

APPLICATION OF NASTRAN TO A FLUID SOLIDS UNIT
IN THE PETROLEUM INDUSTRY

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SUMMARY

The application of NASTRAN to the design of a fluid solids unit plenum/cyclone/dipleg assembly is described. The major loads considered are thermal, pressure and gravity. Such applications are of interest in the petroleum industry since the equipment described is historically critical, and, to the best knowledge of the author, has not previously been fully analyzed.

INTRODUCTION

Traditionally, mechanical equipment engineers at Exxon design and specify certain pressure vessel internals which are deemed critical to good process unit performance. Of the many unit operations carried out in a refinery, the design of the internals for the fluid solids process presents perhaps one of the most difficult challenges to the designer. Until recently, such designs were based upon many years of cumulative company experience, and whatever strength of materials and pressure vessel code approximations were available. This paper deals with the relatively new application at Exxon of design by use of numerical analysis computer codes. This change in approach has occurred for a number of reasons, including continually increasing thermal and pressure loadings for greater processing efficiency, higher cost of labor and materials and the availability of numerical computer codes such as NASTRAN. This paper describes the first plenum chamber/cyclone/dipleg assembly numerically analyzed at Exxon.

STRUCTURAL LOADINGS IN THE FLUID SOLIDS REGENERATOR

A brief description of the fluid solids process is essential to understanding the nature of the loadings on fluid solids unit internals. Figure 1 is a schematic drawing of the process flow. In the reactor, oil is "cracked" at high temperature in the presence of a finely divided fluidized catalyst. This cracked gaseous hydrocarbon passes through several stages of cyclones to recover the catalyst, through the reactor plenum and out for further processing. The cracking process leaves a carbon deposit on the catalyst, which is continuously transferred to a regenerator where the carbon is burnt off. The combustion gases pass through several stages of cyclones, a plenum and from there out of the regenerator.

Both vessels are internally lined with an insulating refractory. However, since air is injected to cause combustion, the regenerator plenum runs at a higher temperature (usually 650 to 750°C) and is, therefore, structurally much more critical than the reactor plenum. Occasionally, combustion occurs for short periods in the dilute phase above the fluid bed, and, in the cyclones. This can raise local cyclone temperatures by several hundred °C during an upset.

In addition to the thermal loadings described above, another major loading occurs due to the pressure differential across the cyclone stages separating the plenum from the reactor. This differential is usually about 14 kPa but may double during unit upsets.

The final major loading is the gravity loading. In addition to the structural masses of the diplegs, cyclones and plenum, there exist substantial nonstructural mass gravity loadings due to erosion-resistant refractory linings in the cyclones and, in some applications, the mass of catalyst in a plugged cyclone.

PHYSICAL LAYOUT AND MODELLING ASSUMPTIONS

Figures 2 and 3 give the plenum planform and elevation for the particular regenerator plenum which was analyzed. In this application, the plenum is joined to the head by an inner and outer skirt. There are ten primary/secondary cyclone pairs which are arranged with the primaries alternately inside and outside the secondaries. The secondaries are supported directly from the plenum floor, whereas the outer and inner primaries are partly supported by rods. Determination of rod loads under the various loadings was one of the objectives of the analysis.

As shown in Figure 2, a 36° segment of the planform was modelled. Since only symmetrical loadings were applied, symmetry boundary conditions were enforced along these meridional planes. Study of Figure 2 will show that true symmetry is not quite satisfied along these boundaries. However, the approximation is close, and, furthermore, the usual compromise with cost must be made. Future NASTRAN levels which permit periodic symmetry will be of great value in such applications.

The model is delineated circumferentially as shown in Figure 3. Displacement boundary conditions for the skirt cylinders were calculated by hand.

In setting up the load cases for the NASTRAN analysis, three general load categories were recognized, i.e., gravity, pressure, and thermal. Since the thermal displacement boundary conditions along the circumferential cuts were at least one order greater than pressure displacement boundary conditions, thermal displacement boundary conditions were assumed for all loadings in the region, and a separate load case was run for the thermal displacement boundary conditions alone. This permitted all solutions to be developed with only one decomposition and the use of the NASTRAN LOAD and SUBCOM cards.

Figure 4 shows the coordinate systems utilized in mesh generation. The ability of NASTRAN to accept multiple coordinate systems worked to great advantage in applying in-house computer codes for mesh generation.

THE NASTRAN MODELS

The complete model is shown in Figure 5. Figure 6 shows the upper portion of the model in more detail. CQUAD2 and CTRIA2 bending/membrane elements were used to model the cylindrical skirts, the head, the floor and part of the secondary cyclone barrels. These cyclone barrels were terminated one cylinder decay length below the floor by a CBAR beam element "spider" at which point a transition was made to stepped CBAR beam elements to model the remainder of the cyclone, the dipleg, and the dipleg bracing. The primary cyclones, their diplegs, and the connecting ducts between primary and secondary cyclones were all modelled using CBAR beam elements. The hanger rods were modelled using CROD rod elements. CQDMEM membrane elements were used for the floor beams.

As mentioned earlier, separate models were developed for the outer cylinder skirt to head intersection. In addition to a high meridional thermal gradient in this area, there is a change in material properties where the stainless steel skirt joins the cooler mild steel shell. By studying stress response to thermal fields arising from various insulation and structural arrangements of the skirt cylinder, it was possible to optimize this detail.

The model in Figure 7 is a symmetry wedge of this skirt to head intersection which utilizes a pad plate. The "tails" are sufficiently long such that temperature boundary conditions calculated from one-dimensional solutions could be applied at the ends. For the plate elements, film coefficients and environmental temperatures on either side were combined to form an equivalent one-sided film coefficient and environmental temperature. In the solid elements film coefficients and environmental temperatures were applied in the usual way, except for the gap behind the pad plate. Here, the environmental temperature was guessed, and an iterative approach adopted.

