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Program

Solenoidal Tracker at RHIC (STAR)

Subprogram

Time Projection Chamber - Inner Field Cage

Title

STAR IFC Finite Element Analysis

Introduction

The inner field cage (IFC) defines the electrical potential along the inner radius of the active TPC volume. The approximate dimensions are one meter diameter by 4 meters long. The IFC will be constructed as a bonded honeycomb sandwich. The faces of the sandwich will be double-sided aluminum traces laminated to Kapton. The aluminum is 0.00035 inch thick bonded with 0.0003 to 0.0005 inch thick adhesive to 0.003 inch thick Kapton. The honeycomb selected is a non-conductive aramid, nominal 3/16 inch cell size, overexpanded cell to allow forming small radii structures, and $4\text{lb.}/\text{ft}^3$. A finite element analysis (FEA) of the IFC was completed using the Rasna Mechanica and ANSYS 5.1 codes. IFC stresses and deflection were evaluated based on an external design pressure of 5 mbar plus the load due gravity.

Discussion

The IFC is a cylinder formed by a honeycomb sandwich. The cross section of the sandwich consists of aluminum/Kapton/aluminum skins bonded to both faces of an aramid honeycomb core (see figure la). An FEA model of the aluminum layer, which are actually traces on 11.5 mm centerlines, would be difficult due to the amount of detail required. Consequently, an equivalent FEA solid model of the aluminum/Kapton was developed. This would reduce modeling six layers for the aluminum/Kapton to two layers and eliminate the need to model individual traces.

First, the actual geometry was modeled, consisting of two full 8 mm traces and the corresponding 10 mm traces was created (see figure lb). This model consisted of two layers of 0.00035 inch thick aluminum traces, 0.003 inch thick Kapton and two layers of 0.001 inch thick adhesive. It is assumed that the significant stresses in the IFC are membrane stresses, i.e. bending stresses can be ignored away from the fixed boundary condition. Based on this assumption, one end was fixed and an arbitrary load was applied in what would be the z-direction of the TPC. The deflection and stress results are shown in figures 2, 3, and 4.

Second, a model consisting of a single layer of solid elements was constructed. The material properties of aluminum were applied. A parametric study of deflection versus thickness was performed to obtain an equivalent single layer aluminum thickness representative of the combined aluminum/Kapton laminate. The same boundary condition and load were applied to the single layer model as in step 1. The results indicate that a thickness of 0.0005 inch aluminum produces the same deflection as the aluminum/Kapton laminate (see figures 2 and 5). The results also indicate that the maximum stress predicted for the single layer material is greater by factor of 1.5 than the predicted maximum stress in the aluminum/Kapton model. These analyses were performed using Mechanica by Rasna Corporation.

Using an equivalent single aluminum layer 0.0005 thick to model the aluminum/Kapton should produce reasonably accurate deflection predictions. The predicted stresses will be conservative.

The third step was to validate the FEA predictions by comparing the theoretical predicted deflection of a thin aluminum cylinder to the predicted FEA deflection. A separate ANSYS 5.1 FEA model was created for this purpose. A quarter cylinder was modeled due to two planes of symmetry. The half-length is 2.147 m and the approximate diameter of the IFC is 0.98 m. The mesh size is shown in figure 7a. The deflection of a thin-walled cylinder due to an external pressure is calculated as follows:

$d + p \cdot a^2 / (E \cdot h),$[i] where p=pressure
a=radius
h=thickness
E=modulus of elasticity

Assuming a cylinder wall thickness equal to two times 0.0005 inch, substituting the appropriate values, the theoretical deflection is:

$$d = 500\mathrm{N/m^2} * (0.49\mathrm{m})^2 \Big/ \left[\left(0.6896\mathrm{e}11\mathrm{N/m^2}\right)(0.00002\mathrm{m})\right]$$

$$d = 0.870\mathrm{e} - 4\mathrm{m}$$

The predicted FEA solution (see figure 7b) for a 5 mbar $\left(500\mathrm{N/m^2}\right)$ pressure load is $0.868 - 4\mathrm{m}$, which agrees very well with the theoretical solution. Therefore, the FEA solution is considered accurate.

The last step was to construct a FEA model of the IFC cylinder using the following: inner and outer 0.0005 inch thick aluminum faces, Ciba Composites $\mathrm{HMX} - 20\ 3/16\mathrm{OX}\left(4\mathrm{lbs./ft^3}\right)$inch thick industrial grade aramid honeycomb, two layers of 0.015 inch thick epoxy, and two layers for the fiberglass doublers. The doublers only extend 30 cm from the ends of the cylinder (see figure la). The same FEA mesh size used for the plain aluminum cylinder was used to predict the deflections and stresses of the IFC. ANSYS 5.1 was used to evaluate deflection and stress of the IFC cylinder due to a gravity load and an external pressure of 5 mbar. ANSYS 5.1 was selected due to the availability of its layered shell element.

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[i] Timoshenko, Theory of Plates and Shells, 2nd edition, McGraw-Hill, New York, 1959, p475

Results

The Von Mises stresses in the outer aluminum layer are shown in figure 8. The yield 2 strength of aluminum 1100-0 is 5000 psi [ii] or 3.45e7 N/m^2. The aluminum in the IFC aluminum/Kapton is type 1145-0, which will have similar properties. The IFC factor of safety given a 5 mbar external pressure and loading due to gravity is 3.5 on yield. An offset of the traces in the z-direction will affect the direction of the electric field. The z-direction maximum offset due to the loading conditions is 30 mm (see figure 9).

