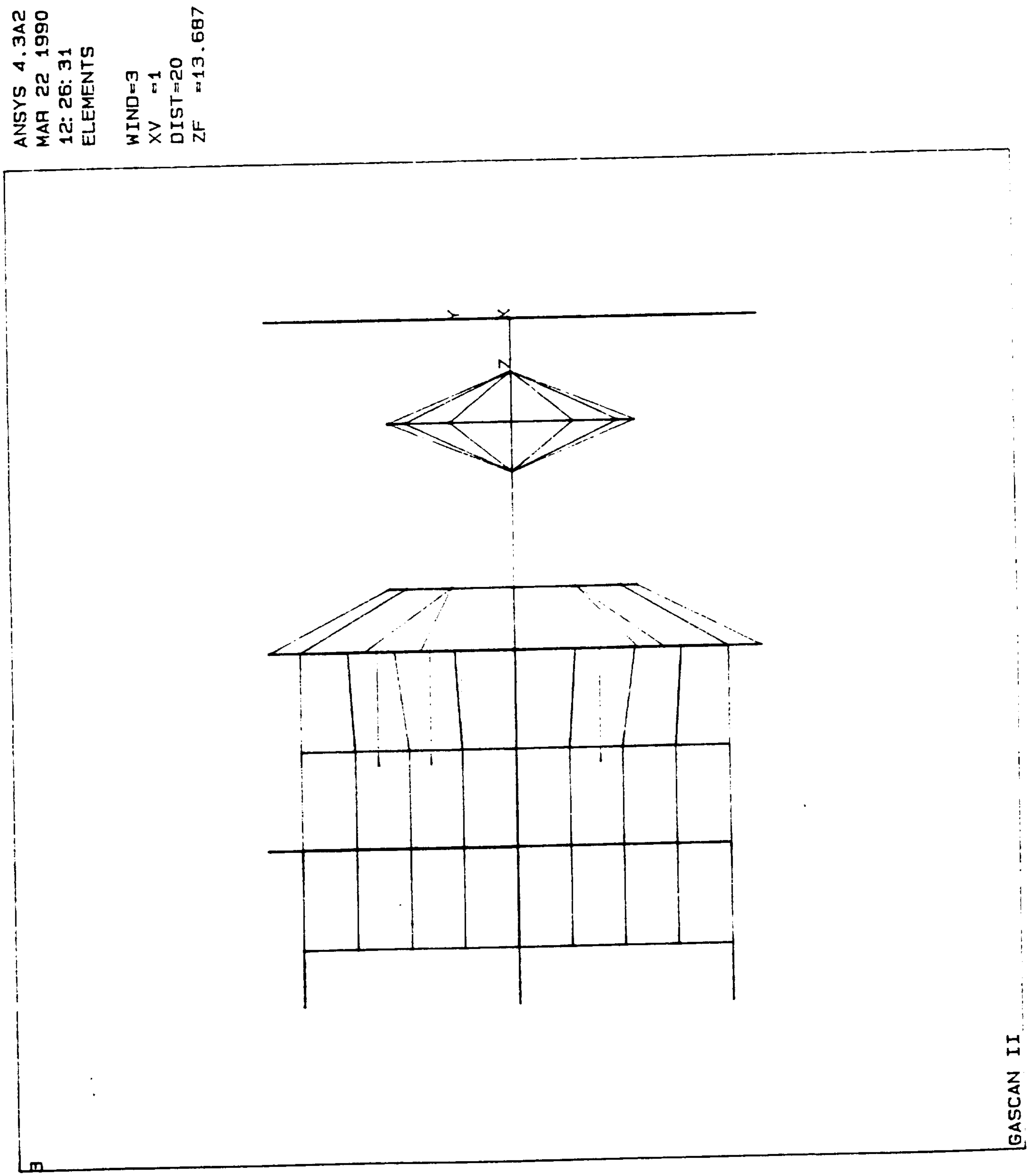

ANSYS 4.3A2
MAR 22 1990
12:26:31
ELEMENTS
WIND=3
XV =1
DIST=20
ZF =13.687
Y
X
Z
GASCAN II

FIGURE - 3.5.40

3.5.3.7.4 BOUNDARY CONSTRAINTS

Two analysis were done as previously explained. All commands have remained the same as the second model.

3.5.3.7.5 APPLYING FORCES

GAScan II was accelerated 6g,s on the x axes and y axes, 12g,s on the z axes. This acceleration induces a force acting on every mass in the model that is consistent with F=ma. In other words, the experimental masses are seen as induced forces and moments on the plate elements while the elements also experience body forces that correlate to their mass. (ANSYS calculates mass by taking the total volume of each element type and multiplying that number by the density entered in the PREP7 commands)

3.5.3.6.6 PREP7 INPUT COMMANDS

The only change in the prep7 commands was the lengthening of the central shaft between the two plates and the new placement of the battery box. The following prep7 commands are the new commands used for this analysis.

ngen,2,49,1,49,1,0,0,13.25	GENERATES MIDDLE PLATE AT NEW DISTANCE
n,185,4.9375,0,10.75 ngen,12,1,185,185,1,0,30	NODAL GENERATION FOR THE BATTERY BOX
type,9 real,9	'STIFF' BEAM GENERATION REAL CONSTANTS

```
mat,9                                      MATERIAL PROPERTIES
e,54,185
e,58,186
e,62,187
e,66,188
e,70,189
e,74,190
e,78,191
e,82,192
e,86,193
e,90,194
e,94,195
e,98,196
e,185,186
egen,11,1,196,206,1
e,196,185

type,14                                    MASS ELEMENT GENERATION
real,14                                    REAL CONSTANTS
mat,3                                      MATERIAL PROPERTIES
e,185
egen,12,1,244,255,1
```

3.5.3.6.7 RESULTS

The results are broken up into four tables. Similiar tables were used for the analysis of model II.

TABLE 3.5.12 MAXIMUM DISPLACEMENTS AND STRESSES FOR BUMPERS FIXED

accelerated x direction

deflections		node	stresses	node
ux =	3.621	168	sx=-75920	54
uy=	0.6061	168	sy= 62430	66
uz=	-2.979	148	sz= 0	0
rotx=	-0.5601	144	si= 89370	70
roty=	1.164	168		
rotz=	1.583	168		

accelerated y direction

deflections	node	stresses	node
ux= -0.0616	125	sx= 16460	140
uy= 0.0714	105	sy= 5981	86
uz= 0.0323	144	sz= 0	0
rotx= 0.0123	119	si= 16960	140
roty=-0.0099	112		
rotz=-0.0182	124		

accelerated z direction

deflections	node	stresses	node
ux= -0.4305	168	sx=-17530	140
uy= -0.7436	168	sy=-14980	127
uz= 2.478	148	sz= 0	0
rotx= 0.4015	144	si= 33130	110
roty= -0.3636	152		
rotz= 0.0297	133		

TABLE 3.5.13 MAXIMUM DISPLACEMENTS AND STRESSES FOR BUMPERS FREE IN Z DIRECTION

accelerated x direction

deflections	node	stresses	node
ux= 3.620	168	sx=-76390	54
uy= 0.6075	168	sy= 62380	66
uz= -2.977	148	sz= 0	0
rotx= -0.5601	144	si= 89230	70
roty= 1.164	168		
rotz= 1.583	168		

accelerated y direction

deflections	node	stresses	node
ux= -0.0604	125	sx= 19890	140
uy= 0.0732	105	sy= 8406	110
uz= 0.0332	144	sz= 0	0
rotx= 0.0129	119	si= 20190	140
roty=-0.0096	112		
rotz=-0.0179	124		

accelerated z direction

deflections	node	stresses	node
ux= -0.4296	168	sx=-32150	140
uy= -0.7415	168	sy=-43000	110
uz= 6.192	45	sz= 0	0
rotx= -0.6488	39	si= 620700	127
roty= 0.7022	27		
rotz= 0.0302	133		

TABLE 3.5.14 SUMMARY OF MAXIMUM DISPLACEMENTS AND STRESSES FOR BUMPERS FIXED

ACCEL.	MAX DEFLECTION	MAX COMP. STRESS	MAX PRIN. STRESS
X-DIR	UX=3.62"(n168)	SX=-75,920psi(n54)	SI=89,730psi(n70)
Y-DIR	UY=.071"(n105)	SX=16,460psi(n140)	SI=16,960psi(n140)
Z-DIR	UZ=2.47"(n148)	SX=-17,530psi(n140)	SI=33,130psi(n110)

TABLE 3.5.15 SUMMARY OF MAXIMUM DISPLACEMENTS AND STRESSES FOR BUMPERS FREE IN Z-DIRECTION

ACCEL.	MAX DEFLECTION	MAX COMP. STRES	MAX PRIN. STRESS
X-DIR	UX=3.62"(n168)	SX=-76,390psi(n54)	SI=89,230psi(n70)
Y-DIR	UY=.073"(n105)	SX=19,890psi(n140)	SI=20,190psi(n140)
Z-DIR	UZ=6.19"(n45)	SY=43,000psi(n110)	SI=62,070psi(n127)

3.5.3.8 GASCAN MODEL IV - VIBRATIONAL

3.5.3.8.1 PURPOSE

The purpose of this model was to estimate the natural frequency of GASCan II. Two models were used to compare the changes in natural frequency due to the placement of the battery box. This natural frequency, at mode 1, must be higher than the natural frequency of all the components of the shuttle. This limit is set at 51.0 hertz.

It was simple to convert the static analysis to a vibrational analysis. The nodal and element construction is the same as the second model. There are no forces to apply on this model. Only a change in the initial prep7 commands and the boundary constraints were needed to run this model. The nodal and element plots are the same as the second model.

3.5.3.8.2 BOUNDARY CONSTRAINTS

The vertical deflection is the major contributor to the natural frequency of the can. As a result, all the nodes were fixed in all directions except the z-axis. This vertical direction is referred to as the master degree of freedom. A plot is included in figure 3.5.41. This assumption must be used due to the increase of the equations ANSYS uses to solve the model. This increase in complexity was due to the introduction of the masses into the equations.

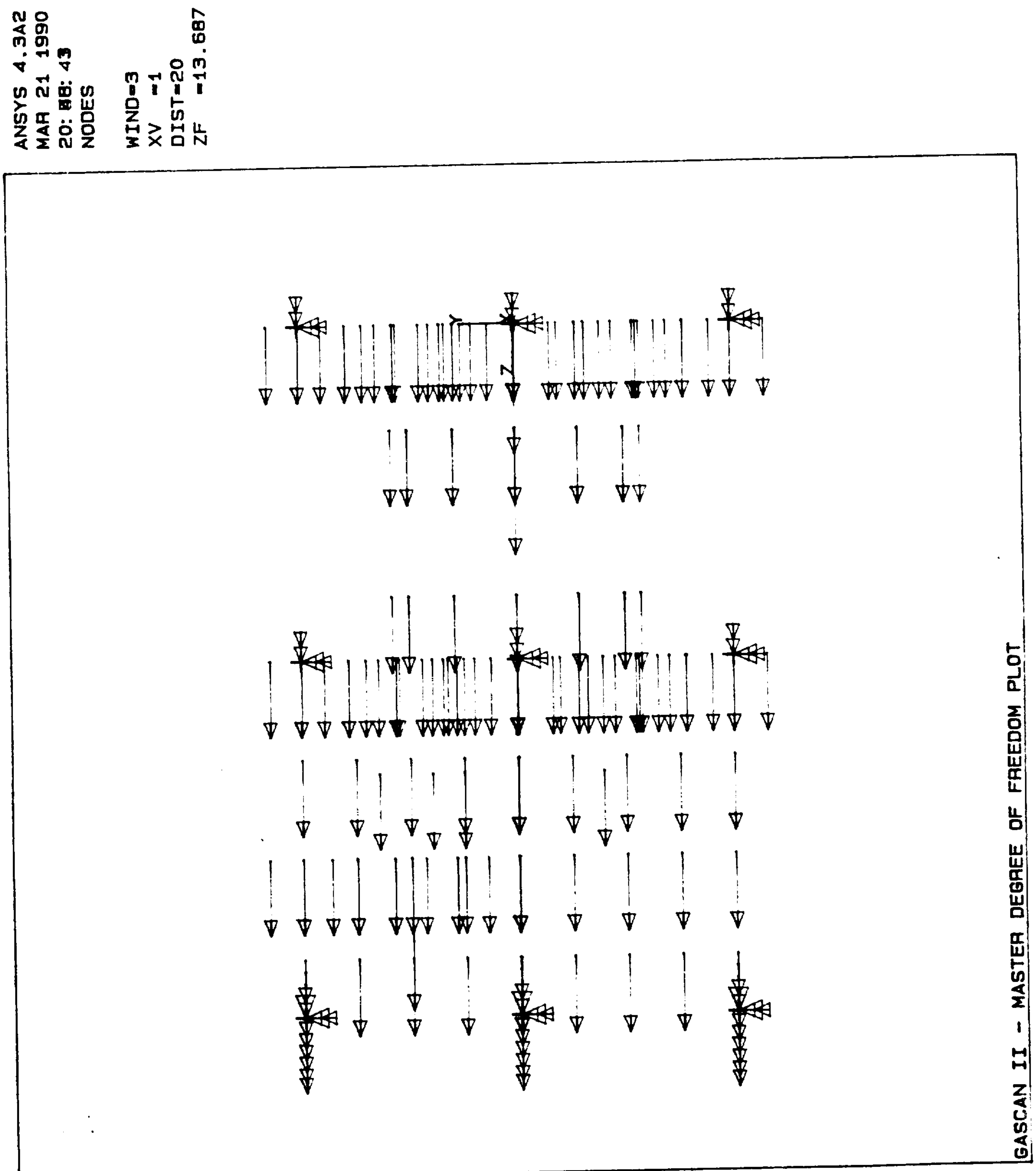

ANSYS 4.3A2
MAR 21 1990
NODES
WIND=3
XV =1
DIST=20
ZF =13.687
Y
Z
GASCAN II - MASTER DEGREE OF FREEDOM PLOT

FIGURE - 3.5.41

3.5.3.8.3 PREP7 INPUT COMMANDS

There are only five changes to the prep7 input commands given in section 3.5.3.6.6 . The first change was to delete the KAN,0 command. This deleted the analysis type. The second alteration was to delete the ACEL command. The vibrational analysis does not see accelerations. The last four added commands are as follows:

kan,2	MODAL ANALYSIS
kay,3,1	FREQUENCY RESPONSE OPTION
kay,2,n	STORES N SOLUTIONS FOR N MODES SO THEY CAN BE EXAMINED WITH SET,,N COMMAND IN THE POST SECTION
m,1,uz,267,1	SETS THE MASTER DEGREE OF THE SYSTEM EQUAL TO ONE IN THE Z DIRECTION

The first three commands should be the first two commands entered in the prep7 module. The forth command was added after the nodal and element generation but before the boundary constraint commands. As mentioned previously, there were two analysis done. These alterations are performed on the model with the battery box on the bottom and in the middle. These analyses also incorporate the bumpers free and fixed.