Symmetry conditions were enforced on the meridional planes for both thermal and stress solutions. In both cases, the number of unknowns was halved by using multipoint constraints, NASTRAN MPCs, to tie like meridional points. NASTRAN, CHEXA2, and CWEDGE solid elements were used in the junction zone and CQUAD2 plate-membrane elements were used in the "tails".

Figure 8 shows an alternative model studied wherein the junction between stainless and mild steel components is located 5 cm below the intersection point. Boundary conditions were developed as described previously for the solid model. This model consists entirely of CQUAD2 elements.

The large overall model contained 6787 degrees of freedom. It was solved on the IBM 360-168 computer, with high speed multiplier, at a region size of 2048K bytes. The semibandwidth was 279 and there were 258 active columns. The large semibandwidth was due to the lack of a bandwidth optimizer being operational at Exxon at that time. Decomposition time was 2458 CPU seconds.

DISCUSSION OF RESULTS

In assessing the results, much use was made of NASTRAN deformed plots. Because of the different nature of thermal and sustained loads, three general load case categories were established. These are mechanical loads (which consist of pressure and gravity loadings), thermal loads, and combined loads (which are the sum of the first two).

Figure 9 is a meridional cut near the center of the wedge showing underlaid deformations due to mechanical loads. The effects of pressure on the outer skirt and head, as well as the effect of the hanger rod on the head are clearly evident. The effect of the gravity load of the cyclone/diaphragm assembly on the floor deformations is also clear.

Figure 10 shows the effect of combined loads along the same meridian. Since the thermal load induced displacement field is at least an order greater than the mechanical load induced displacement field, essentially only thermal displacements can be seen. High local bending at the outer skirt to shell junction can be clearly identified in this plot.

A study of the stress printout showed that the structure as designed, with a few minor modifications, was indeed good for all the intended loads. The design pressure differential across the plenum was found to be easily accommodated within allowable stresses. This was found to be true in spite of the fact that it was twice that which would have been allowed by previously developed empirical procedures. These procedures limit the pressure differential over the planform area to the equivalent gravity effect of the head, floor, cyclones and diplegs.

The one point of very high stress was the junction area between the outer cylindrical skirt and the head under thermal load. Figure 11 shows the underlaid deformed plot of the design utilizing a mild steel pad plate. Figure 12 shows deformation vectors for the design employing a 5 cm long mild steel skirt stub, at which point the junction to the stainless steel skirt is made. Of the two designs, the latter shows lower stresses, and is the one which was finally adopted.

CONCLUSIONS

This analysis has shown that modern applied mechanics computer codes such as NASTRAN can be effectively used in the petroleum industry to remove overly conservative empirical restrictions which have developed over the years. In this instance, not only was the empirical restriction on differential plenum pressure removed, but the analysis also focused attention upon the real area of high stress; namely, the skirt to head intersection. Using NASTRAN heat transfer and structural capabilities, a junction design was developed which brought stresses within allowable limits.

Various improvements planned for future NASTRAN levels would be most valuable now. Specifically, the ability to treat periodic symmetry, as well as the ability to handle constitutive nonlinearities under thermal loadings would be most welcome.