Conclusion

Constructing the IFC of double-sided 0.00035 inch thick aluminum traces laminated to 0.003 inch thick Kapton, and bonded to 0.4 inch aramid honeycomb will satisfy the minimum factor of safety requirement of 3 for experimental equipment. The offset of the traces in the z-direction due to the loading conditions will have a neglible affect on the direction of the electric field.

ii Avallone, Eugene and Baumeister III, Theodore, Marks' Standard Handbook for Mechanical Engineers, Ninth Edition, McGraw-Hill, New York, 1978, p6-78

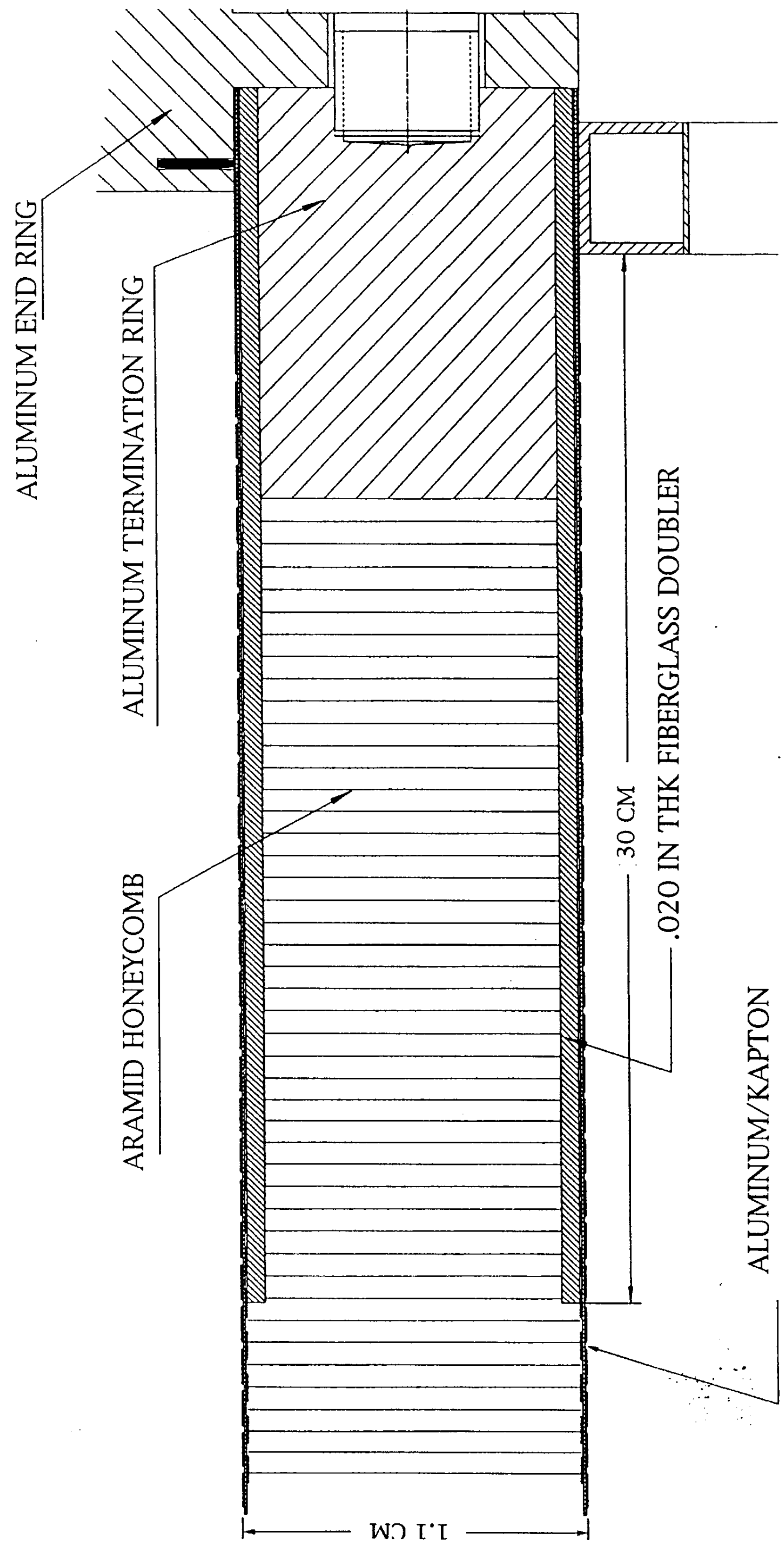

Figure 1a. Inner Field Cage Cross-Section

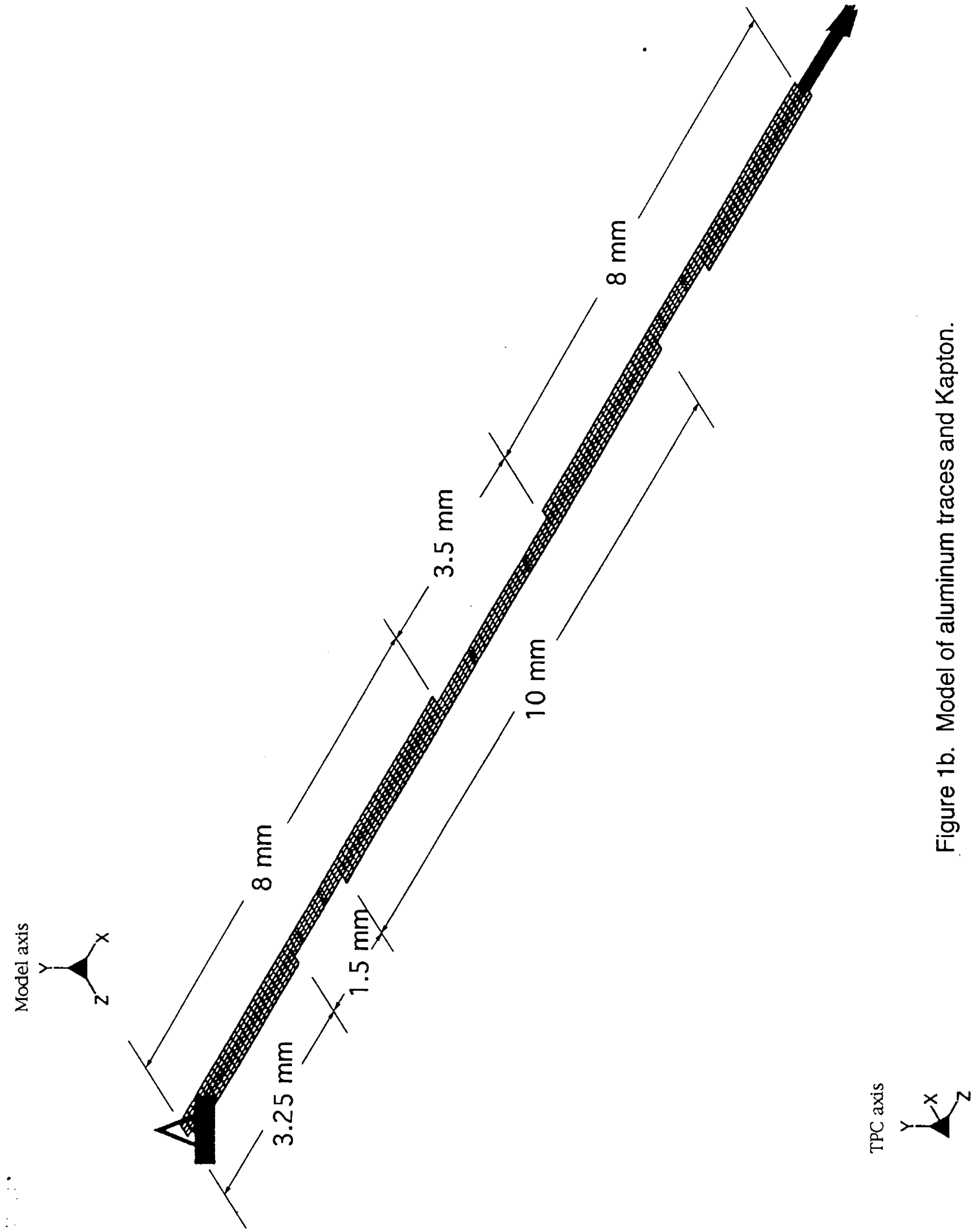

Figure 1b. Model of aluminum traces and Kapton.