3.5.3.8.4 RESULTS

This model was run at the Mitre facility. It was found that this model was an inaccurate representation of GAScan II when considering vibrations. The model did not include the bumpers, which serve as added stiffeners and it did not accurately model the experiments. In the structural analysis, the massless, infinitely stiff beam was used to translate loads. In this analysis, the beams must contain a relative stiffness that coincides with the experiments. As a result, the frequencies that initiate resonance responses in GAScan II were very low. The results are shown in the following table.

TABLE 3.5.16 VIBRATIONAL ANALYSIS RESULTS

ANALYSIS	FIRST MODE OF VIBRATION (HZ)	REQUIRED FREQUENCY
BATTERY BOX ON BOTTOM		
-bumpers free	2.852	51
-bumpers fixed	2.857	51
BATTERY BOX IN MIDDLE		
-bumpers free	4.376	51
-bumpers fixed	4.562	51

The final vibrational analysis must show that GAScan II can experience up to fifty-one hertz without experiencing resonance conditions. These results indicate that this model is far from achieving the required frequency. However, it does indicate that GAScan II will avoid resonance at a higher frequency with the battery box connected to the middle plate. Further analysis is needed to support this result.

3.5.3.9 GASCAN MODEL V

3.5.3.9.1 PURPOSE

The objective of this model was to use all the knowledge gained in the previous models combined with a significant increase of elements to converge to the true stress distributions in GAScan II. This model contained enough elements to model the can as it actually appears in the drawings, with the exception of the mounting brackets and the bumpers. The mounting brackets and bumpers are to be modeled separately and the internal forces and moments, found from this model, will be applied on to them.

This model will serve as the foundation of many analyses. It is possible to model the central shaft with the bearing mounts included. The allowable torque that the central shaft will permit can be discovered. The experiments themselves can be represented will a great deal of accuracy. It is also possible to find the limiting acceleration at which interference with the central shaft and the rotational flow experiment begins. A more exact natural frequency can be determined. All these analysis will offspring from this fine model. As a result of the increase in elements used, this model will have to run at the Mitre facility.

3.5.3.9.2 NODAL CONSTRUCTION

The nodal generation includes several key location to represent GAScan II correctly. Nodes were placed at the bolt hole locations. Nodes were placed at the correct distances apart at the bearing mount locations. The central shaft was modeled as a circular shaft, not as a line of nodes. The mounting brackets were modeled with a line of nodes because the beam elements are used. The entire process of node generation was carefully planned to insure that the node numberings would allow for the exploitation of the EGEN command. If the nodes are randomly generated, thousands of elements would have to be entered individually. A nodal plot is shown in figure 3.5.42.

3.5.3.9.3 ELEMENT CONSTRUCTION

There are three elements used in this ANSYS model. They are the quadrilateral shell elements (to represent the plates and bearing mount), the beam elements (to represent the mounting brackets and the massless experiment supports), and the mass elements (to represent the experiment mass). These elements were generated by using th EGEN command and by entering the elements individually. The total amount of element was about 5000. An element plot of the empty GAScan II is included figure 3.5.43

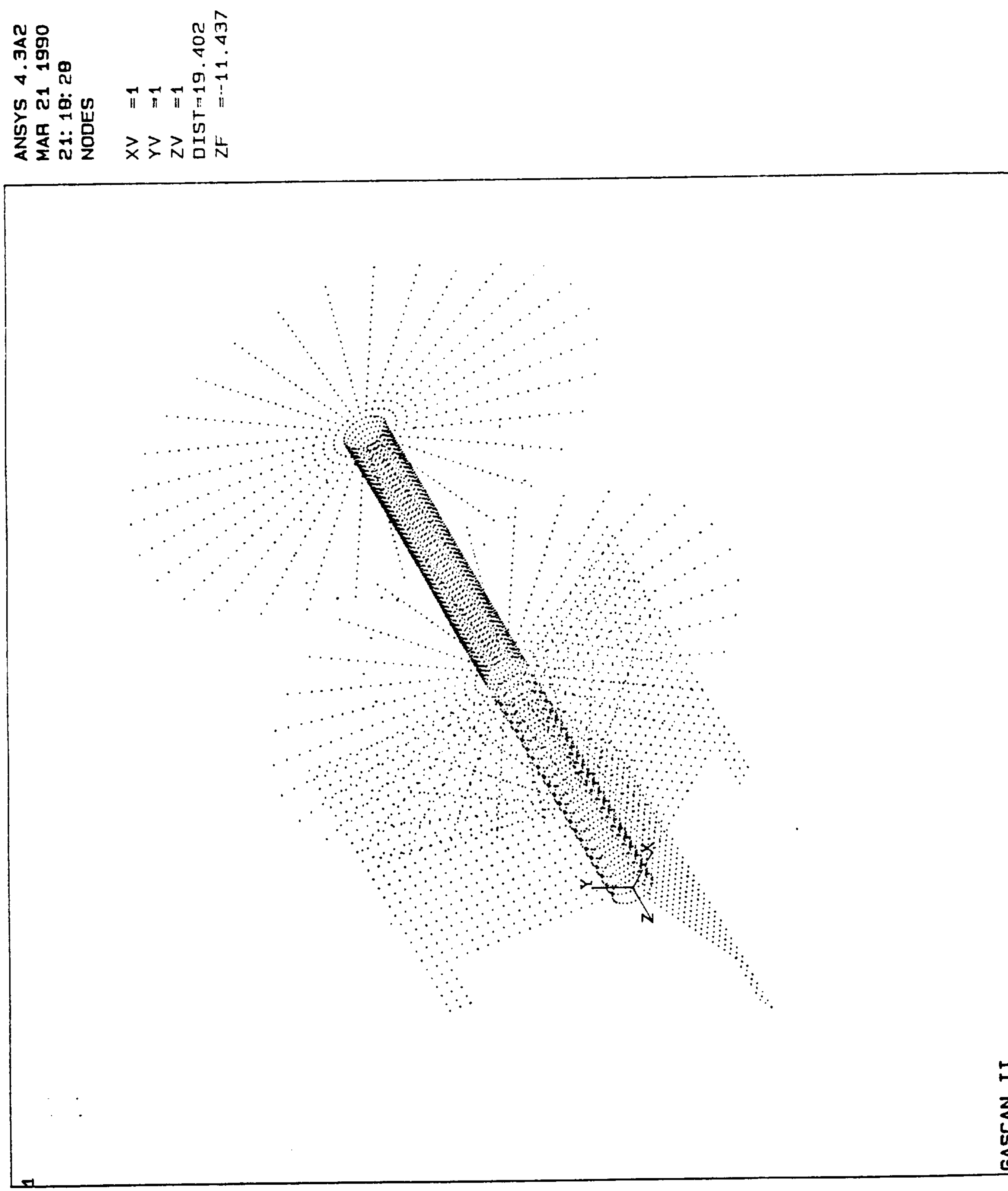

ANSYS 4.3A2
MAR 21 1990
21:18:28
NODES
XV =1
YV =1
ZV =1
DIST=19.402
ZF =-11.437
GASCAN II

FIGURE - 3.5.42

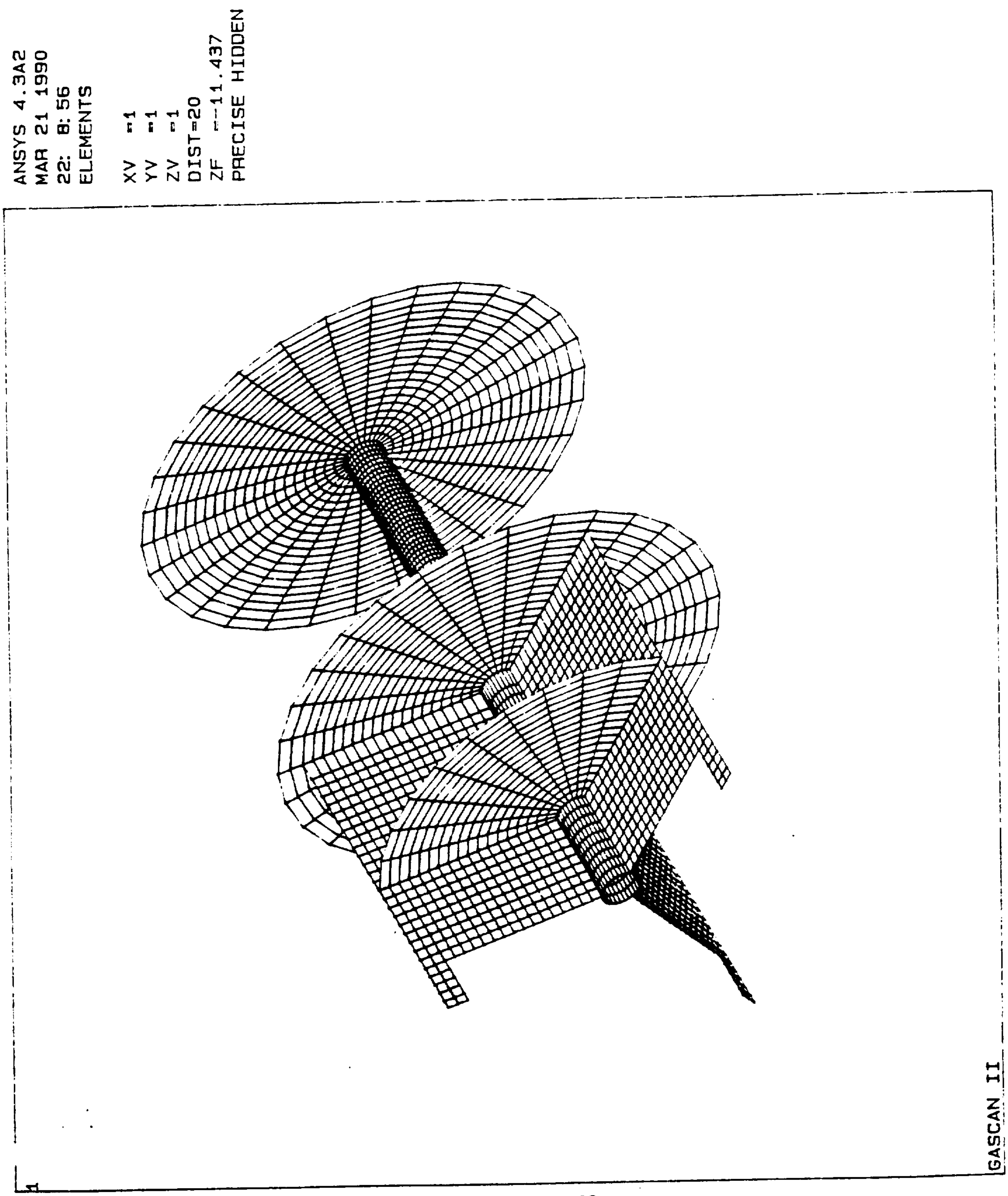

ANSYS 4.3A2
MAR 21 1990
22: 8:56
ELEMENTS
XV =1
YV =1
ZV =1
DIST=20
ZF =-11.437
PRECISE HIDDEN
GASCAN II
1

FIGURE - 3.5.43

3.5.3.9.4 BOUNDARY CONSTRAINTS

The constraints on this system are the same as the earlier models. The mounting brackets are assumed to be fixed. The bumpers are assumed not to slip. It is only at these locations that GAScan II will experience a resistance to motion.

3.5.3.9.5 APPLYING FORCES

The accelerations that this model will experience correlate to the yield and ultimate loadings. NASA requires that these runs and all the stress data for every element must be available. This model will serve as the final structural analysis model requiring these load spectrums to be analyzed.

3.5.3.9.6 PREP7 COMMANDS

The following commands are all the prep7 commands that are used to generate this model.

```
kan,0                              STATIC ANALYSIS

et,1,63                            QUAD. SHELL ELEMENT
r,1,.25,.25,.25,.25                REAL CONSTANTS
ex,1,1e7                           MATERIAL PROPERTIES
ey,1,1e7
nuxy,1,.3
dens,1,.00026

et,2,63                            QUAD. SHELL ELEMENTS
r,2,1.5,1.5,1.5,1.5                REAL CONSTANTS
```

```
et,3,63                              QUAD SHELL ELEMENTS
r,3,2.32,2.32,2.32,2.32              REAL CONSTANTS

et,4,63                              QUAD. SHELL ELEMENTS
r,4,3.14,3.14,3.14,3.14              REAL CONSTANTS

et,5,63                              QUAD. SHELL ELEMENTS
r,5,3.96,3.96,3.96,3.96              REAL CONSTANTS

et,6,63                              QUAD. SHELL ELEMENTS
r,6,4.78,4.78,4.78,4.78              REAL CONSTANTS

et,7,63                              QUAD. SHELL ELEMENTS
r,7,5.875,5.875,5.875,5.875          REAL CONSTANTS

et,8,21                              MASS ELEMENT
r,8,10,10,10                         REAL CONSTANTS

et,9,4                               3-D ELASTIC BEAM ELEMENT
r,9,.1                               REAL CONSTANTS
ex,9,1e1000000                       MATERIAL PROPERTIES
nuxy,9,.3
dens,9,0

et,10,21                             MASS ELEMENTS
r,10,7,7,7                           REAL CONSTANTS

et,11,21                             MASS ELEMENTS
r,11,6.4,6.4,6.4,6.4                 REAL CONSTANTS

et,12,21                             MASS ELEMENTS
r,12,2.33,2.33,2.33                  REAL CONSTANTS

csys,1                               CYLINDRICAL COORDINATE SYSTEM

                                     NODAL GENERATION
n,1,.875                              - flanges and centeral shaft
n,17,7.905
fill
n,19,8.78
fill
n,20,.875,12
ngen,9,1,20,28,1,0,12
ngen,3,28,1,28,1,0,120
ngen,23,84,1,84,1,0,0,-.5

n,1933,1.375,12,-4.5                  - shelf
n,1950,8.78,12,-4.5
fill
ngen,9,18,1933,1950,1,0,12

n,2095,.875,0,-11.875                 - middle plate
n,2113,8.78,0,-11.875
fill
n,2115,9.875,0,-11.875
fill
```

```
ngen,30,21,2095,2115,1,0,12

ngen,2,630,2095,2724,1,0,0,-13.25      - bottom plate

n,3355,.875,0,-12.125                  - central shaft between
ngen,30,1,3355,3355,1,0,12               plates
ngen,52,30,3355,3384,1,0,0,-.25

n,4915,7.905,0,.46875                  - mounting brackets
n,4917,8.78,0,.46875
fill
ngen,3,3,4915,4917,1,0,120
ngen,4,10,4915,4923,1,0,0,.46875
n,4954,7.905,0,2.25
n,4956,8.78,0,2.25
fill
ngen,3,3,4954,4956,1,0,120

n,6000,3.94,60,-1.5                    - experiment mass
n,6001,5.55,22.5,-7.375                  locations
n,6002,5.55,97.5,-7.375
n,6003,5.55,142.5,-7.375
n,6004,5.55,217.5,-7.375

n,6005,4.9375,0,-14.375
ngen,15,1,6005,6005,1,0,24

n,6020,4.9375,0,-20.875
ngen,15,1,6020,6020,1,0,24

                                      SHELL ELEMENT GENERATION
type,1                                 - flanges and central shaft
e,1,2,86,85
egen,18,1,1,18,1
e,1,85,104,20
e,20,104,105,21
egen,9,1,20,28,1
egen,2,28,1,56,1
e,57,58,142,141
egen,18,1,57,74,1
e,57,76,160,141
e,76,77,161,160
egen,8,1,76,83,1
e,84,1,85,168
egen,22,84,1,1848,1

e,757,758,1933,776                     - shelf
e,776,1933,1951,777
e,777,1951,1969,778
e,778,1969,1987,779
e,779,1987,2005,780
e,780,2005,2023,781
e,781,2023,2041,782
e,782,2041,2059,783
e,783,2059,2077,784
e,784,2077,786,785
```

```
e,758,759,1934,1933
egen,17,1,1859,1875
e,1933,1934,1952,1951
egen,17,1,1876,1892,1
egen,8,18,1876,2011,1
e,786,2077,2078,787
egen,17,1,2012,2028,1
```