FLOW DIAGRAM OF TYPICAL FLUID SOLIDS UNIT

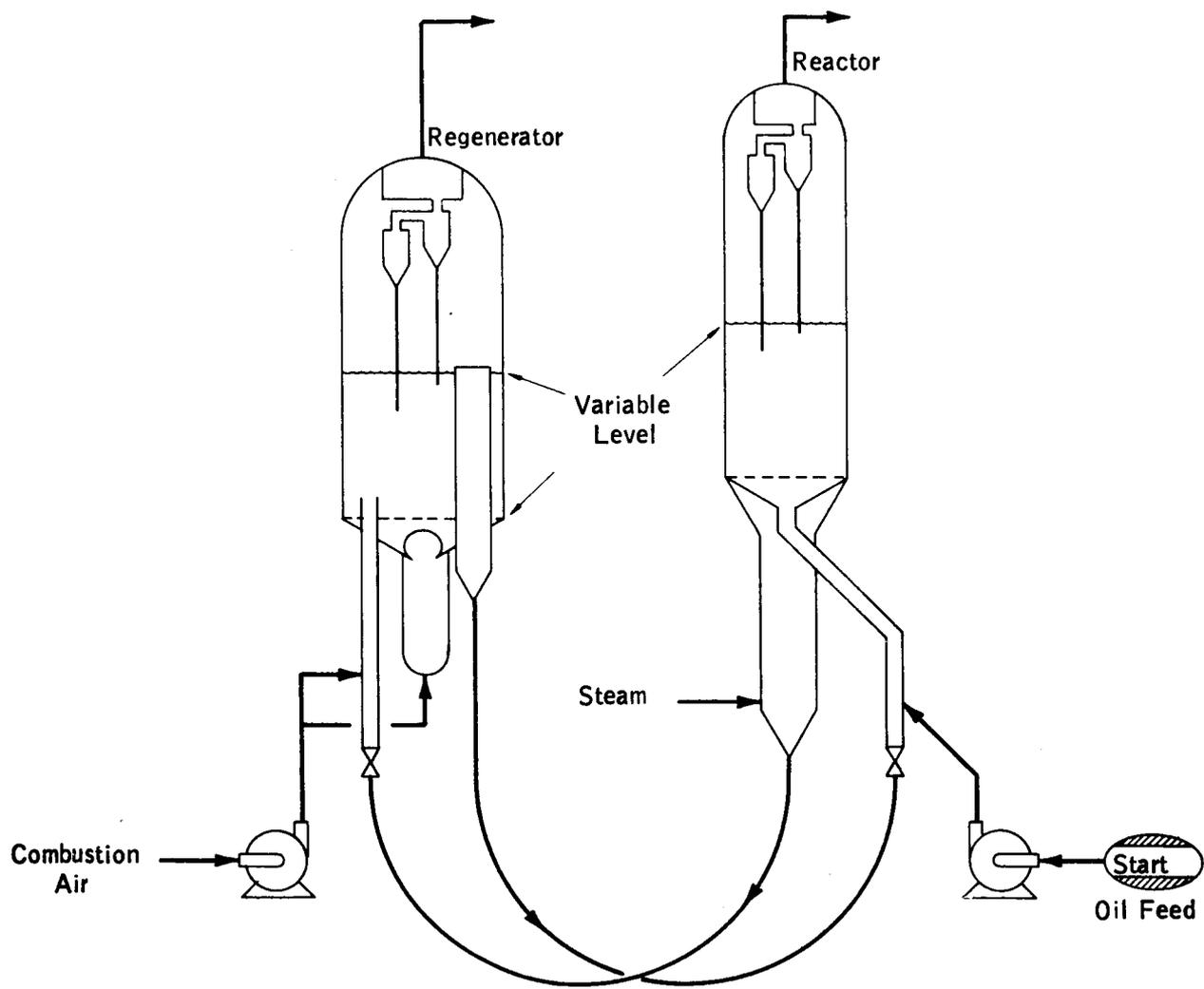


Figure 1

PLANFORM OF PLENUM CHAMBER AND CYCLONES

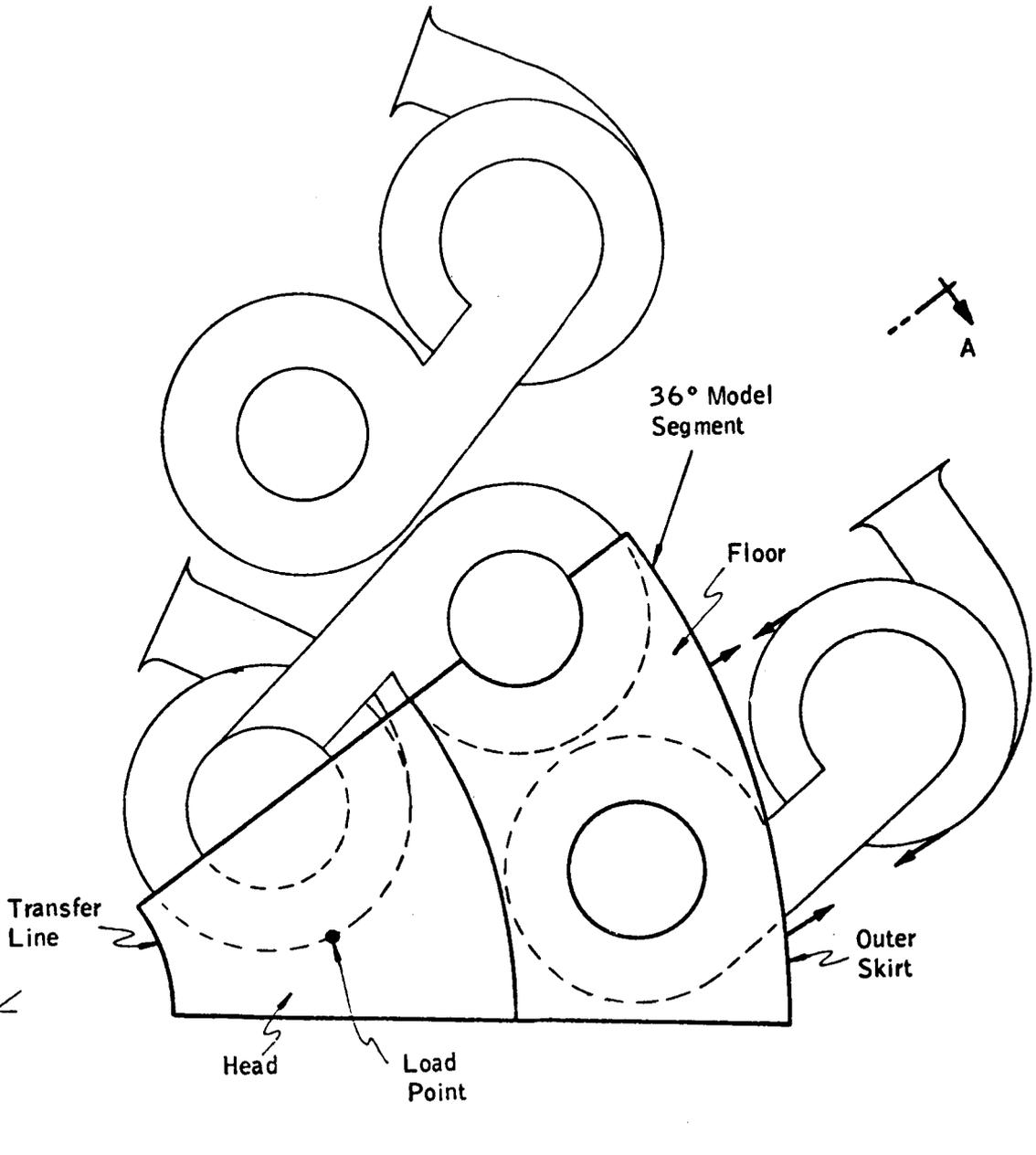


Figure 2

ELEVATION VIEW OF PLENUM CHAMBER AND CYCLONES

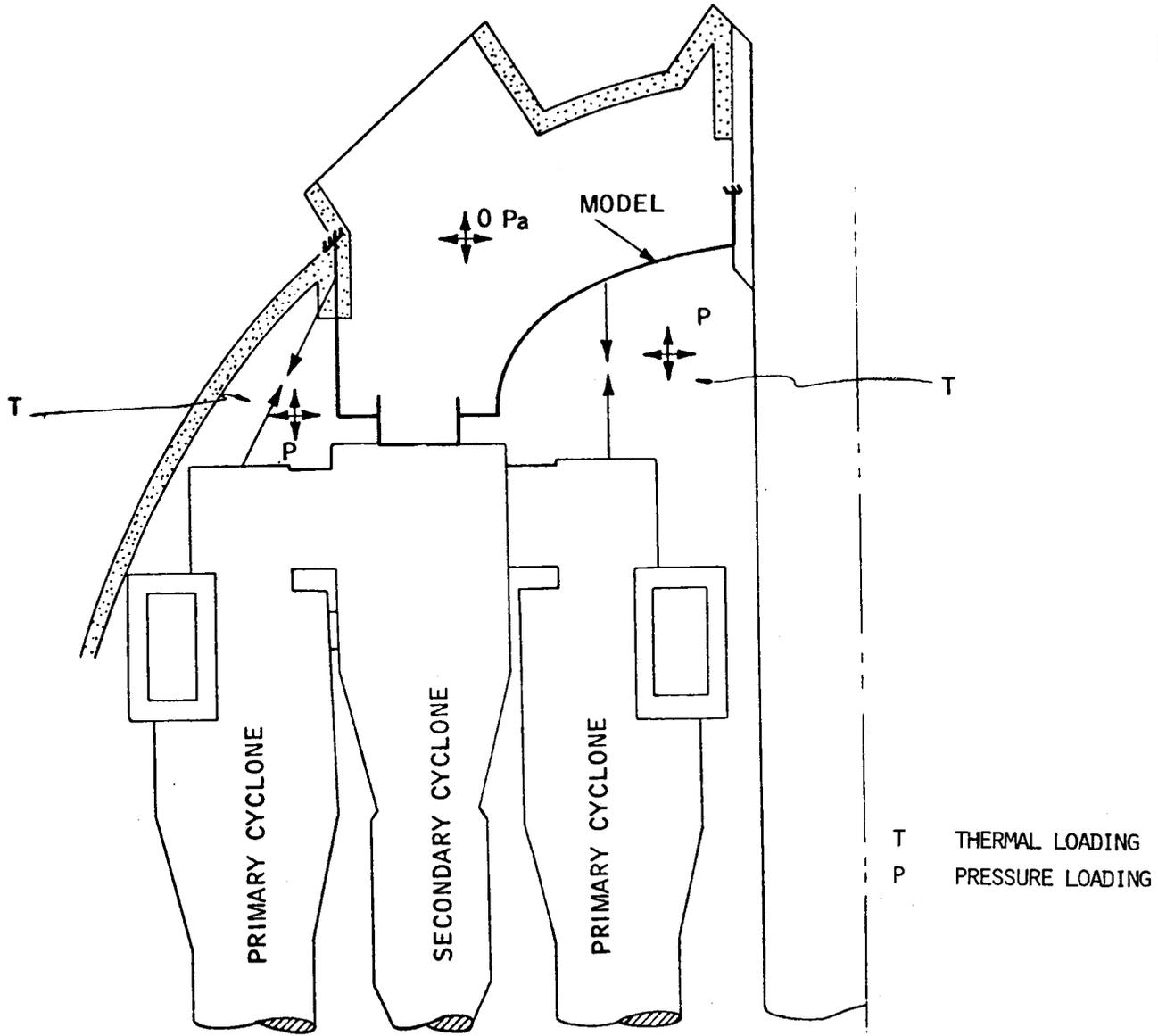