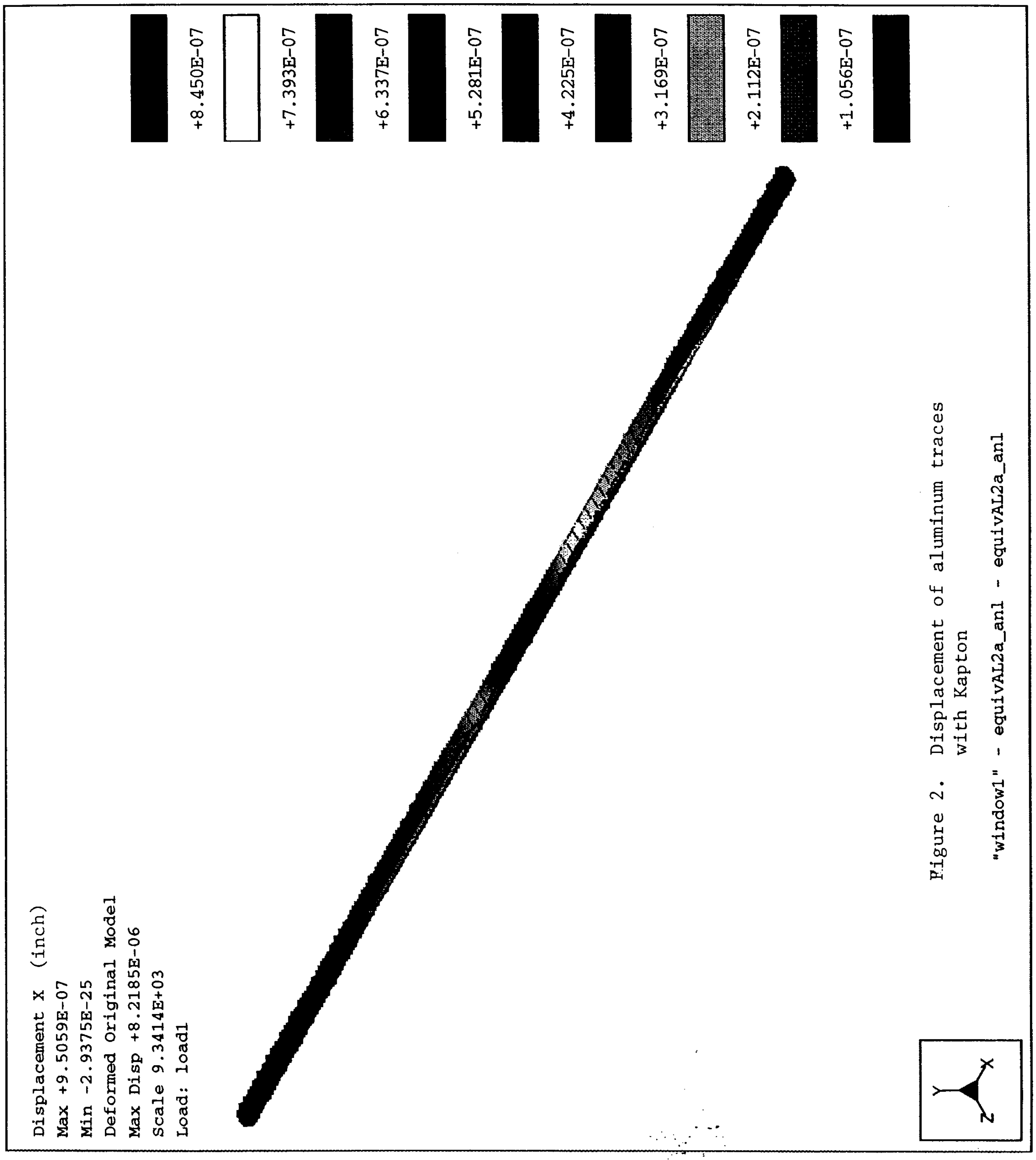

Figure 2. Displacement of aluminum traces with Kapton

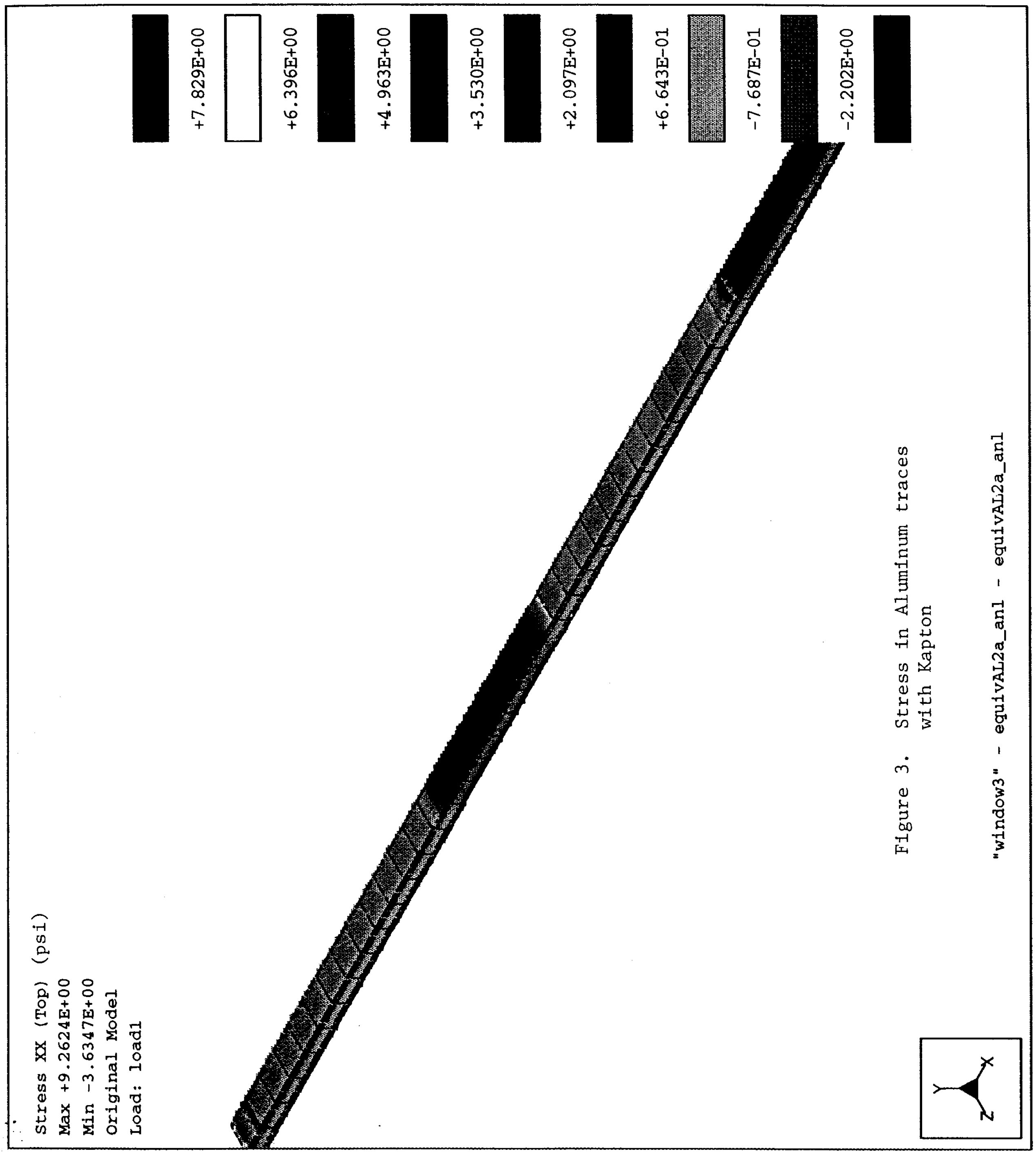