- mating of flanges and the central shaft with the middle plate

```
e,1849,1850,2096,2095
egen,18,1,2029,2048,1
e,1849,1868,2116,2095
e,1868,1869,2137,2116
e,1869,1870,2158,2137
e,1870,1871,2179,2158
e,1871,1872,2200,2179
e,1872,1873,2221,2200
e,1873,1874,2242,2221
e,1874,1875,2263,2242
e,1875,1876,2284,2263
e,1876,1877,2305,2284


e,1877,1878,2306,2305
egen,18,1,2057,2074,1
e,1877,1896,2326,2305
e,1896,1897,2347,2326
e,1897,1898,2368,2347
e,1898,1899,2389,2368
e,1899,1900,2410,2389
e,1900,1901,2431,2410
e,1901,1902,2452,2431
e,1902,1903,2473,2452
e,1903,1904,2494,2473
e,1904,1905,2515,2494

e,1905,1906,2516,2515
egen,18,1,2085,2102,1
e,1905,1924,2536,2515
e,1924,1925,2557,2536
e,1925,1926,2578,2557
e,1926,1927,2599,2578
e,1927,1928,2620,2599
e,1928,1929,2641,2620
e,1929,1930,2662,2641
e,1930,1931,2683,2662
e,1931,1932,2704,2683
e,1932,1849,2095,2704
```

- middle plate

```
e,2095,2096,2117,2116
egen,20,1,2113,2132,1
egen,29,21,2113,2711,1
e,2704,2705,2096,2095
egen,20,1,2693,2712,1
```

- bottom plate

```
e,2725,2726,2747,2746
egen,20,1,2713,2732,1
```

```
egen,29,21,2713,3411,1
e,3334,3335,2726,2725
egen,20,1,3293,3312,1

e,2095,2116,3356,3355          - mating of the middle plate
e,2116,2137,3357,3356            with the central shaft
e,2137,2158,3358,3357
e,2158,2179,3359,3358
e,2179,2200,3360,3359
e,2200,2221,3361,3360
e,2221,2242,3362,3361
e,2242,2263,3363,3362
e,2263,2284,3364,3363
e,2284,2305,3365,3364
e,2305,2326,3366,3365
e,2326,2347,3367,3366
e,2347,2368,3368,3367
e,2368,2389,3369,3368
e,2389,2410,3370,3369
e,2410,2431,3371,3370
e,2431,2452,3372,3371
e,2452,2473,3373,3372
e,2473,2494,3374,3373
e,2494,2515,3375,3374
e,2515,2536,3376,3375
e,2536,2557,3377,3376
e,2557,2578,3378,3377
e,2578,2599,3379,3378
e,2599,2620,3380,3379
e,2620,2641,3381,3380
e,2641,2662,3382,3381
e,2662,2683,3383,3382
e,2683,2704,3384,3383
e,2704,2095,3355,3384

e,3355,3356,3386,3385          - cetral shaft between the
egen,29,1,3343,3371,1            two plates
e,3384,3355,3385,3414
egen,51,30,3343,4901,1

e,4885,4886,2746,2725          - mating of the central shaft
e,4886,4887,2767,2746            with the bottom plate
e,4887,4888,2788,2767
e,4888,4889,2809,2788
e,4889,4890,2830,2809
e,4890,4891,2851,2830
e,4891,4892,2872,2851
e,4892,4893,2893,2872
e,4893,4894,2914,2893
e,4894,4895,2935,2914
e,4895,4896,2956,2935
e,4896,4897,2977,2956
e,4897,4898,2998,2977
e,4898,4899,3019,2998
e,4899,4900,3040,3019
e,4900,4901,3061,3040
```

```
e,4901,4902,3082,3061
e,4902,4903,3103,3082
e,4903,4904,3124,3103
e,4904,4905,3145,3124
e,4905,4906,3166,3145
e,4906,4907,3187,3166
e,4907,4908,3208,3187
e,4908,4909,3229,3208
e,4909,4910,3250,3229
e,4910,4911,3271,3250
e,4911,4912,3292,3271
e,4912,4913,3313,3292
e,4913,4914,3334,3313
e,4914,4885,2725,3334

edel,17,18,1                    - deleting the flange elements
edel,45,46,1                      to replace with mounting
edel,73,74,1                      bracket elements

edel,101,102,1
edel,129,130,1
edel,157,158,1

edel,185,186,1
edel,213,214,1
edel,241,242,1

edel,269,270,1
edel,297,298,1
edel,325,326,1

edel,353,354,1
edel,381,382,1
edel,409,410,1

edel,437,438,1
edel,465,466,1
edel,493,494,1

edel,521,522,1
edel,549,550,1
edel,577,578,1

edel,605,606,1
edel,633,634,1
edel,661,662,1

type,2                          - mounting brackets
real,2
e,17,18,102,101
e,18,19,103,102
egen,3,28,4903,4908,1
egen,8,84,4903,4952,1

type,3
real,3
```

```
e,17,18,4916,4915
e,18,19,4917,4916
e,45,46,4919,4918
e,46,47,4920,4919
e,73,74,4922,4921
e,74,75,4923,4922

type,4
real,4
e,4915,4916,4926,4925
e,4916,4917,4927,4926
e,4918,4919,4929,4928
e,4919,4920,4930,4929
e,4921,4922,4932,4931
e,4922,4923,4933,4932

type,5
real,5
e,4925,4926,4936,4935
e,4926,4927,4937,4936
e,4928,4929,4939,4938
e,4929,4930,4940,4939
e,4931,4932,4942,4941
e,4932,4933,4943,4942

type,6
real,6
e,4935,4936,4946,4945
e,4936,4937,4947,4946
e,4938,4939,4949,4948
e,4939,4940,4950,4949
e,4941,4942,4952,4951
e,4942,4943,4953,4952

type,7
real,7
e,4945,4946,4955,4954
e,4946,4947,4956,4955
e,4948,4949,4958,4957
e,4949,4950,4959,4958
e,4951,4952,4961,4960
e,4952,4953,4962,4961
                                - mass element for the IPPE
type,8
real,8
e,6000
                                - beam elements for the IPPE
type,9
real,9
mat,9
e,6000,1936
e,6000,1981
e,6000,2053
e,6000,2080
                                - mass elements for IG
type,10
```

```
real,10
e,6001
e,6002
e,6003
e,6004

type,9
real,9                                  - beam elements for the IG
mat,9
e,6001,2121
e,6001,2131
e,6001,2211
e,6001,2175
e,6002,2289
e,6002,2299
e,6002,2211
e,6002,2260
e,6003,2331
e,6003,2341
e,6003,2421
e,6003,2386
e,6004,2499
e,6004,2509
e,6004,2421
e,6004,2470

type,11
real,11                                 - mass elements for the
e,6005                                    battery box
e,6006
e,6007
e,6008
e,6009
e,6010
e,6011
e,6012
e,6013
e,6014
e,6015
e,6016
e,6017
e,6018
e,6019

type,9
real,9                                  - beam elements for the
mat,9                                     battery box
e,6005,2114
e,6006,2156
e,6007,2198
e,6008,2240
e,6009,2282
e,6010,2324
e,6011,2366
e,6012,2408
e,6013,2450
```

```
e,6014,2492
e,6015,2534
e,6016,2576
e,6017,2618
e,6018,2660
e,6019,2702
e,6005,6006
e,6006,6007
e,6007,6008
e,6008,6009
e,6009,6010
e,6010,6011
e,6011,6012
e,6012,6013
e,6013,6014
e,6014,6015
e,6015,6016
e,6016,6017
e,6017,6018
e,6018,6019
e,6019,6005

type,12                              - mass elements for the
real,12                                rotational flow
e,6020
e,6021
e,6022
e,6023
e,6024
e,6025
e,6026
e,6027
e,6028
e,6029
e,6030
e,6031
e,6031
e,6033
e,6034

type,9                               - beam elements for the
real,9                                 rotational flow
mat,9
e,6020,4045
e,6021,4047
e,6022,4049
e,6023,4051
e,6024,4053
e,6025,4055
e,6026,4057
e,6027,4059
e,6028,4061
e,6029,4063
e,6030,4065
e,6031,4067
e,6032,4069
```

```
e,6033,4071
e,6034,4073
e,6020,4795
e,6021,4797
e,6022,4799
e,6023,4801
e,6024,4803
e,6025,4805
e,6026,4807
e,6027,4809
e,6028,4811
e,6029,4813
e,6030,4815
e,6031,4817
e,6032,4819
e,6033,4821
e,6034,4823
e,6020,6021
e,6021,6022
e,6022,6023
e,6023,6024
e,6024,6025
e,6025,6026
e,6026,6027
e,6027,6028
e,6028,6029
e,6029,6030
e,6030,6031
e,6031,6032
e,6032,6033
e,6033,6034
e,6034,6020

d,4954,all                              BOUNDARY CONSTRAINTS
d,4955,all
d,4956,all
d,4957,all
d,4958,all
d,4959,all
d,4960,all
d,4961,all
d,4962,all
d,2115,all
d,2325,all
d,2535,all
d,2745,all
d,2955,all
d,3165,all

acel,4636.8                             APPLIED FORCES
/show,ega256                            SET UP GRAPHICS
/menu,yes
/title,GAScan II                        TITLE
/view,1,1,1,1                           VIEW FOR WINDOW 1
iter,1,1                                SET ITERATION TO ONE
```

3.5.3.9.7 RESULTS

The model was run at the Mitre facility were it was determined that the model was too large to run on any system. The Mitre ANSYS system could have solved the model. However, it would have taken approximately eight days of computer time to solve. ANSYS offers the capability to mesh elements in certain areas on a model. This option can be found in the 4.4 version of ANSYS. The next structural team is highly recommended to use that version.

4.0 RESULTS/CONCLUSIONS

Several structural questions, that would have been difficult to answer with hand calculations, were addressed using ANSYS. The final models to be tested were made using the beam element, the plate element and the mass element. Using these elements in our models yielded sufficient data to represent the experiments and the parts of the can in a concise manner.

The beam element was used in three places on the can. The first was the center shaft, where it was given the properties of the shaft. This method was fine for the analysis because it gave moments and deflections at the two plates and between the two plates. It also reduced the number of elements necessary to model the center shaft allowing us to use WPI's computer facilities. The second was in modeling the experiments. The element was given a density of near zero and stiffness large enough to eliminate internal deflections in the beam. The beams allowed us to transfer the acceleration of a mass to moments and forces at the fastening locations. This also gave stresses and deflections in the plates at the experiment locations. The last place the beam element was used was the mounting brackets. Here the beams were given the properties of the mounting brackets. Using beams allowed any forces and moments induced within the beams to be transferred to the plate elements of the flanges.

The plate element was used to model the plates and flanges of GAScan II. From the three different models, of the plates, created in section 3.5.3.3, the plates consisting of forty eight elements gave accurate stresses and deflections. The mass elements represented the mass of the experiment and were attached to the beams as mentioned above. All the elements were then compatible with each other and the model was analyzed.

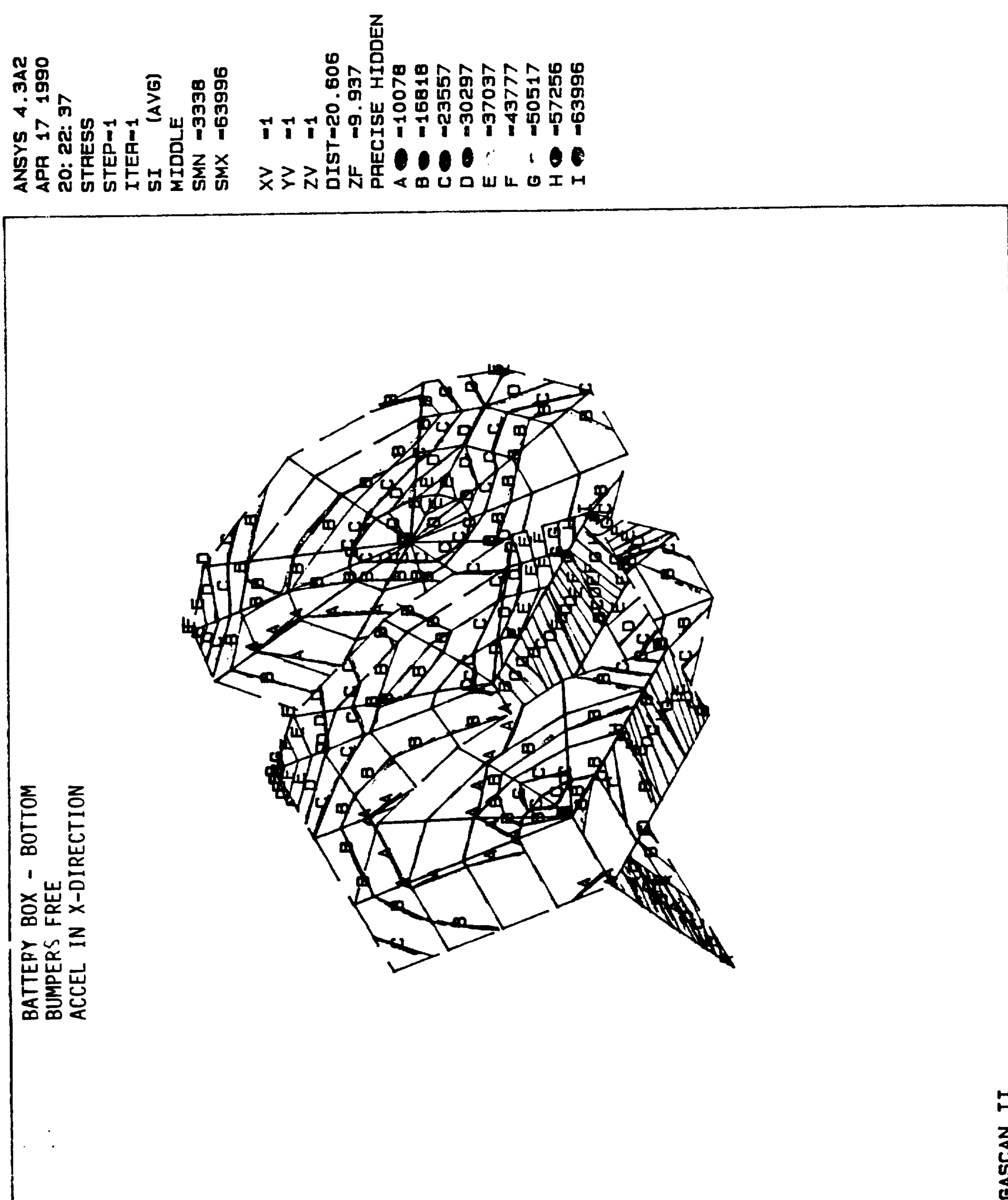
The first model developed of the can, Model I, consisted of the plates, flanges and center post. To develop forces on GAScan II, we calculated the force that would result from the mass of each experiment being accelerated at 6 g's. This force was applied to GAScan II at its proper location. The largest deflection that occurred was at node 45, on the outer edge of the bottom plate, and occurred in the z direction. The largest stress in a component direction was at node 140, on the upper corner of a flange, and occured in the y direction. This was also the location of the highest principle stress. All other high stresses occurred at the bumpers and upper flange locations, these are the points where the degrees of freedom were fixed. We were not able to extract stresses from the center shaft but deflections were low indicating low stresses. All the stresses that occurred were low in comparison to the yield stress and ultimate stress which showed that a better model had to be created.

