MSC/NASTRAN-CAD APPLICATION IN ORTHOPEDICS

Much attention is focused on the combination of interactive computer graphics with large scale engineering analysis systems such as MSC/NASTRAN. The productivity increase from this combination of technologies has indeed been dramatic. A particularly interesting aspect of the synergism is the insight offered to the analysis of unusual structural design. A hip joint prothesis is such a case and a particular design interation is described below.

The total-hip replacement concept is an example of a relatively simple device anchored with a gluing material inside a very complex biological structure, the human leg as shown in Figure 1. The biological medium is complex because of a) the three-dimensional geometry, b) anisotropic constitutive materials, c) dynamic loadings produced by gravity and locomotion.

The artificial joint has to be designed so that it has a similar range of motion, function and stress as the joint being replaced. Once the prosthesis device is implanted it doesn't solve all the patient's problems. Since the artificial implant is harder than the surrounding bone it's connected to, after 10 to 15 years the bone can wear away loosening the joint. When this happens the joint must be replaced.

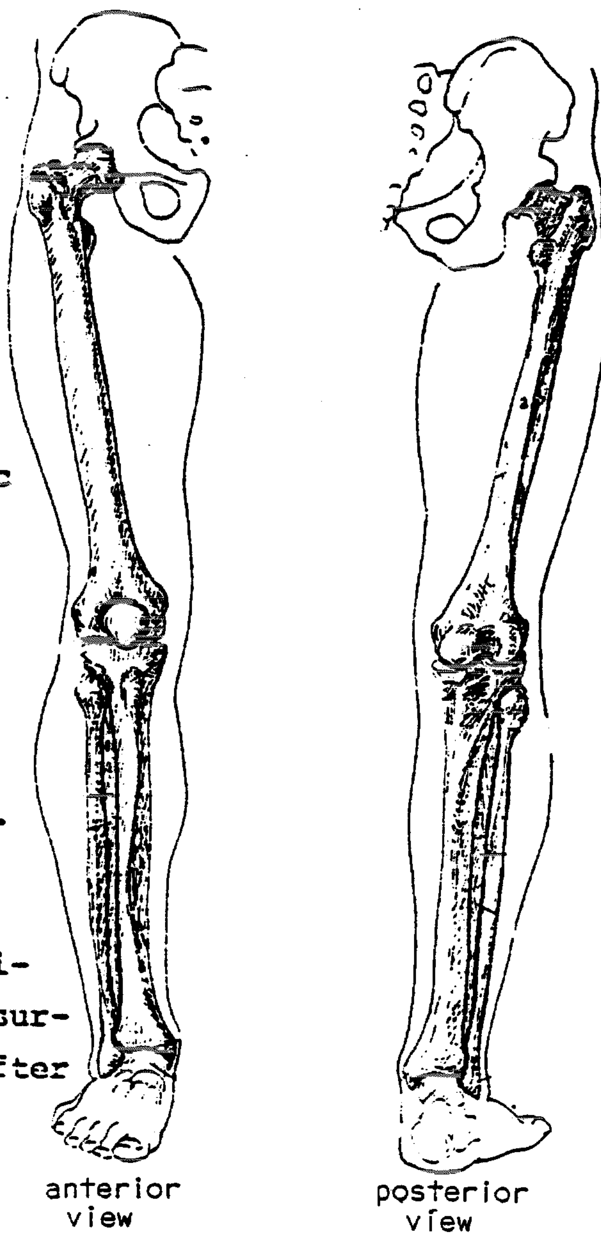

FIGURE 1. THE HUMAN LEG

The first step in developing a theoretical model for stress analysis is to obtain the geometry of the structure. Advances in automated diagnosis have allowed us to look inside the body. With a Computer-Aided Tomography (CAT), in which an x-ray scanner is rotated about the patient and the resulting signals are analyzed by computer to provide a cross-sectional image. Using a CAT scan the leg bone is scanned at various locations to get the two-dimensional geometry.

Each of the geometrical definitions is then digitized into a data base using an intéractive Computer-Aided Design (CAD) system to obtain the three-dimensional geometry as shown in Figure 2. The geometry definition or wire frame is provided at the cortical and cancellous bone.