Figure 3. Stress in Aluminum traces with Kapton

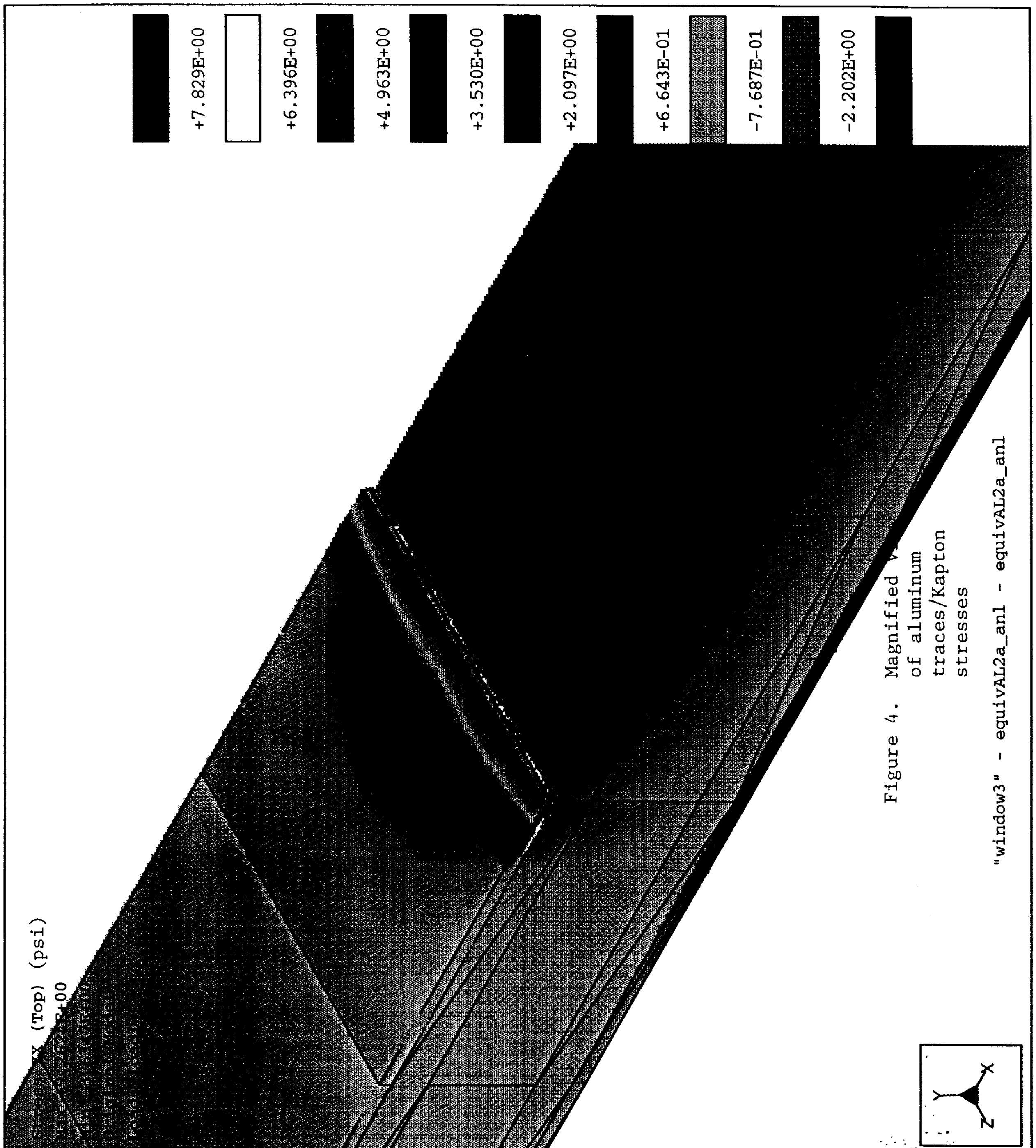

Figure 4. Magnified v of aluminum traces/Kapton stresses