The second and third model were identical in structure with the exception of the location of the battery box, the second had the battery box underneath the bottom plate and the third had the battery box above the rotational fluid flow experiment. Additional elements were added to represent the experiments and the mounting brackets. These were added on the discovery that we neglected moments induced by the experiments being accelerated. These moments added to the stresses in the structure. Another idea was that the whole model should be accelerated to take into account the body forces that occur in the parts of the structure.

A further reason for the two models was to compare the structural rigidity and vibrational stability. For design reasons, mainly the fastening arrangement of the battery box, the battery box was positioned above the rotational fluid flow experiment. Both designs were analysed to see if moving the battery box affected the structural integity of GAScan II. The stresses that occurred in these two models were much higher than in the first one.

The reason for the higher stresses was the addition of the mass/beam elements and the acceleration of the whole structure. The highest stresses that resulted in either case were in the si direction for all directions of accelerations. The si direction is characterized as the average of all the principle stresses. The comparison of all the models using these stresses showed where the trouble spots were.

The highest stresses occurred where the nodes were fixed. This occurred due to the fact that stress inversely proportional to area. At these points the area is reduced to almost zero and the stresses increase. As seen in figures 4.0.1 through 4.0.12, the areas of GAScan II that are away from the fixed points have considerably lower stresses.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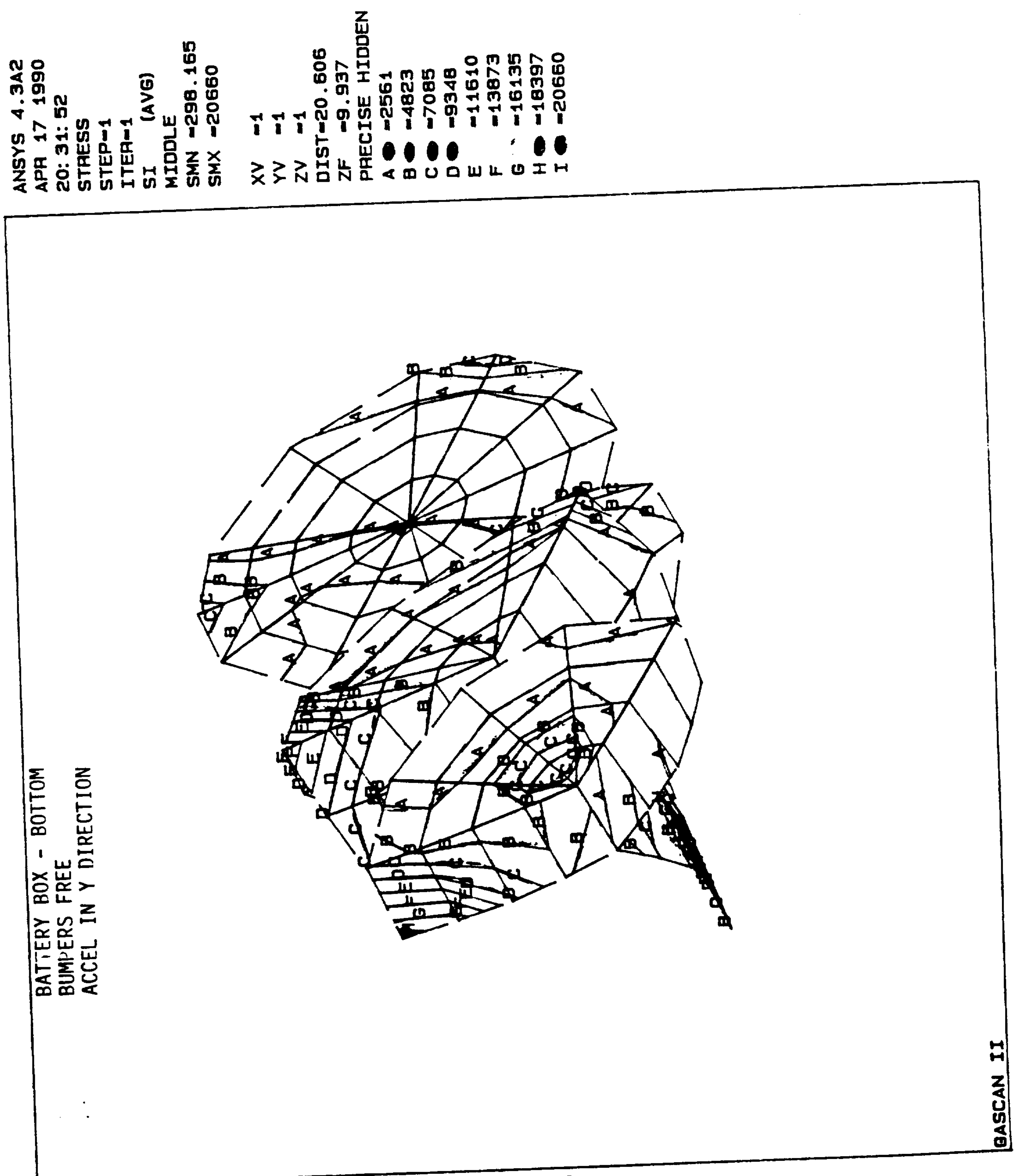
APR 17 1990
20:22:37
STRESS
STEP=1
ITER=1
SI (AVG)
MIDDLE
SMN =3338
SMX =63996
XV =1
YV =1
ZV =1
DIST=20.606
ZF =9.937
PRECISE HIDDEN
A =10078
B =16818
C =23557
D =30297
E =37037
F =43777
G =50517
H =57256
I =63996
BATTERY BOX - BOTTOM
BUMPERS FREE
ACCEL IN X-DIRECTION
GASCAN II

FIGURE - 4.0.1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20:31:52
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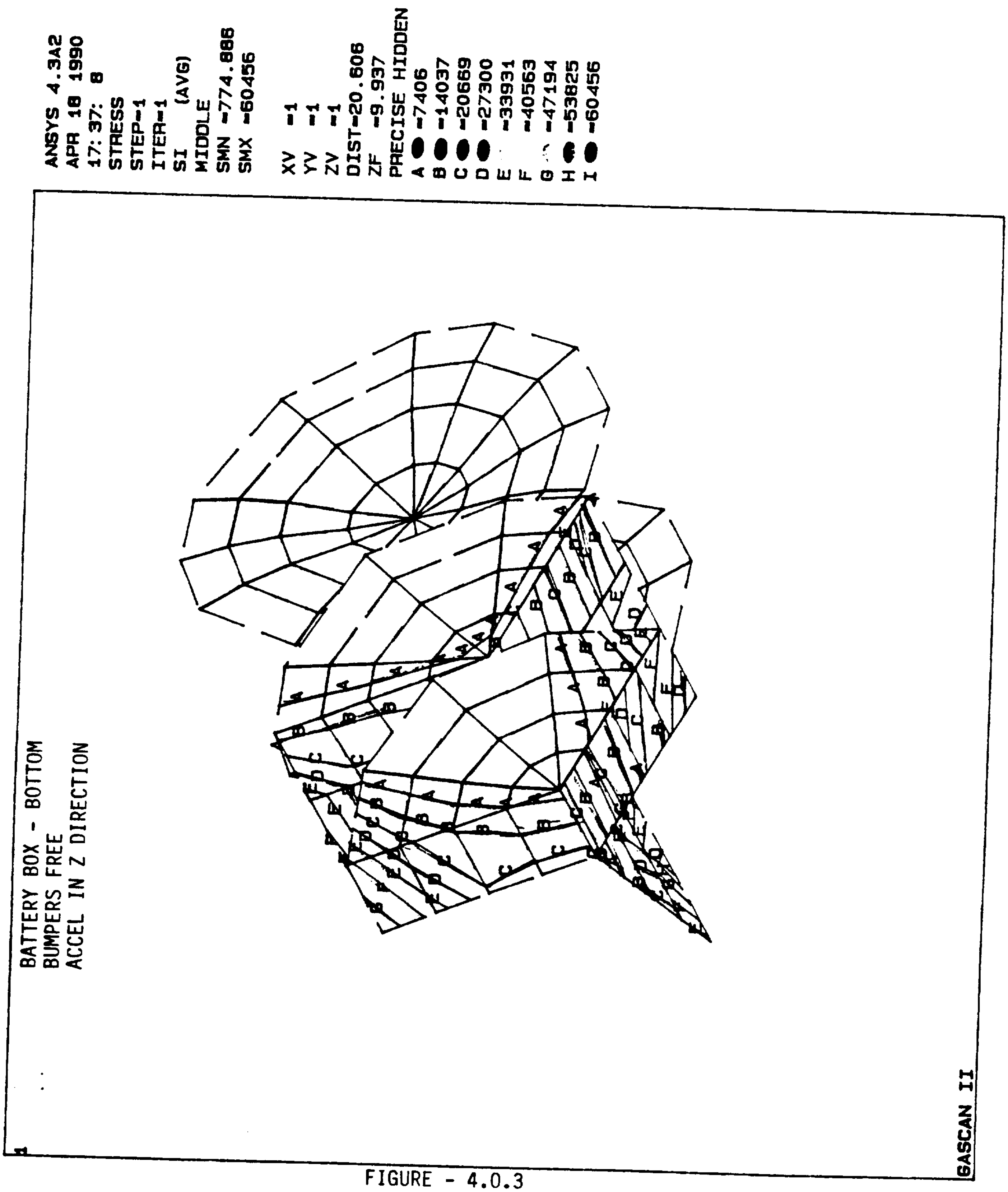
MIDDLE
SMN =298.165
SMX =20660
XV =1
YV =1
ZV =1
DIST=20.606
ZF =9.937
PRECISE HIDDEN
A =2561
B =4823
C =7085
D =9348
E =11610
F =13873
G =16135
H =18397
I =20660
BATTERY BOX - BOTTOM
BUMPERS FREE
ACCEL IN Y DIRECTION
GASCAN II

FIGURE - 4.0.2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17:37: 8
STRESS
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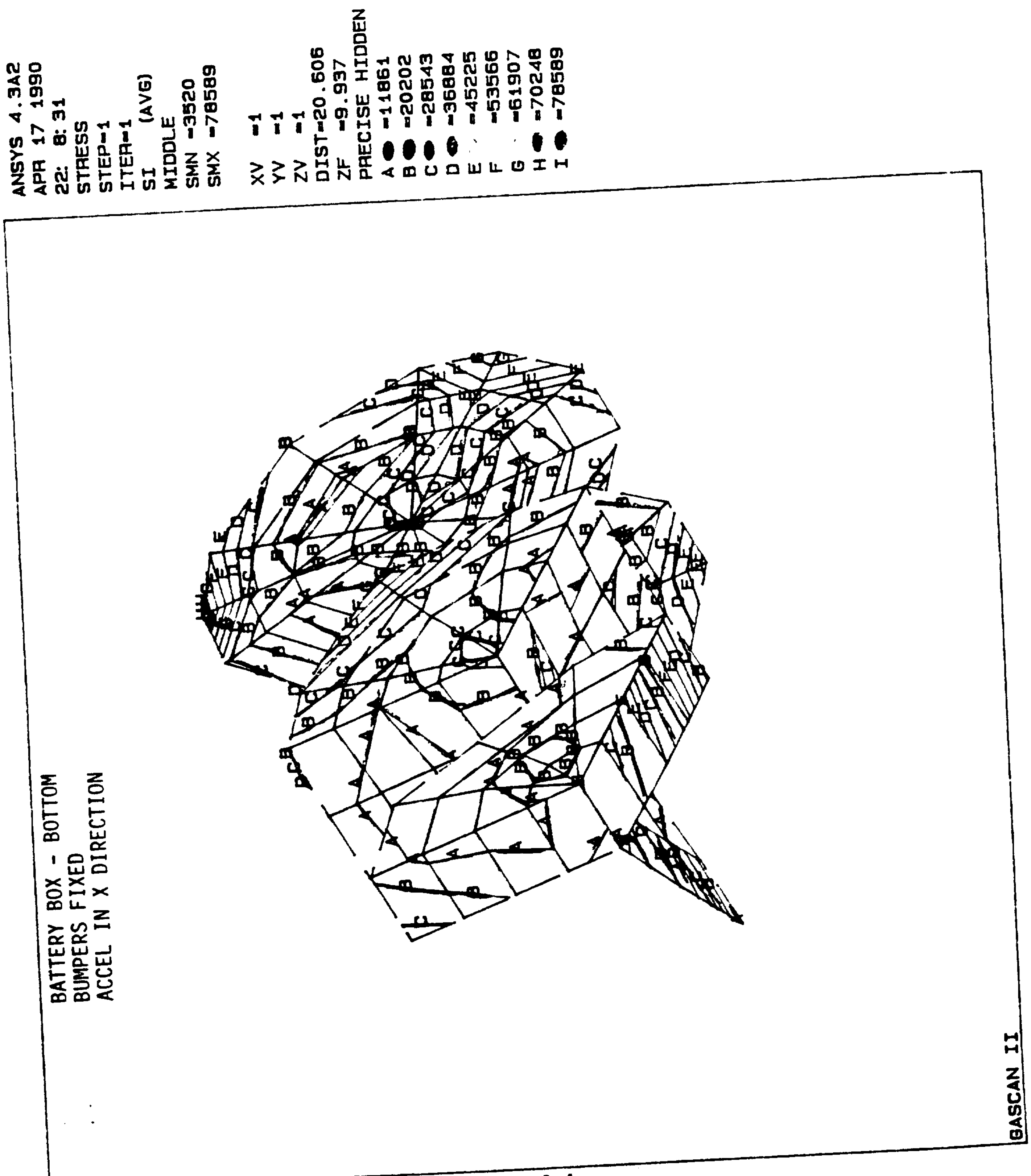
ITER=1
SI (AVG)
MIDDLE
SMN =774.886
SMX =60456
XV =1
YV =1
ZV =1
DIST=20.606
ZF =9.937
PRECISE HIDDEN
A =7406
B =14037
C =20669
D =27300
E =33931
F =40563
G =47194
H =53825
I =60456
BATTERY BOX - BOTTOM
BUMPERS FREE
ACCEL IN Z DIRECTION
GASCAN II