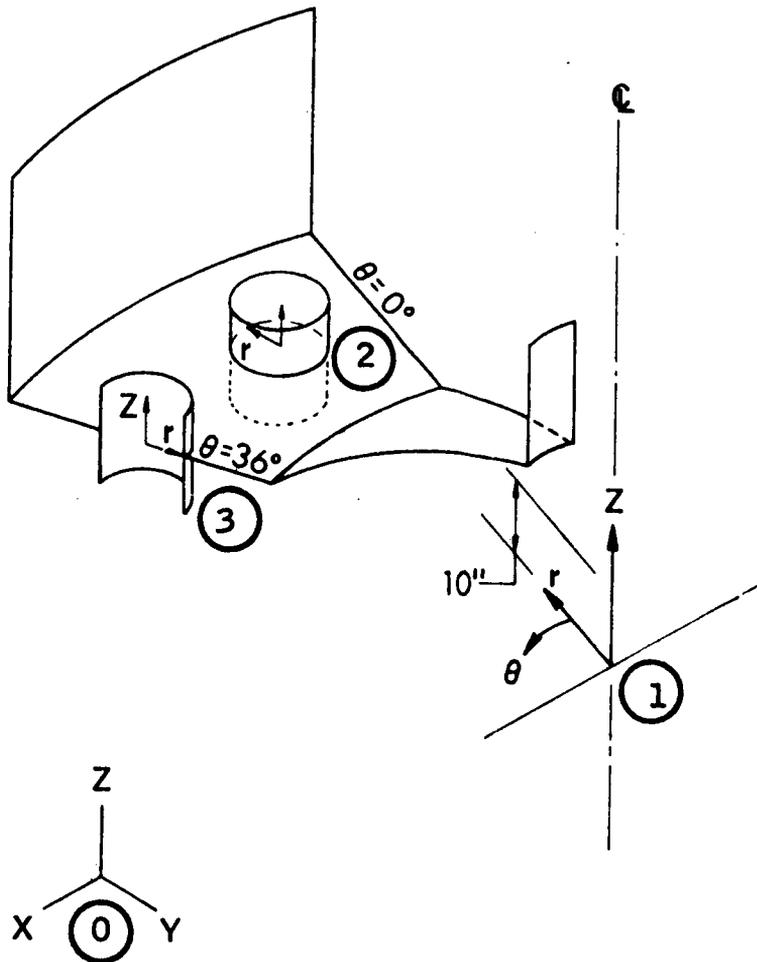


Figure 3

COORDINATE SYSTEM IDENTIFICATION



Notes:

- 0 = Implicit Cartesian System
- 1 = Cylinder System For Skirts, Floor And Head
- 2 = Cylinder System For Full Cyclone Barrel and Dipleg
- 3 = Cylinder System For One-Half Cyclone Barrel and Dipleg