"window3" - equivAL2a_anl - equivAL2a_anl

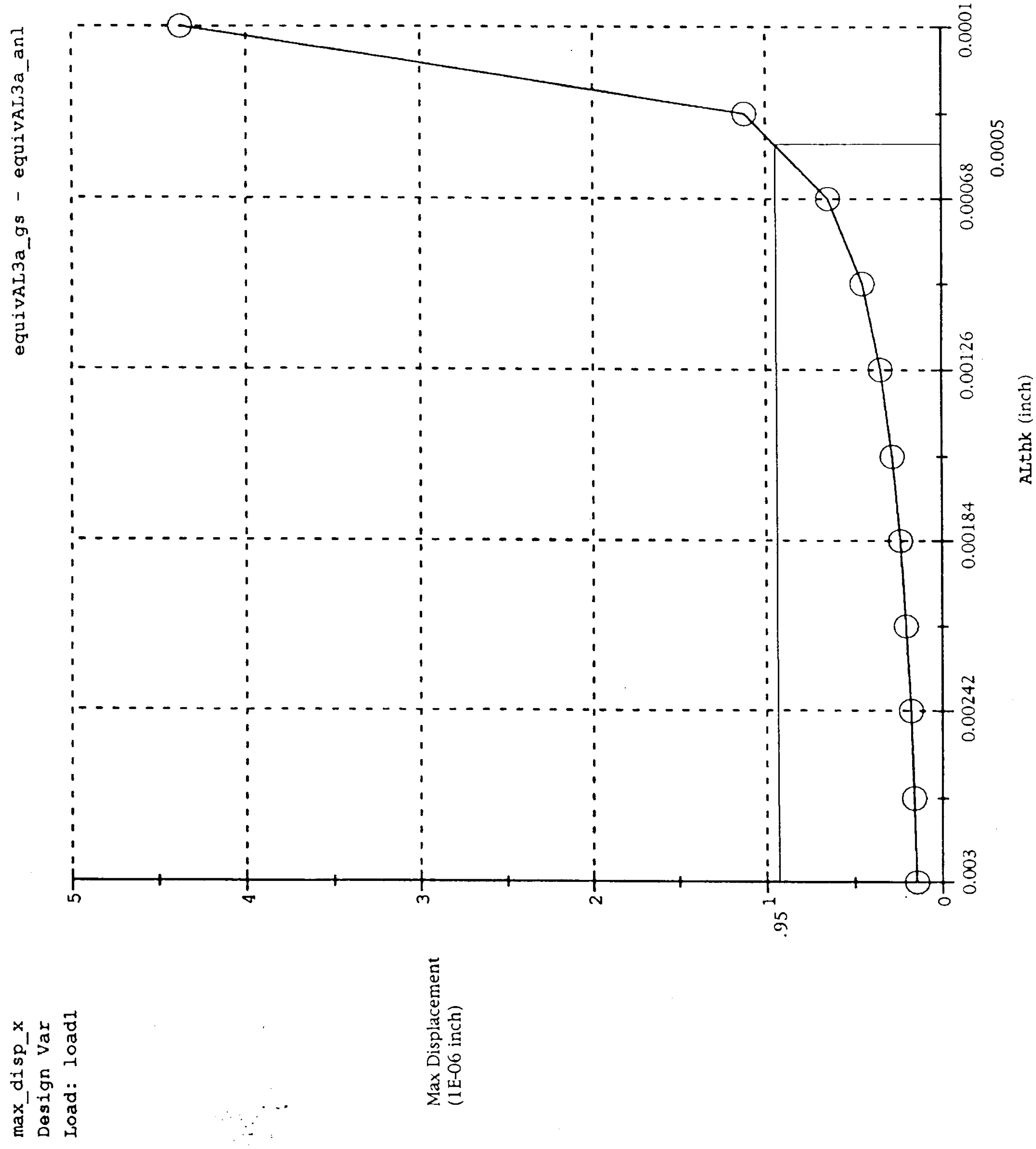

Figure 5. Aluminum deflection vs. thickness

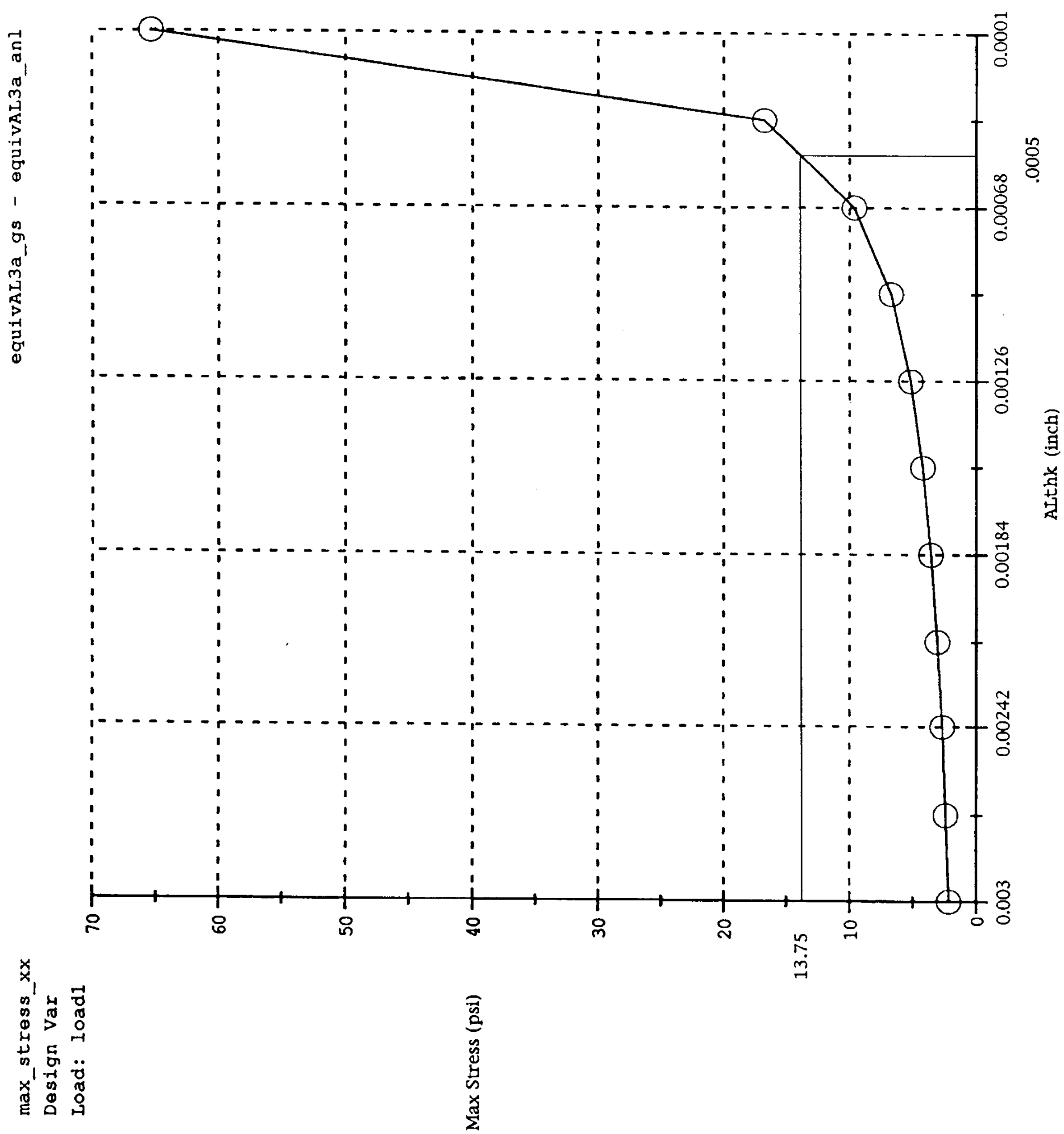