FIGURE - 4.0.3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22: 8:31
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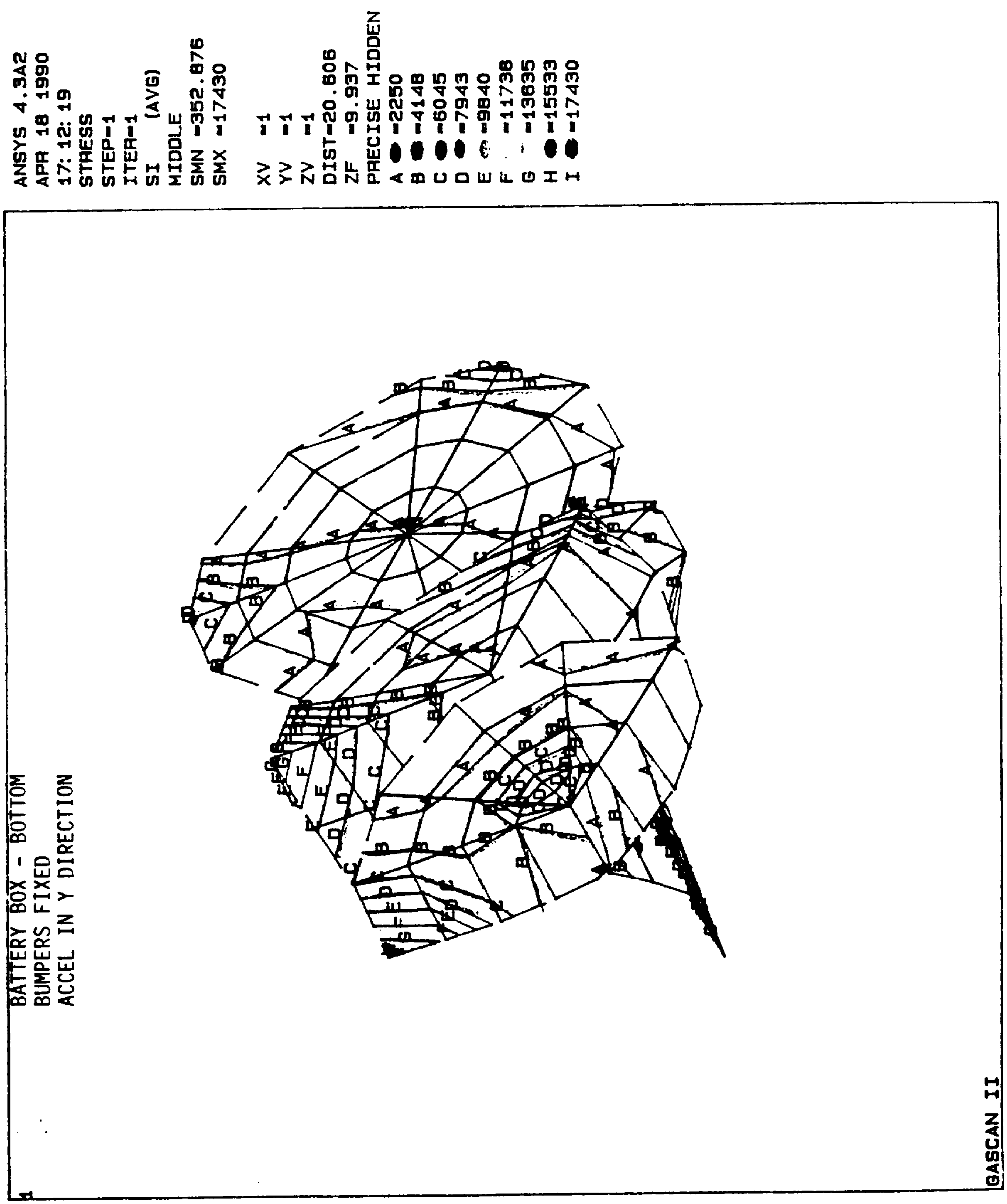
ITER=1
SI (AVG)
MIDDLE
SMN =3520
SMX =78589
XV =1
YV =1
ZV =1
DIST=20.606
ZF =9.937
PRECISE HIDDEN
A =11861
B =20202
C =28543
D =36884
E =45225
F =53566
G =61907
H =70248
I =78589
BATTERY BOX - BOTTOM
BUMPERS FIXED
ACCEL IN X DIRECTION
BASCAN II

FIGURE - 4.0.4


BATTERY BOX - BOTTOM
BUMPERS FIXED
ACCEL IN Y DIRECTION
ANSYS 4.3A2
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ITER=1
SI (AVG)
MIDDLE
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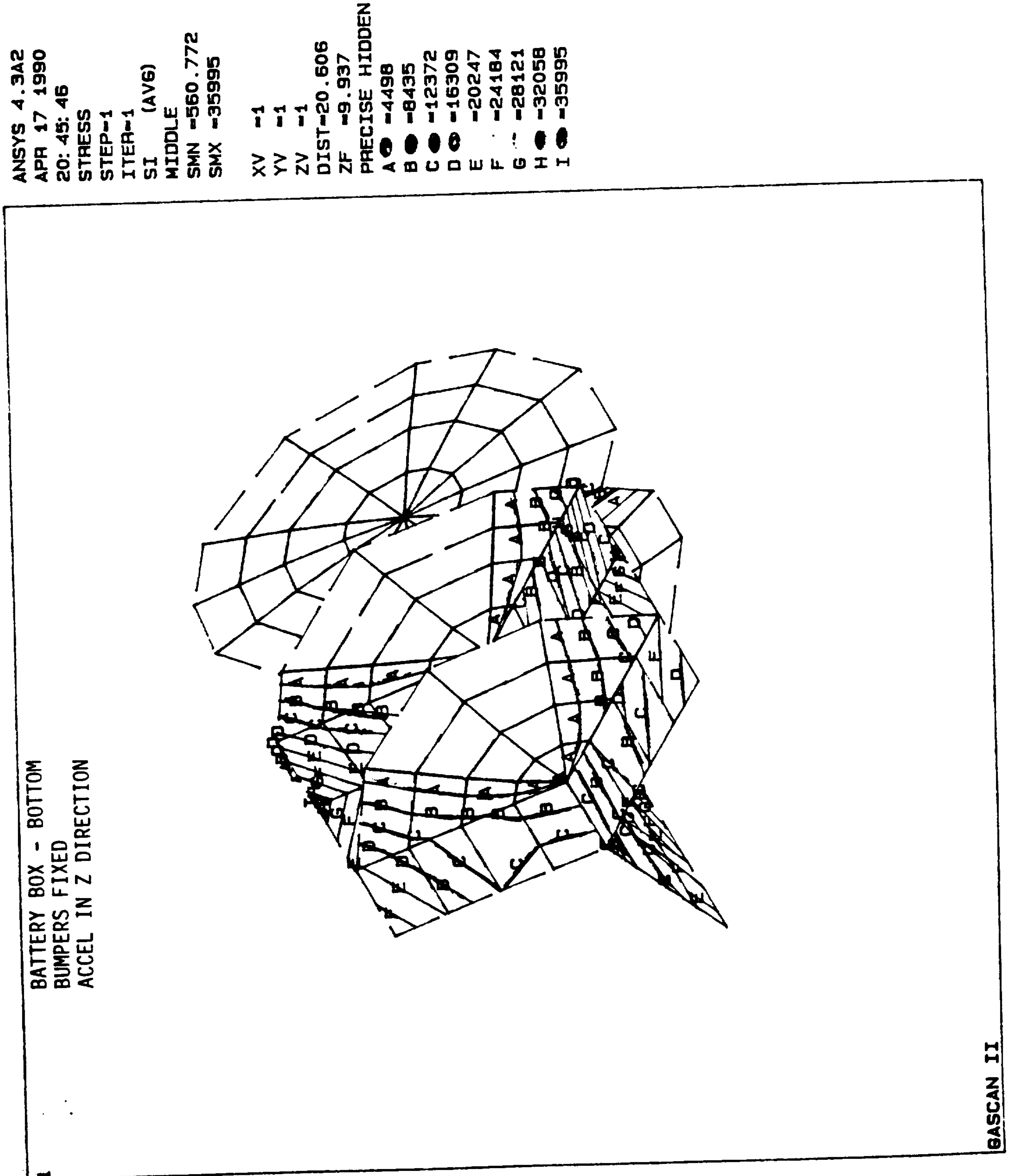
SMX =17430
XV =1
YV =1
ZV =1
DIST=20.606
ZF =9.937
PRECISE HIDDEN
A =2250
B =4148
C =6045
D =7943
E =9840
F =11738
G =13635
H =15533
I =17430
GASCAN II

FIGURE - 4.0.5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ITER=1
SI (AVG)
MIDDLE
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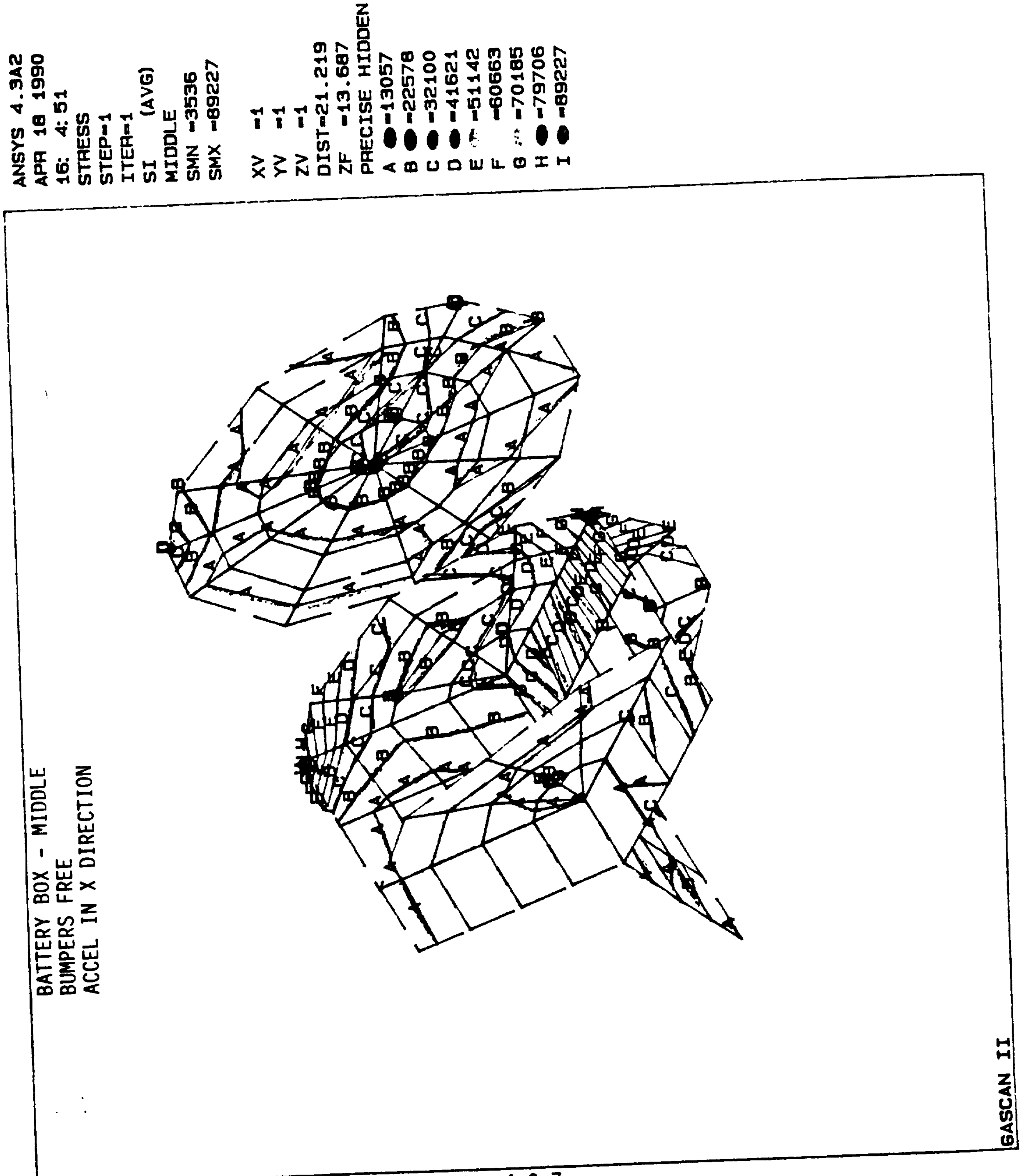
SMX =35995
XV =1
YV =1
ZV =1
DIST=20.606
ZF =9.937
PRECISE HIDDEN
A =4498
B =8435
C =12372
D =16309
E =20247
F =24184
G =28121
H =32058
I =35995
BATTERY BOX - BOTTOM
BUMPERS FIXED
ACCEL IN Z DIRECTION
BASCAN II