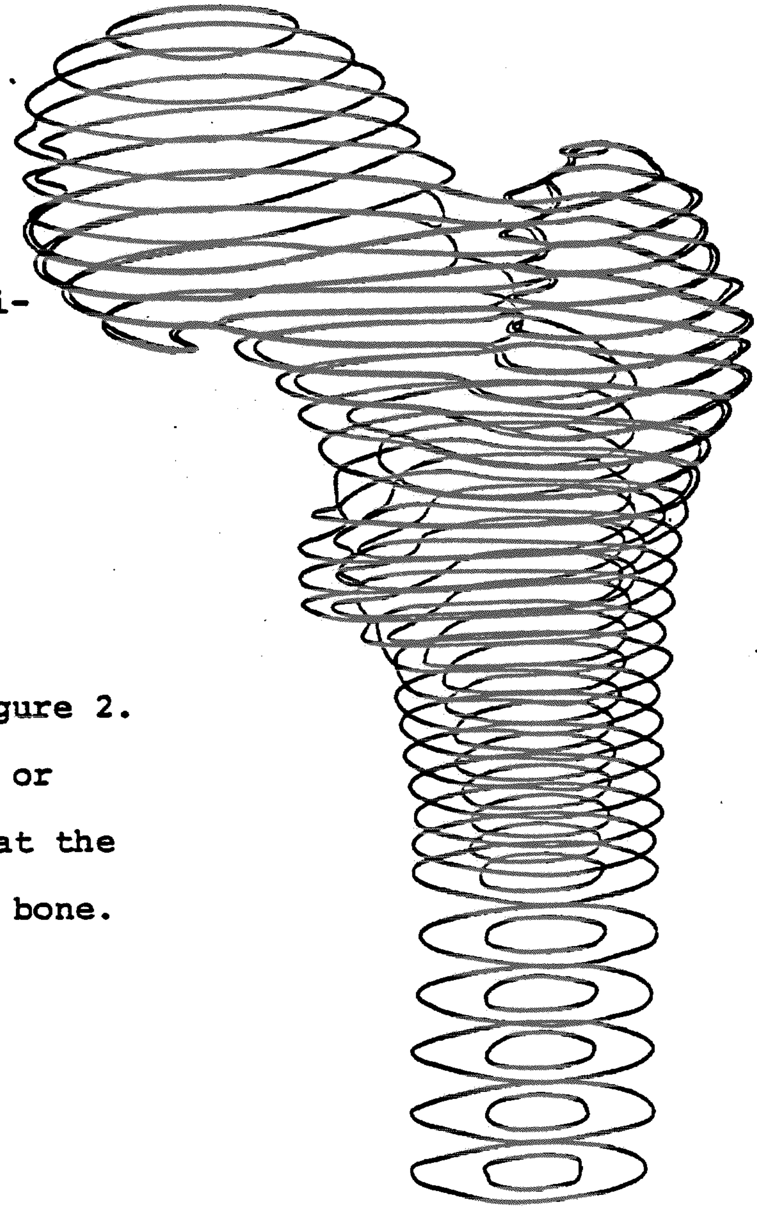

FIGURE 2. GEOMETRY FROM CAT SCAN

The hip joint prosthesis essentially a ball joint with a stem - somewhat like a tie rod is shown in Figure 3. Hip implants are made of highly polished metal alloys and polythylene. Inert steels are used to combat the body's reaction to the material.

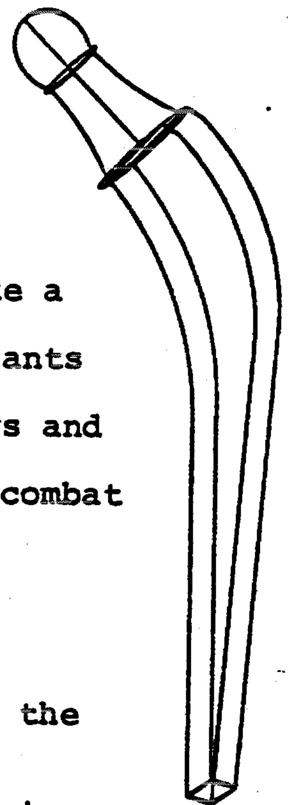

FIGURE 3.
HIP PROSTHESIS

Now having defined the geometry of both the prosthesis and hip joint we are able to insert the prosthesis into the inner region of the bone.

One aspect of the design problem is the careful alignment of the prosthesis inside bone. If successful, this will minimize bending moments and reduce interface stresses between the prosthesis/glue/bone. A 'good' design is a prothesis insertation that outlives the recipient. Evolving a satisfactory design is particularly suitable to analysis as experimental subjects are somewhat reticent.

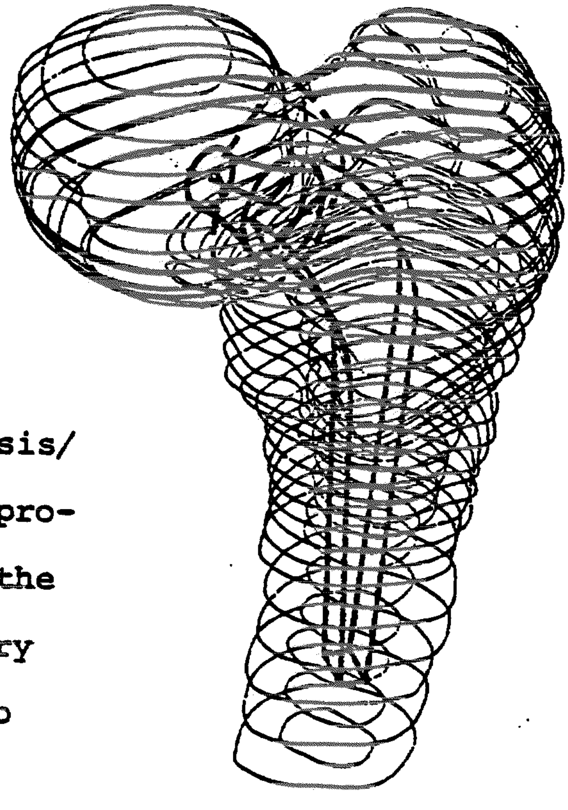

FIGURE 4.
PROTHESIS PLACED

Product design usually begins with an inspired sketch on an envelope which evolves to a blueprint. Computer graphics enters somewhere during this process, hopefully at the beginning. Using a CAD system allows the designer to visually determine the geometrical effect of changes in the design. Due to the complex geometry, it is necessary to visualize the orientation of the prosthesis in different views at the same time. The CAD system allows up to six different viewing windows to be displayed as shown in Figure 5.