Figure 6. Aluminum stress vs thickness

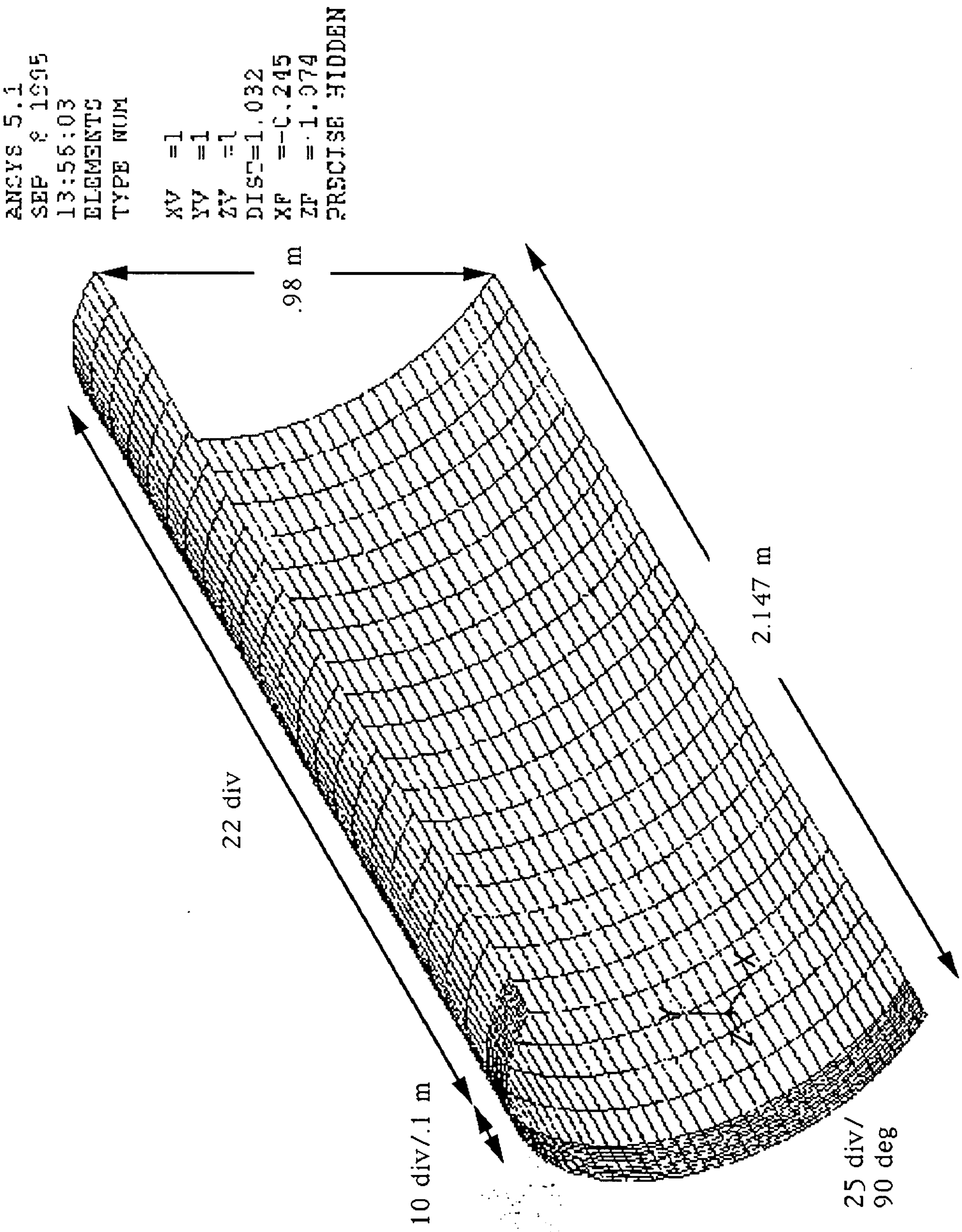

Figure 7a. Quarter symmetric model dimensions and mesh.