FIGURE - 4.0.6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ITER=1
SI (AVG)
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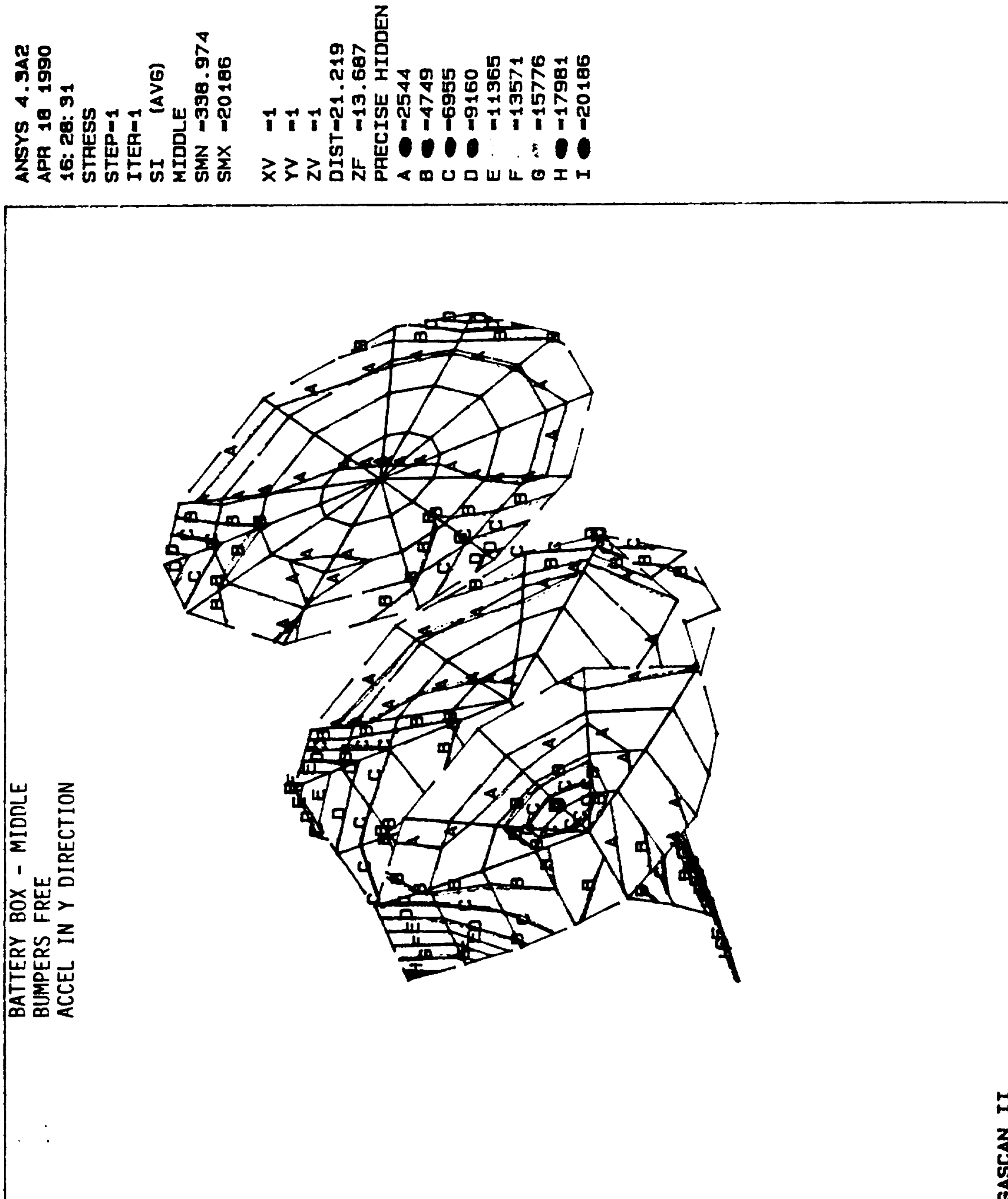
SMX =89227
XV =1
YV =1
ZV =1
DIST=21.219
ZF =13.687
PRECISE HIDDEN
A =13057
B =22578
C =32100
D =41621
E =51142
F =60663
G =70185
H =79706
I =89227
BATTERY BOX - MIDDLE
BUMPERS FREE
ACCEL IN X DIRECTION
GASCAN II

FIGURE - 4.0.7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MIDDLE
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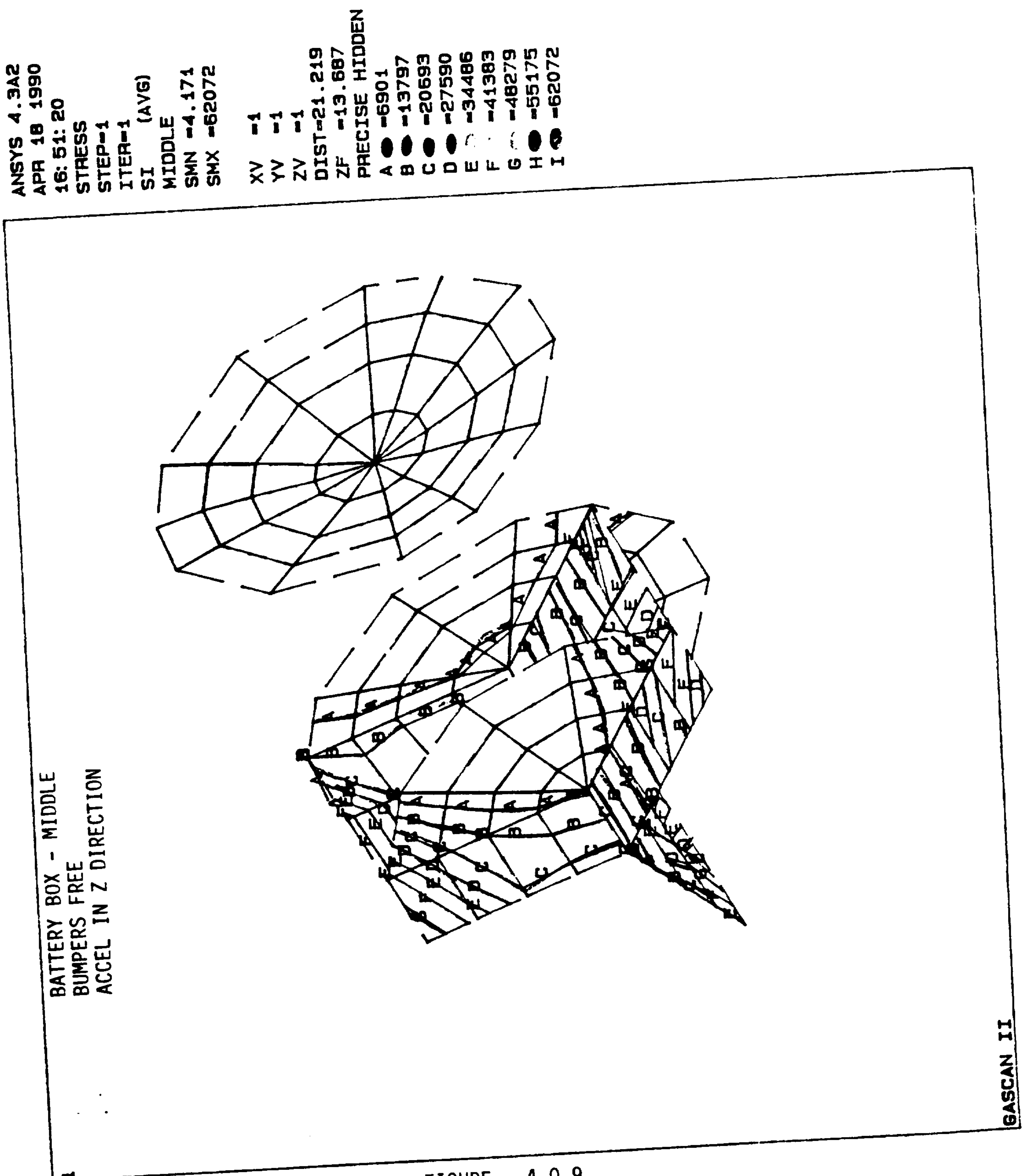
SMX =20186
XV =1
YV =1
ZV =1
DIST=21.219
ZF =13.687
PRECISE HIDDEN
A =2544
B =4749
C =6955
D =9160
E =11365
F =13571
G =15776
H =17981
I =20186
BATTERY BOX - MIDDLE
BUMPERS FREE
ACCEL IN Y DIRECTION
GASCAN II

FIGURE - 4.0.8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SI (AVG)
MIDDLE
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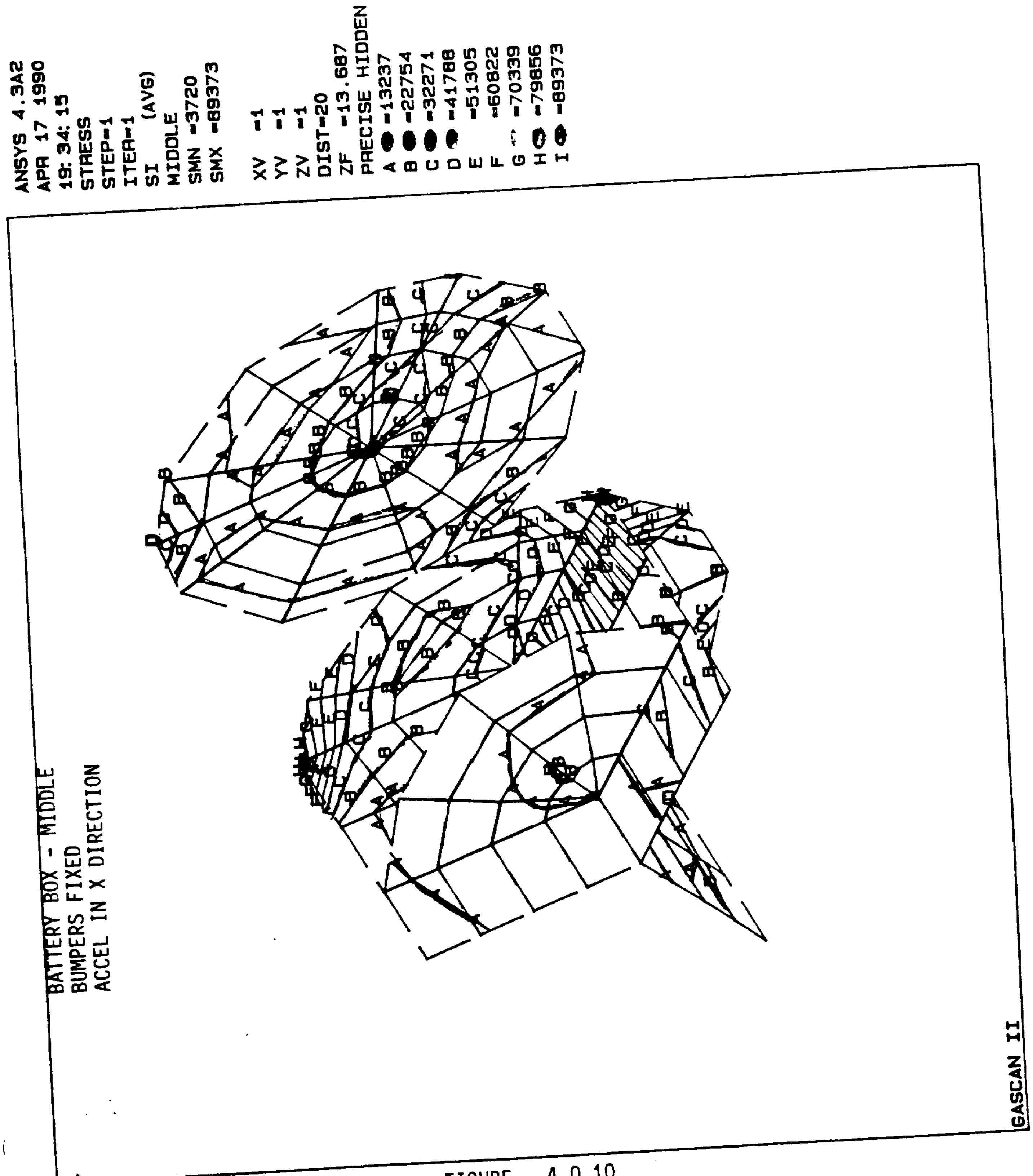
XV =1
YV =1
ZV =1
DIST=21.219
ZF =13.687
PRECISE HIDDEN
A =6901
B =13797
C =20693
D =27590
E =34486
F =41383
G =48279
H =55175
I =62072
BATTERY BOX - MIDDLE
BUMPERS FREE
ACCEL IN Z DIRECTION
GASCAN II

FIGURE - 4.0.9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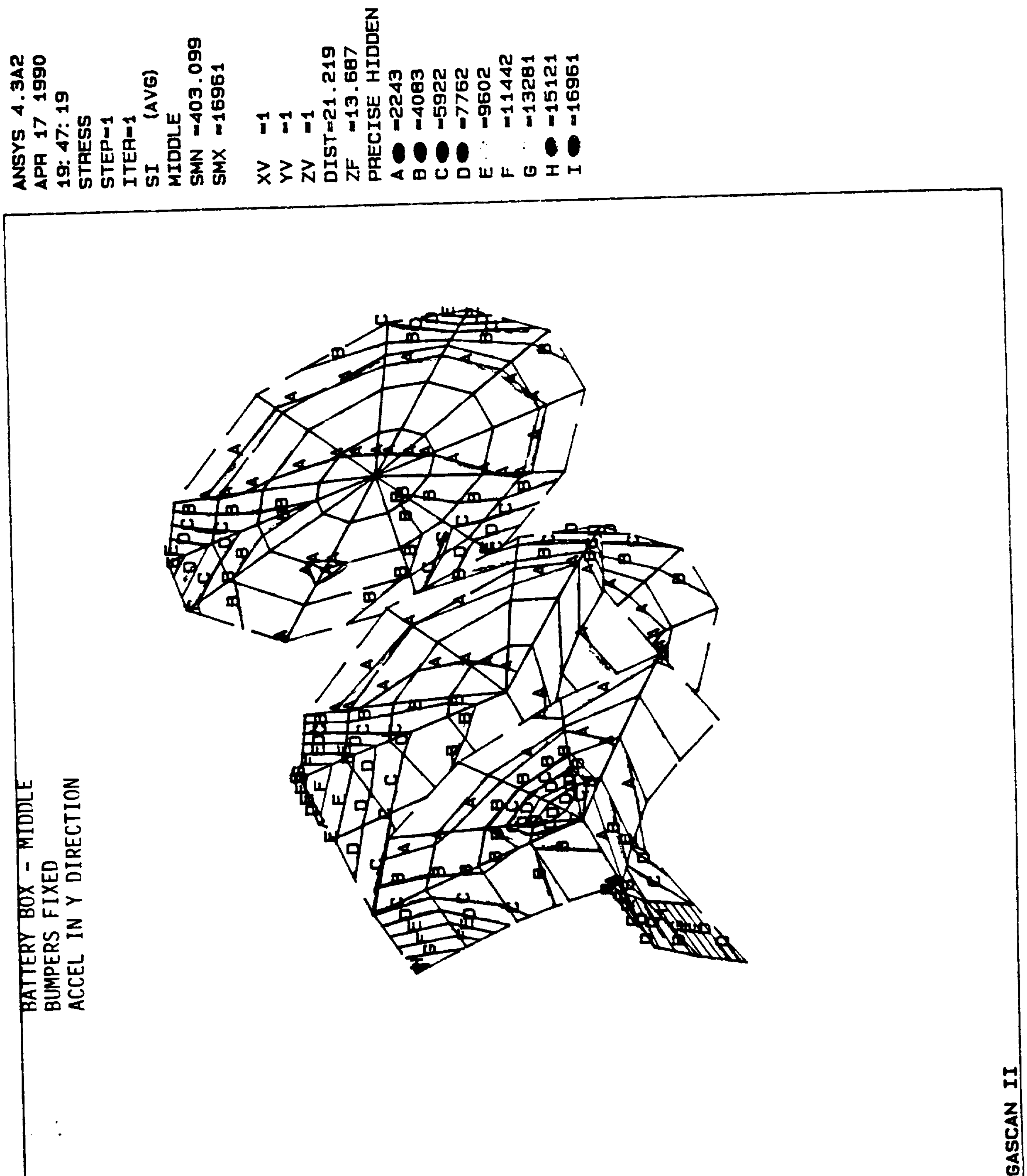
XV =1
YV =1
ZV =1
DIST=20
ZF =13.687
PRECISE HIDDEN
A =13237
B =22754
C =32271
D =41788
E =51305
F =60822
G =70339
H =79856
I =89373
BATTERY BOX - MIDDLE
BUMPERS FIXED
ACCEL IN X DIRECTION
GASCAN II