Figure 4

**PLENUM CHAMBER
OVERALL VIEW :**

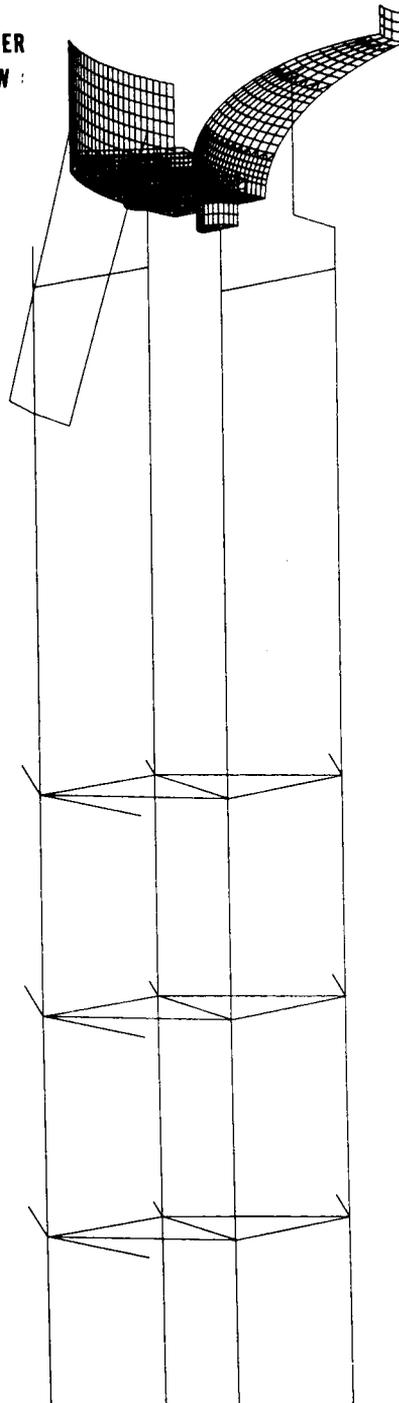


Figure 5

OVERALL VIEW

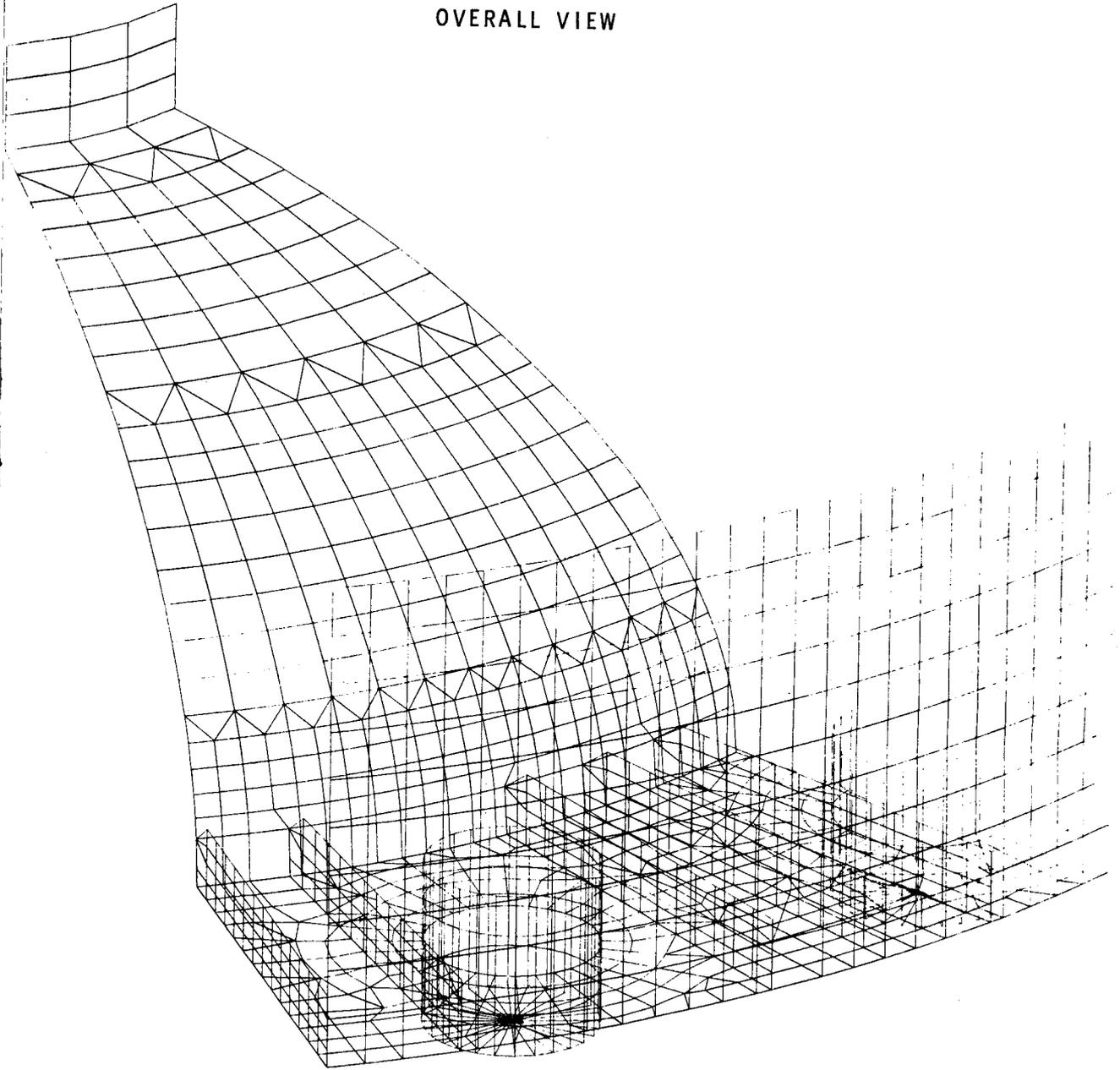


Figure 6

CARBON STEEL PLATE MOUNTING OF SKIRT TO HEAD
(3-D MODEL)