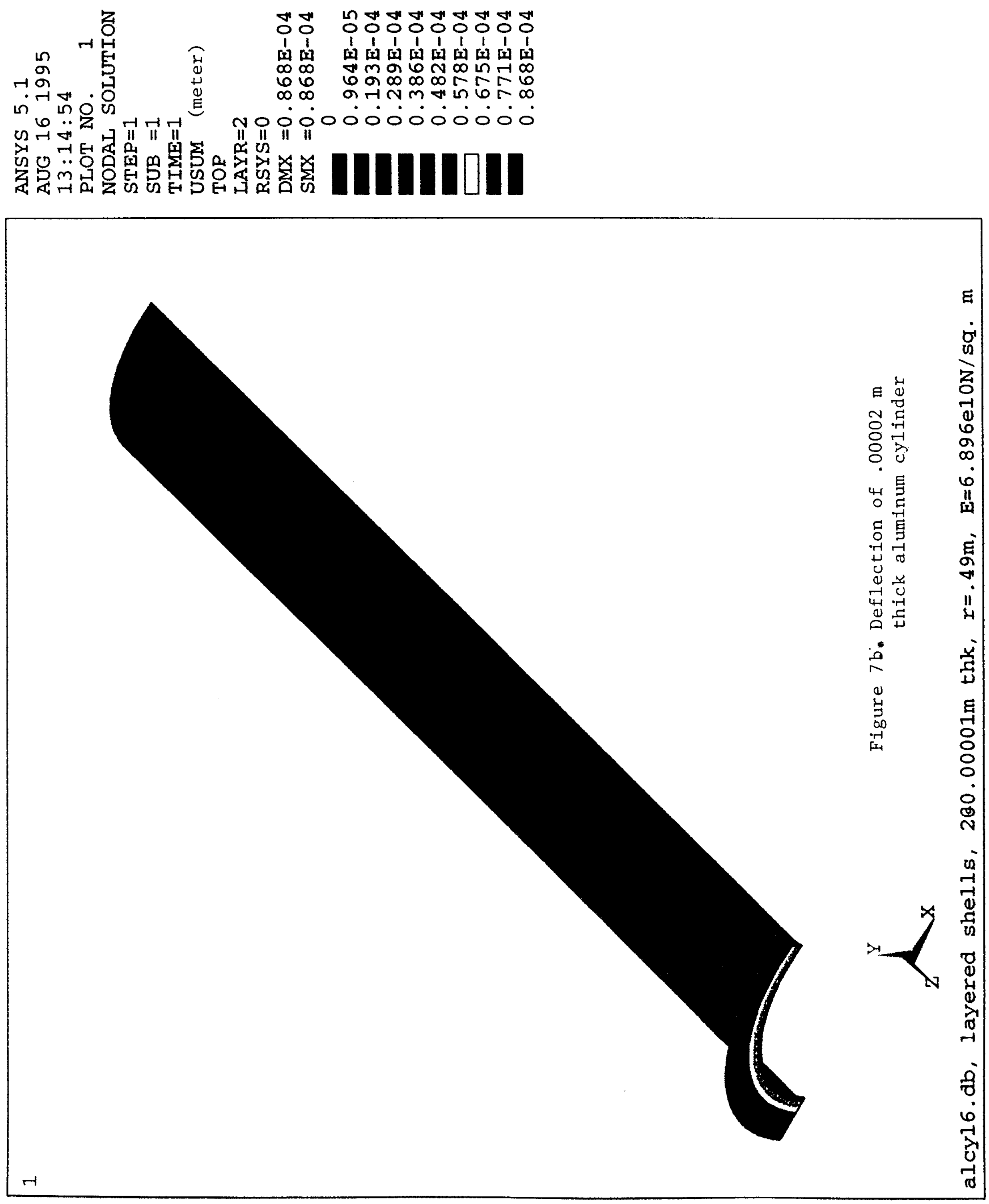

Figure 7b. Deflection of .00002 m thick aluminum cylinder

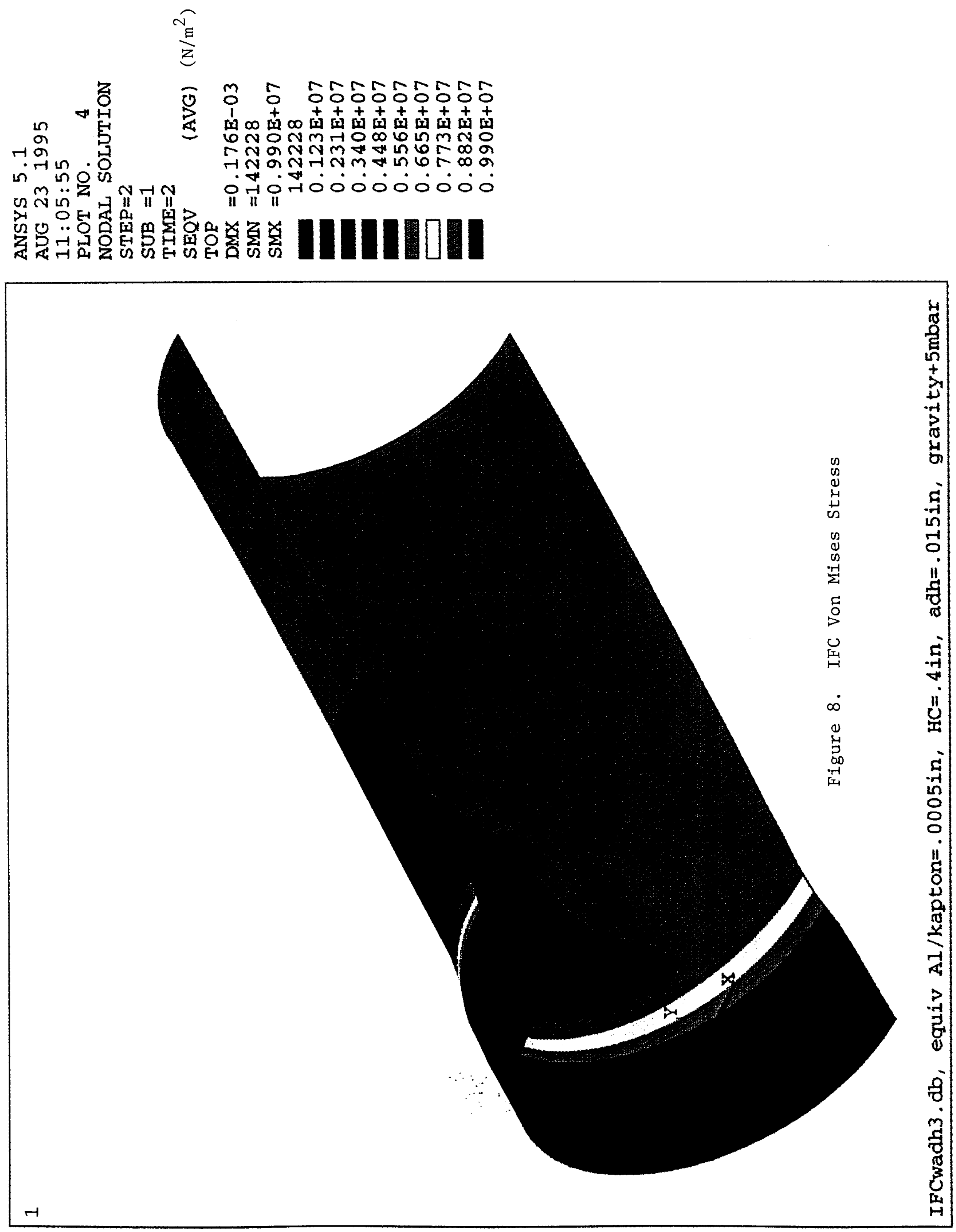