FIGURE - 4.0.10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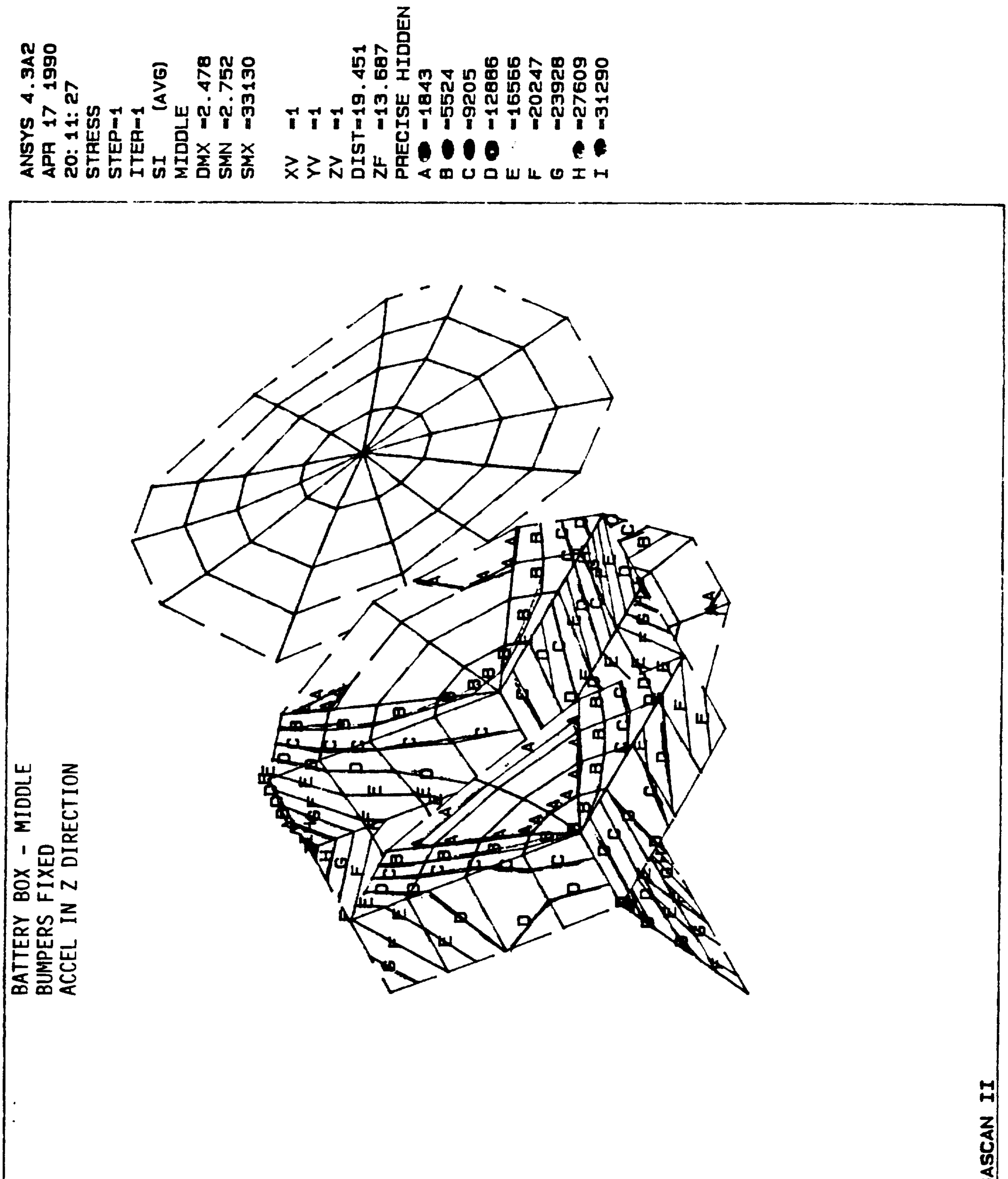
XV =1
YV =1
ZV =1
DIST=21.219
ZF =13.687
PRECISE HIDDEN
A =2243
B =4083
C =5922
D =7762
E =9602
F =11442
G =13281
H =15121
I =16961
BATTERY BOX - MIDDLE
BUMPERS FIXED
ACCEL IN Y DIRECTION
GASCAN II

FIGURE - 4.0.11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BUMPERS FIXED
ACCEL IN Z DIRECTION
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ITER=1
SI (AVG)
MIDDLE
DMX =2.478
SMN =2.752
SMX =33130
XV =1
YV =1
ZV =1
DIST=19.451
ZF =13.687
PRECISE HIDDEN
A =1843
B =5524
C =9205
D =12886
E =16566
F =20247
G =23928
H =27609
I =31290
GASCAN II

FIGURE - 4.0.12

The stresses also depended on direction of acceleration and the type of model. The first type was with the battery box on the bottom and the bumpers fixed in all directions, the second type was with the battery box on the bottom and the bumpers free in the z direction, the third was with the battery box above the rotational fluid flow experiment and the bumpers fixed in all directions and the fourth was with the battery box above the rotational fluid flow experiment and the bumpers free in the z direction. The models were each accelerated in the x, y, and z directions.

The lowest stresses occurred when GAScan II was accelerated in the y-direction. As seen in figures 4.0.2, 4.0.5, 4.0.8, and 4.0.11. (These are all the y plots), when you get away from the areas around the fixed points, the stresses are in the range of 2000psi to 5000psi which is well within the acceptable range for aluminum. The maximum allowable stress for aluminum is 37000psi in tension and compression. At the bumpers and mounting brackets, where GAScan II is fixed, the stresses are in the range of 15000psi to 20000psi, which is still in the acceptable range. For accelerations in the y direction the stresses are all within the acceptable range for all four conditions mentioned.

The accelerations in the x direction, as seen in figures 4.0.1, 4.0.4, 4.0.7, and 4.0.10, yielded high stresses at the bumper locations and the mounting brackets. Away from the areas that were fixed the stresses ranged from 10000psi to 13000psi. At the bumper locations the stresses were in the 60000psi to 90000psi range. In one model the stresses were considerably lower. This was the condition with the battery box above the rotational fluid flow experiment and the bumpers fixed in all directions. The stresses in this model ranged from 2000psi away from the bumpers to 33000psi at the bumper locations. This result was good because it justified moving the battery box above the rotational flow platform.

The accelerations in the z direction, figures 4.0.3, 4.0.6, 4.0.9, and 4.0.12, were the most important because this is the direction under which GAScan II would undergo the most acceleration. In the x direction and the y direction GAScan IIwas accelerated at 6g's. In the z direction the accelerations were 12g's. This is also the direction under which the bumpers were free to slide. Any movement in the previous directions would only be do to moments. The main concern was what GAScan II would do with the battery box above the rotational fluid flow experiment. In our worse case, where the bumpers would fail and slip, stresses were low in the plates. They were in the range of below 7000psi in the bottom plate, and between 7000psi and 14000psi in the middle plate. The high stresses occurred at the mounting brackets. These were the only three points holding the entire can from moving. Here is where the stresses reached the 60000psi range again due to small areas. These stresses carried into the flanges and the shelf and ranged between 25000psi and 48000psi. Some of these numbers were above the allowed maximums but could be lower if actual areas were used for the places where the bumpers were fixed.

We found that moving the battery box would not disrupt the structural integrity of GAScan II. Under certain conditions the stresses were slightly higher, in the order of 1000psi to

2000 psi, but in others it was considerably lower. To sum up the results, the design with the battery box above the rotational flow platform should meet NASA safety specifications but must be further analyzed with a finer mesh. Further detail design of the can should proceed from this design taking into account the problem areas specified above.

RECOMMENDATIONS

The following recommendations are made:

Battery Box Detail Design- The battery box and the layout of the batteries within the box must be designed. This project has used a conceptual design for the battery box but an actual design must be done. The venting of this box and the electrical layout for each experiment must also be designed.

Venting System Details-The venting system of this canister is designed to be through the centerpost. However the details of this plumbing must be properly designed.

Experiment Fastening Design-This MQP was concerned with the fastening of each component of the support structure. The next group must determine the fastening techniques of each experiment to this support structure. The use of angle irons, nuts and bolts, wingnuts, and welding must be determined as each experiment warrants. It is important that the assembly of each experiment within the payload be self contained within its own compartment,i.e. if an experiment needs to removed, then it should be easy to remove without reaching around flanges, moving other experiment hardware, or taking apart the support structure.

Modifications of the Central Processing Unit Area- Placement of the CPU, NASA Box, Low Power Data Acquisition System, and other system components must be integrated beneath the IPPE shelf and fastened to the support structure.

Bolt Sizing-ANSYS-The bolt sizes of the mounting brackets, bumpers, flanges, mid-plate, and centerpost must be sized based on the magnitudes of the stresses encountered at these positions. The ANSYS computer package should be used to make a fine mesh of these areas.

Modifications of Design- Based on the results of our ANSYS models, the design of the support structure should be modified to ensure that the NASA regulations are met. A major task is to determine whether the flange/plate assembly should be welded or screwed as our drawings specify. If the plate need not be moved after installation for any reason, then it can be welded. If for removal or mounting of experiments requires this plate to be removed from the flanges, then it should be screwed and these screws should be sized properly as mentioned above.

Weight Reduction- Presently the weight of GAScan II is over the 200 lb. limit. The next group must look into weight reduction not only of the support structure but also to battery weight and experiment weight.

Build and Prepare for Flight- Once the entire detailed design is complete, the canister must be built and assembled. Once each component is added, a shaker table test must be completed to ensure the frequency limit is met.

Finite Modeling- A finer model must be made to diverge to the actual stress distribution in the GAScan. The 4.4 version of ANSYS is recommended for use because it has the capability to mesh elements in desired areas. If the ANSYS computer package is not available at the Mitre facility, it is recommended to use the finite modeling packages that they do offer. The WPI modeling packages have a limited wave front. The finer model of the can must be done at Mitre.

The fine model of GAScan II should have few elements in the low stressed areas and a high number of elements in the high stressed areas. The areas that require a lot of elements are the mounting brackets, outer edges of each flange, and the bumper locations. The central shaft should be modeled using plate elements. This allows the programmer to see how the stresses vary around the shaft and near the bolt hole locations. If a new modeling package is used, it is recommended that the mounting brackets and the bumpers be modeled with the can. If ANSYS is used, the model should include the mounting brackets and bumpers by using compatible elements. (six-degree of freedom nodes mesh with six-degree of freedom nodes). When this model is completed, it should contain, at most, two thousand elements. This will lower the computer time to solve the model.

A second model should be done that includes all the holes that will be cut in the flanges and plates. This model should be a simple modification of the previous model. The purpose of the model is to investigate possible stress concentrations due to these holes.

The last analyses performed should be the vibrational analysis. These models are also generated from the original model. The changes in the commands are the same as those discussed in section 3.5.3.8.7 .

6.0 ENDNOTES

[1]J. Beeck and J. Kamhazi, Get-Away Special Canister Structural Design, 74.

[2]NASA, Get-Away Special Payloads-Experimenter Handbook, 18.

[3]Ibid., 19.

[4]Ibid., 21.

[5]Ibid., 23.

[6]Ibid., 25.

[7]W. Elliott, Ionisphere Propagation and Properties Experiment.

[8]M. Barry, Rotational Fluid Flow Experiment.

[9]J. Siemasko, Micro-Gravity Ignition Experiment.

[10]J. Beeck and J. Kamhazi, Get-Away Special Canister Structural Design, 72.

[11]NASA, Get-Away Special Payloads-Safety Manual, A-5.

[12]Ibid., A-4.

[13]NASA, Get-Away Special Payloads-Experimenters Handbook, 23.

[14]G. DeSalvo and R. Gorman, ANSYS Engineering Analysis System User's Manual, sec. 4.63.

[15]Ibid., sec. 4.63.

[16]Ibid., sec. 4.4.

[17]Ibid., sec. 4.4.

[18]Ibid., sec. 4.21.

[19]A. Buresi and O. Sidebottom, Advanced Mechanics and Materials, 158.

[20]R. Hibbeler, Engineering Mechanics-Statics 4th ed., 296.

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DeSalvo, G.J. and Gorman, Robert W., ANSYS Engineering Analysis System User's Manual vol. 1 and 2 (Houston,Pa.) 1989

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________. Get Away Special Payloads-Experimenter Handbook 1986.

Siemasko, J. and others, Micro-Gravity Ignition Experiment MQP WPI 1990.

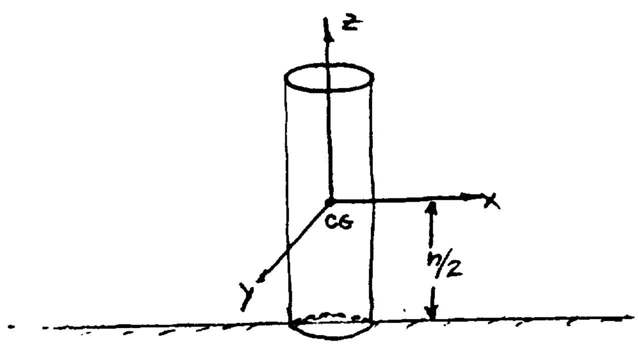
Yankee, H.W. Engineering Graphics (PWS Publishers Boston) 1985.

Appendix 1

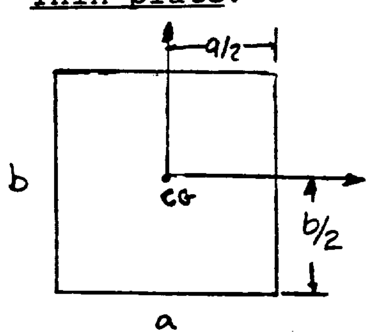
HAND CALCULATIONS OF CENTER OF GRAVITY FOR INTEGRATED SUPPORT STRUCTURE

To get the center of gravity (CG) for the entire structure it was necessary to compute the CG for each individual piece and then add them. The center of gravity is given in cartesian coordinates.