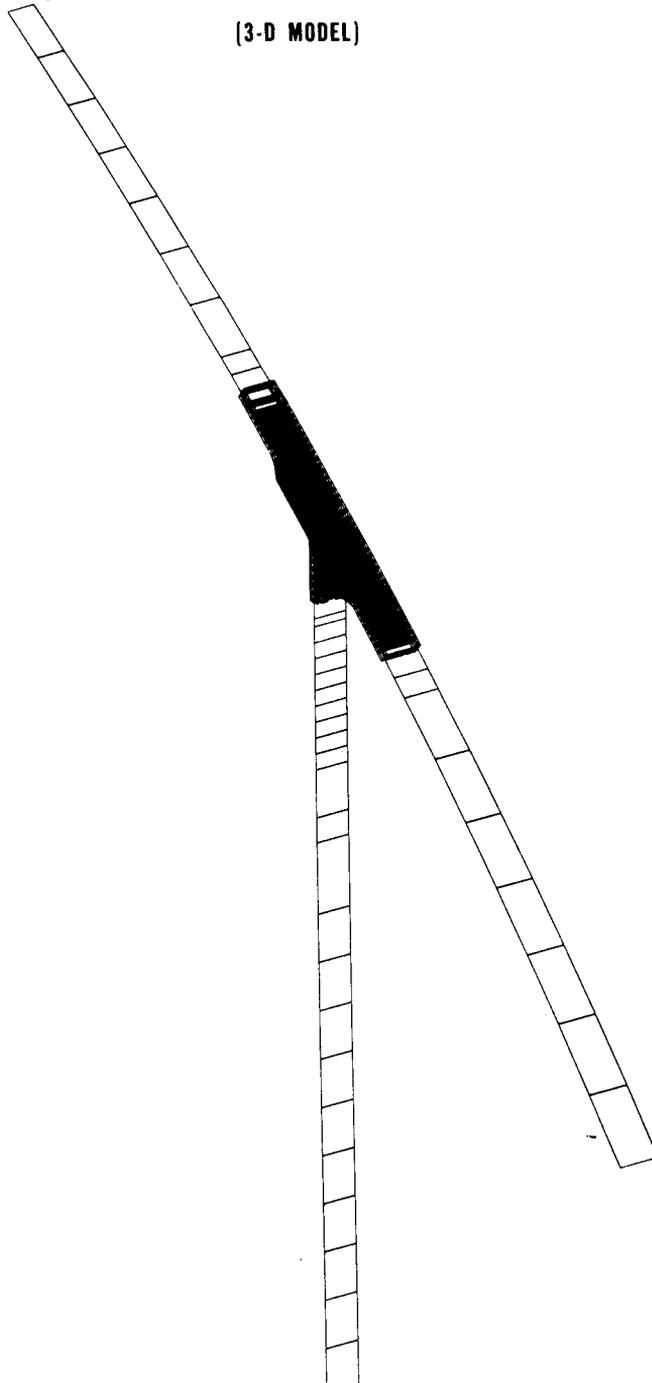


Figure 7

**STUB MOUNTING OF SKIRT TO HEAD
(3-D MODEL)**

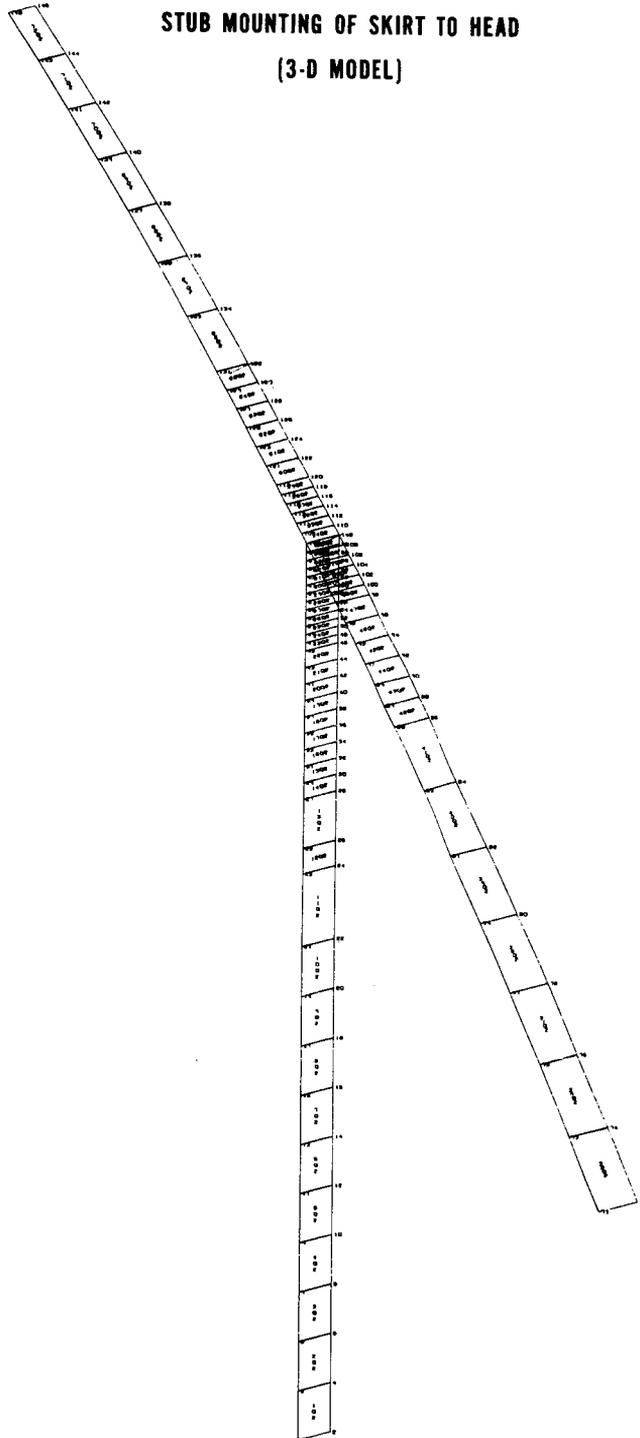


Figure 8

PROFILE VIEW
(UNDEFORMED AND DEFORMED)
MECHANICAL LOADS