Figure 8. IFC Von Mises Stress

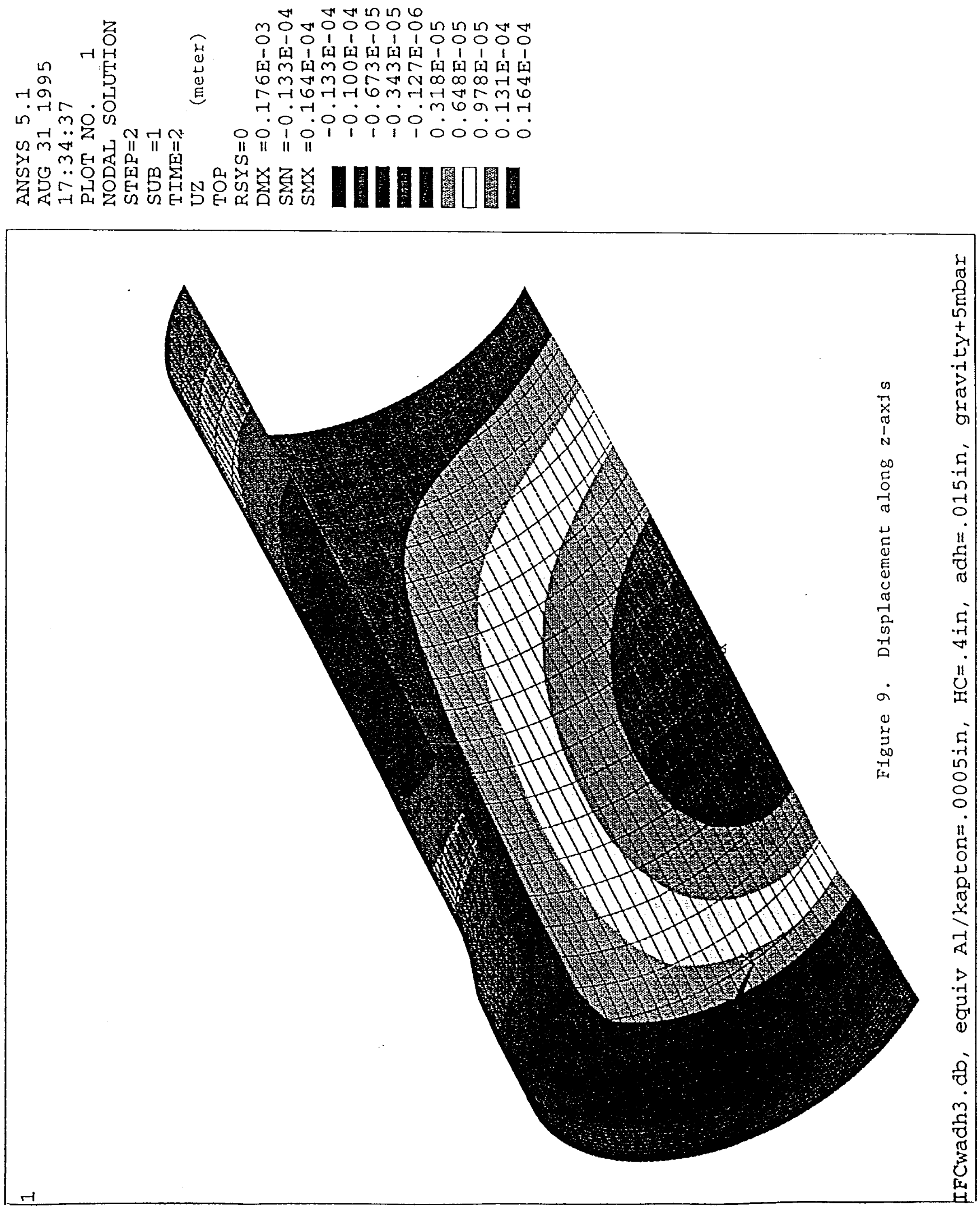

Figure 9. Displacement along z-axis