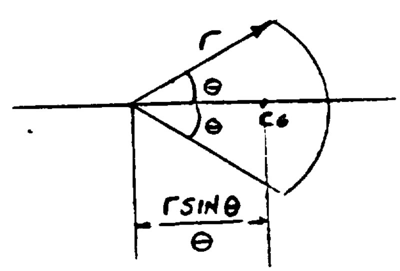
Cylinder (Solid or Hollow): CG along z axis a h/2



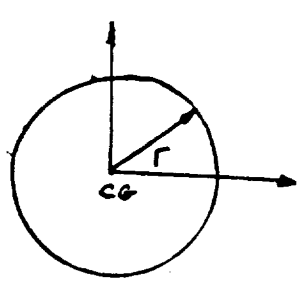
Thin plate:



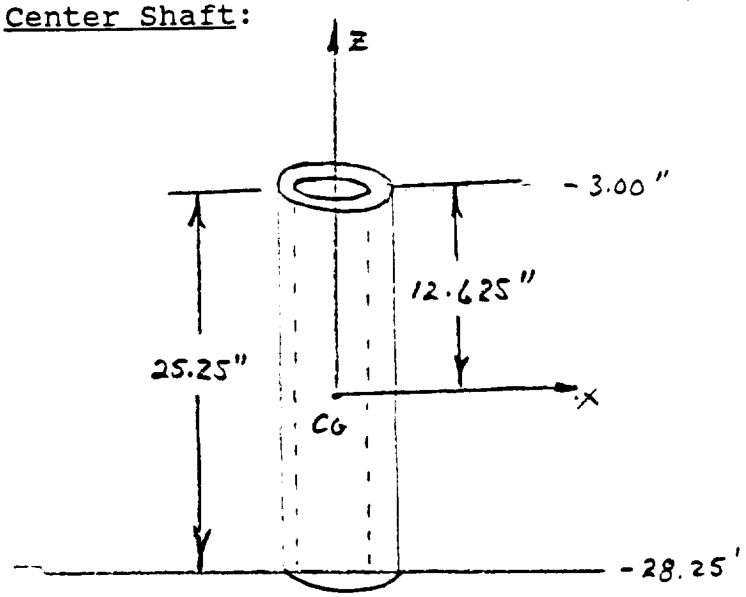
Circular arc:



Circular disk:



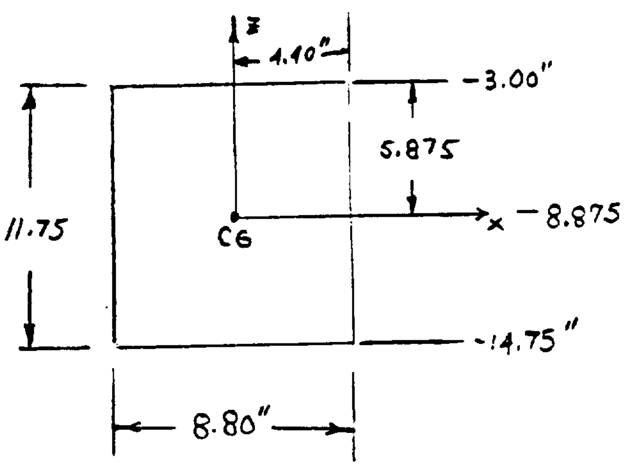
Center Shaft:

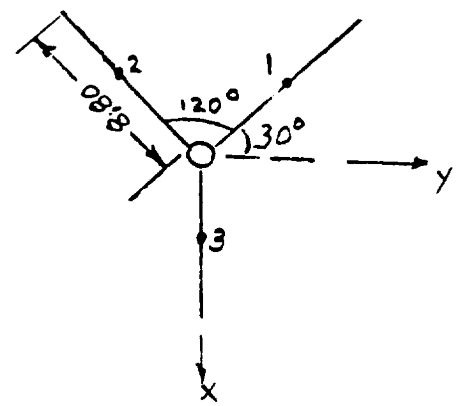


OD = 2.00"
ID = 1.50"

CG= (0,0,-15.625")

Flanges:



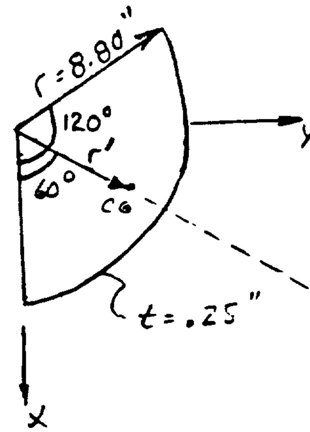


$X_1 = 4.4'' \sin -30° = -2.2''$
$Y_1 = 4.4'' \cos -30° = 3.811''$

$X_2 = 4.4'' \sin -150° = -2.2''$
$Y_2 = 4.4'' \cos -150° = -3.811''$

CG_1= (-2.2",3.811",-8.875")
CG_2= (-2.2",-3.811",-8.875")
CG_3= (4.4",0,-8.875")

Shelf:



$$r' = \frac{r \sin\theta}{\theta} = \frac{(8.80)(\sin 60^\circ)}{60^\circ\left(\frac{2\pi \text{ rad}}{360^\circ}\right)} = \frac{7.621}{1.0472} = 7.278 \text{ in}$$

$x = r' \cos\theta = 7.278 \cos 60^\circ$

$y = r' \sin\theta = 7.278 \sin 60^\circ$

$z =$ depth of plate $+ t/2$

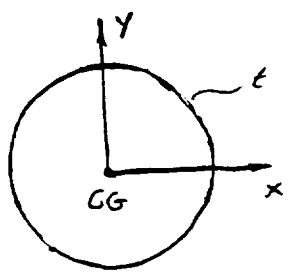
$x = 3.639$ in

$y = 6.303$ in

$z = -7.525$ in

CG= (3.639",6.303",-7.525")

Circular Plates: (middle and bottom)

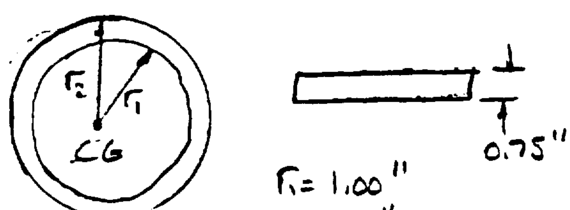


$t_1 = 0.25"$ $\quad z_1 = -14.75 - t/2 = -14.875$

$t_2 = 0.25"$ $\quad z_2 = -28.00 - t/2 = -28.125$

CG_1= (0,0,-14.875")
CG_2= (0,0,-28.125")

Slip Ring:



$r_1 = 1.00"$

$r_2 = 1.5"$

$z = -20.25 + 0.75/2$

$z = -20.625"$

CG= (0,0,-20.625")

Equations for finding the Center of Gravity fo a three dimensional body.

$$X=\frac{\Sigma X'W}{\Sigma W} \qquad Y=\frac{\Sigma Y'W}{\Sigma W} \qquad Z=\frac{\Sigma Z'W}{\Sigma W}$$

X', Y', and Z' represent the algebraic distance from the center of gravity of each component to the origin. ΣW represents the sum of all the weights of the components, or simply the total weight of the structure.(20)

Calculation of weights of each component

Weight(W) = Volume(V) * density(p)

density of Aluminum 6061-T6 = 0.098 lb/in^3

Center Post:

$$V = \pi h(r_1^2 - r_2^2)$$
$$V = \pi(25.25in)(1^2 - 0.75^2)$$
$$V = 34.71in^3$$
$$W = (34.71in^3)(0.098lb/in^3)$$
$$W = 3.4\ lbs$$

Flanges:

$$V = l * h * t$$
$$V = (8.8in)(11.75in)(0.25in) * 3(\text{no. of flanges})$$
$$V = 77.55in^3$$
$$W = (77.55in^3)(0.098lb/in^3)$$
$$W = 7.6\ lbs$$

Shelf:

$$V = \theta r^2 t$$
$$V = 60^\circ(\pi/180)(8.8in)\ (0.25in)$$
$$V = 20.274in^3$$
$$W = (20.274in^3)(0.098lb/in^3)$$
$$W = 1.99lbs$$

Circular Plates:

$$V = \pi r^2 t$$
$$V = \pi(19.75/2)^2(0.25) * 2(\text{no. of plates})$$
$$V = 153.2in^3$$
$$W = (153.2in^3)(0.098lb/in^3)$$
$$W = 15.01lbs$$

Slip Ring:

$$V = \pi(r_1^2 - r_2^2)h$$
$$V = \pi(1.5^2 - 1^2)(0.75in)$$
$$V = 2.95in^3$$
$$W = (2.95in^3)(0.098lb/in^3)$$
$$W = 0.29lbs$$

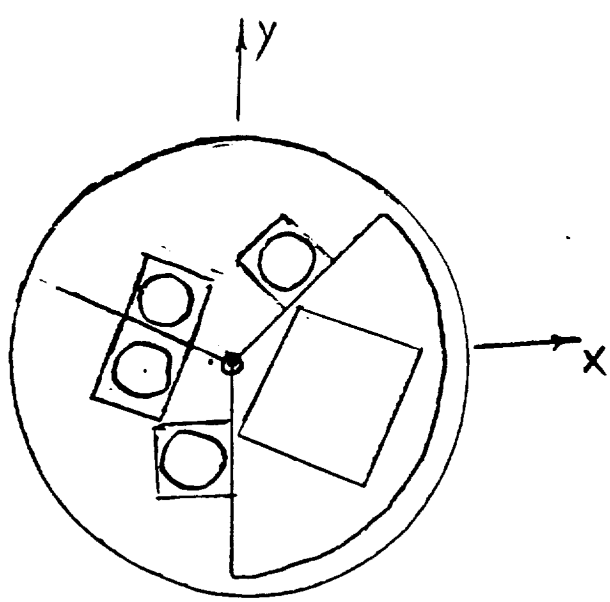
3 Mounting Brackets (approx.)

$$V = (1.5in)(7.0in)(0.875in) + 2(2.188in)0.875in)(0.375in)$$
$$V = 10.623in^3$$
$$W = (10.623in^3)(0.098lb/in^3)$$
$$W = 1.04lbs \text{ each}$$
$$W = 3.12lbs \text{ total}$$

$$X = \frac{\Sigma X'W}{\Sigma W} = \frac{-45.363}{187.37} = -0.242in$$

$$Y = \frac{\Sigma Y'W}{\Sigma W} = \frac{74.093}{187.37} = 0.395in$$

$$Z = \frac{\Sigma Z'W}{\Sigma W} = \frac{-3306.01}{187.37} = -17.644in$$



PART	X	Y	Z	WEIGHT	XW	YW	ZW	VOLUME
CENTERSHAFT	0	0	-15.625	3.4	0	0	-53.125	34.71 IN^3
FLANGE 1	-2.2	3.cl	-8.875	2.53	-5.56	9.642	-22.454	25.85
FLANGE 2	-2.2	-3.811	-8.875	2.53	-5.56	-9.642	-22.454	25.85
FLANGE 3	4.4	0	-8.875	2.53	11.132	0	-22.454	25.85
SHELF	3.639	6.303	-7.525	1.99	-27.384	12.543	-14.975	20.27
MID PLATE	0	0	-14.875	7.51	0	0	-111.711	76.60
SUPPORT RING	0	0	-20.625	.29	0	0	-5.981	2.95
BOTTOM PLATE	0	0	-28.125	7.51	0	0	-211.219	76.60
BRACKET 1	0	-9.45	-2.75	1.04	0	-9.828	-2.86	10.623
BRACKET 2	8.184	4.725	-2.75	1.04	8.511	4.914	-2.86	10.623
BRACKET 3	-8.184	4.725	-2.75	1.04	-8.511	4.914	-2.86	10.623
ROT. FLOW	0	0	-24.0	35.04	0	0	-840.96	2450.835
IPPE	2.469	4.26	-9.00	9.0	22.221	38.34	-81.0	755.67
MICRO 6-1	3.041	4.642	-15.125	5.0	15.21	23.31	-75.625	753.12
MICRO 6-2	-3.041	4.642	-15.125	5.0	-15.21	23.31	-75.625	753.12
MICRO 6-3	-5.54	.313	-15.125	5.0	-27.7	1.565	-75.625	753.12
MICRO 6-4	-2.5	-4.955	-15.125	5.0	-12.5	-24.775	-75.625	753.12
BATTERY BOX	0	0	-17.5	91.92	0	0	-1608.60	1531.77
TOTAL				187.37	-45.363	74.093	-3306.01	8071.654

ELEMENT FORMATION	ELEM= 35	L.S.= 1	ITER= 1	CP=	62.840
ELEMENT FORMATION	ELEM= 143	L.S.= 1	ITER= 1	CP=	93.370
ELEMENT FORMATION	ELEM= 172	L.S.= 1	ITER= 1	CP=	124.020
ELEMENT FORMATION	ELEM= 211	L.S.= 1	ITER= 1	CP=	154.620
ELEMENT FORMATION	ELEM= 240	L.S.= 1	ITER= 1	CP=	184.720

***** CENTROID, MASS, AND MASS MOMENTS OF INERTIA *****

CALCULATIONS ASSUME ELEMENT MASS AT ELEMENT CENTROID

TOTAL MASS = 188.72

CENTROID	MOM. OF INERTIA ABOUT ORIGIN	MOM. OF INERTIA ABOUT CENTROID
XC = 0.35324E-01	IXX = 0.3412E+05	IXX = 9490.
YC = 0.46071	IYY = 0.3403E+05	IYY = 9437.
ZC = 11.416	IZZ = 5286.	IZZ = 5245.
(TAKEN FROM BOTTOM	IXY = -147.1	IXY = -144.0
of CAN)	IYZ = -1829.	IYZ = -836.1
	IZX = -278.6	IZX = -202.5

ONLY THE FIRST REAL CONSTANT MASS TERM IS USED FOR THE STIF21 ELEMENTS.
ONLY THE FIRST REAL CONSTANT MASS TERM IS USED FOR THE STIF21 ELEMENTS.
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*** MASS SUMMARY BY ELEMENT TYPE ***

'PE	MASS
1	25.2612
2	3.86770
3	1.28625
4	0.279909
5	0.377606
6	0.477520
7	0.576401
8	0.566307
9	0.276904E-08
10	9.00000
11	20.0000
13	35.0400
14	91.9920

RANGE OF ELEMENT MAXIMUM STIFFNESS IN GLOBAL COORDINATES
MAXIMUM= 0.337229E+11 AT ELEMENT 173.
MINIMUM= 0.117629E+07 AT ELEMENT 105.

*** ELEMENT STIFFNESS FORMULATION TIMES

TYPE	NUMBER	STIF	TOTAL CP	AVE CP
1	148	63	136.480	0.922
2	7	4	0.400	0.057
3	3	4	0.180	0.060
4	3	4	0.210	0.070
5	3	4	0.150	0.050
6	3	4	0.230	0.077
7	3	4	0.180	0.060
8	3	4	0.150	0.050
9	65	4	5.260	0.081
10	1	21	0.000	0.000