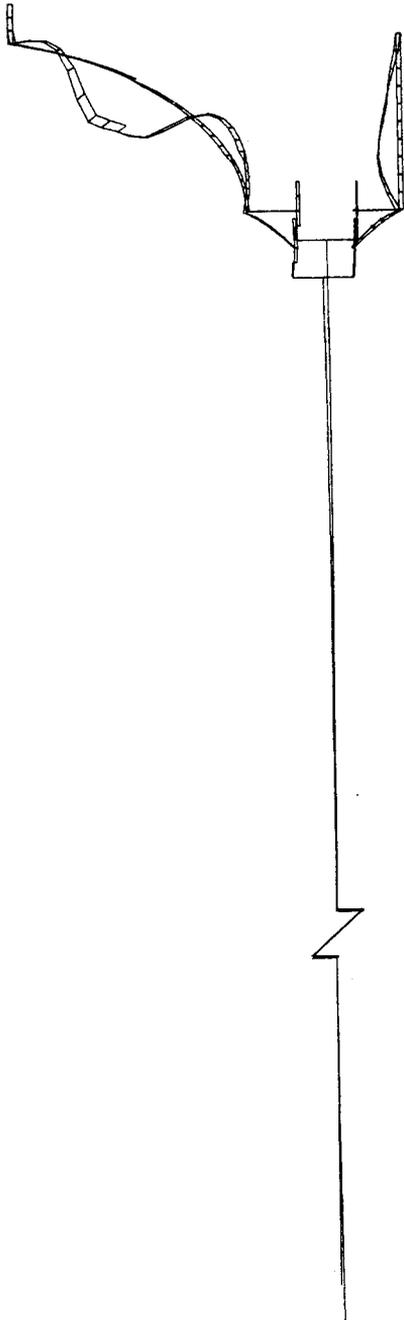


Figure 9

MODEL PROFILE
(UNDEFORMED AND DEFORMED)
COMBINED THERMAL AND MECHANICAL LOADS

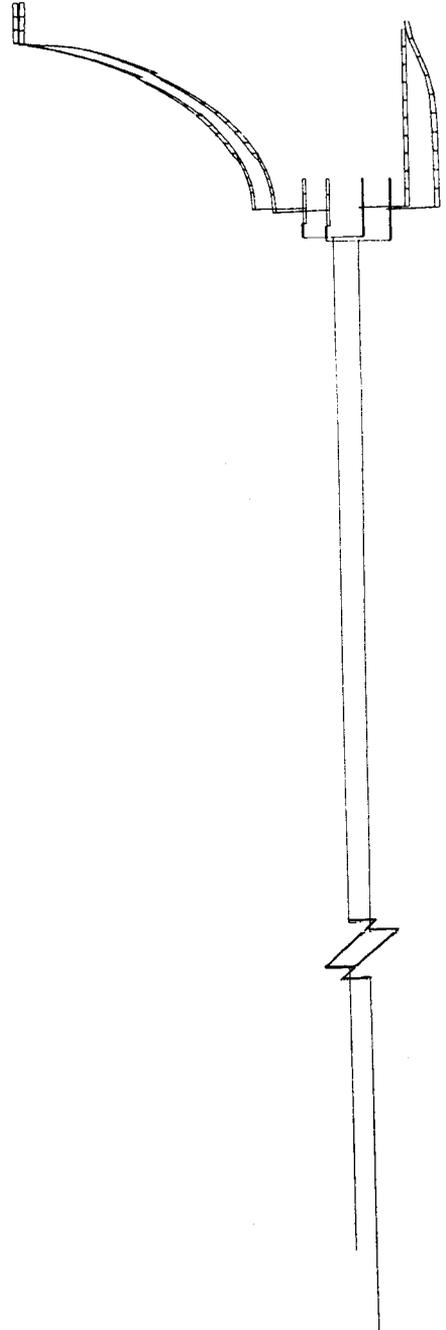


Figure 10

**CARBON STEEL PLATE MOUNTING OF SKIRT TO HEAD
(THERMAL STRESS SOLUTION)**

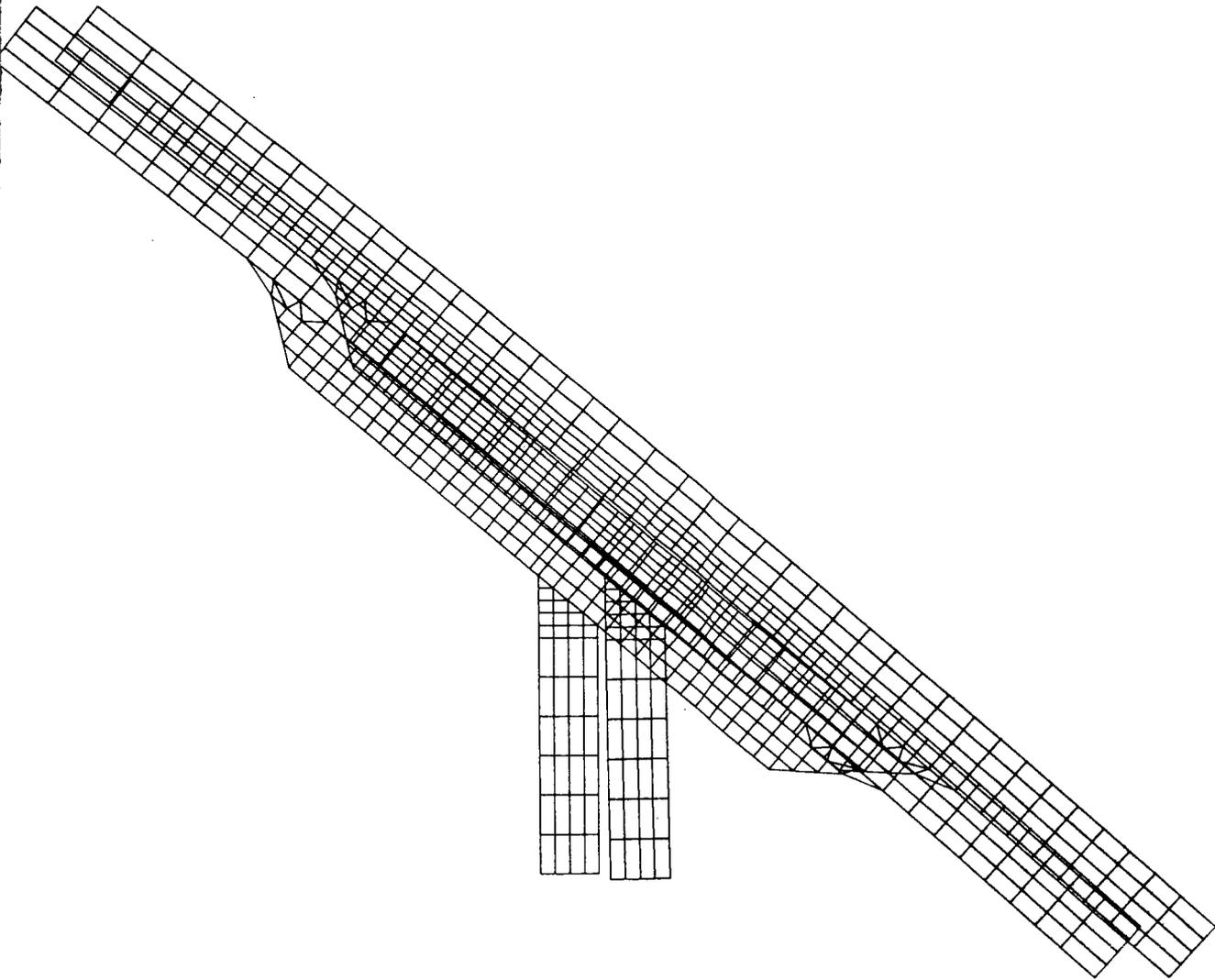


Figure 11

**CARBON STEEL STUB MOUNTING OF SKIRT TO HEAD
(THERMAL STRESS SOLUTION)**

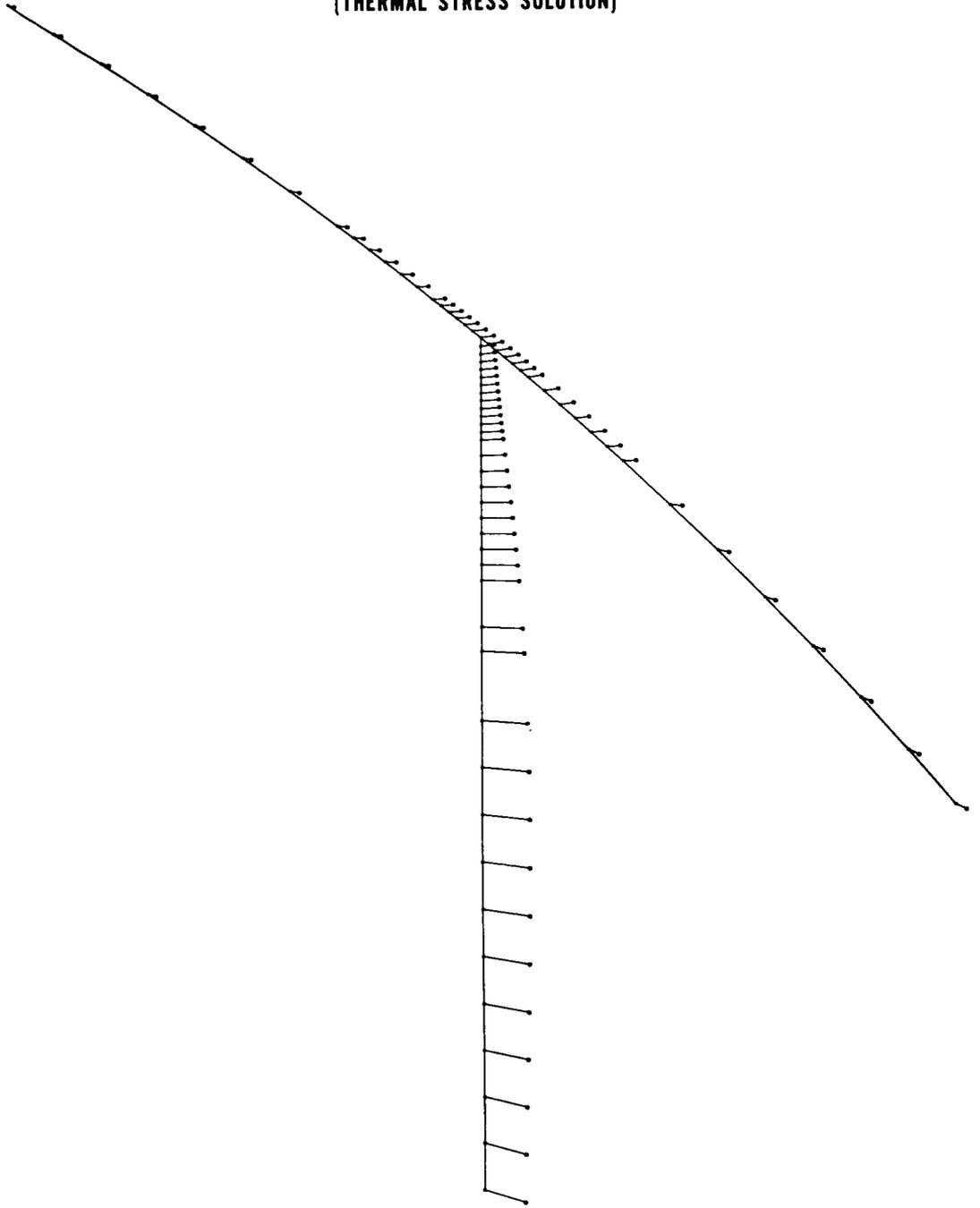


Figure 12