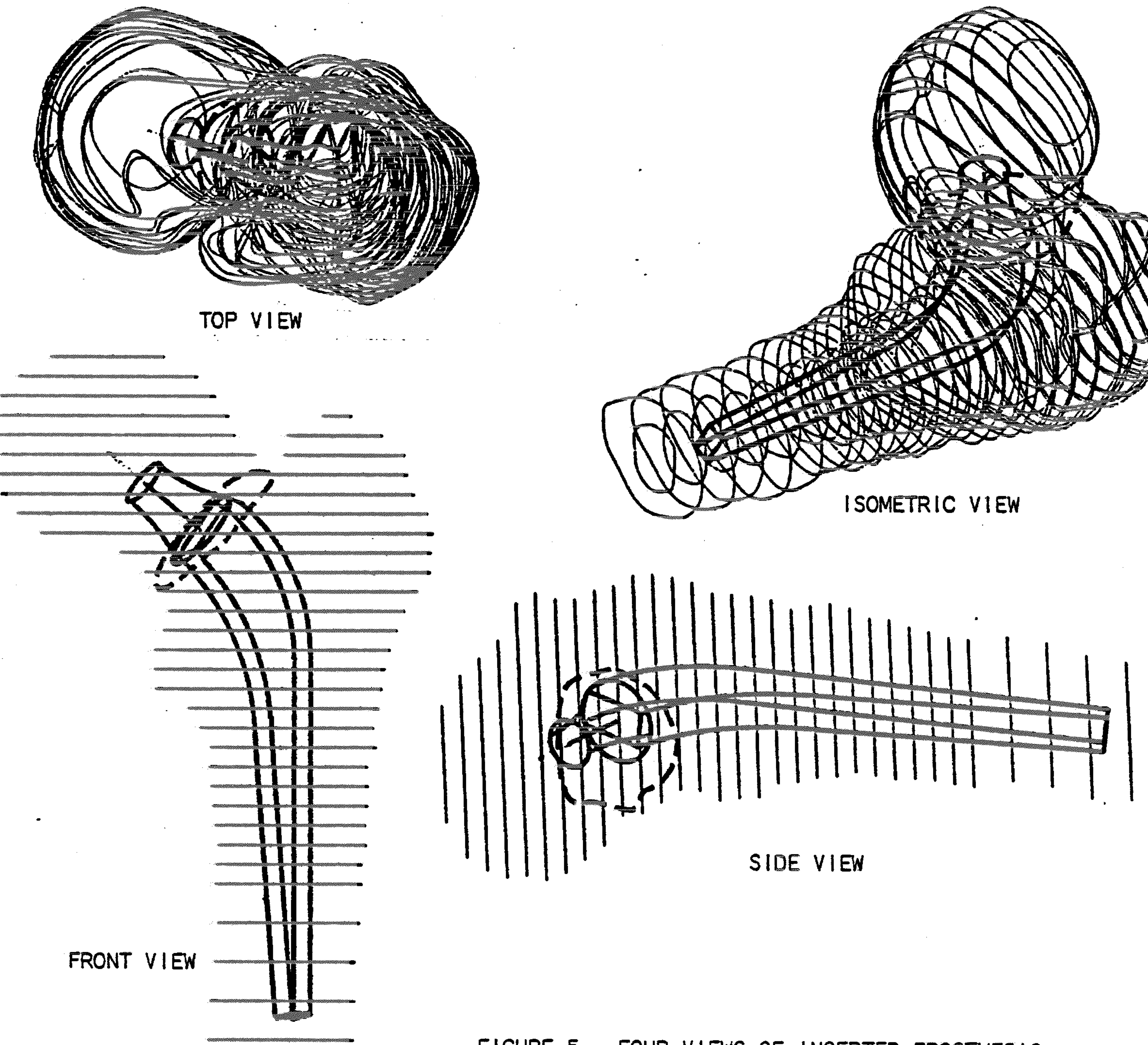

FIGURE 5. FOUR VIEWS OF INSERTED PROSTHESIS

The wire frame representation is converted into a MSC/NASTRAN model, comprised of three-dimensioned solid elements namely CHEXA, CPENTA, and CTETRA, on the graphics systems. The model has 2310 degrees of freedom and 98 TETRA, 442 HEXA, and 234 PENTA elements. The loading on the structure included a 250 lb load at the ball of the prosthesis and 100 lb load at the outer bone as shown in Figure 6.

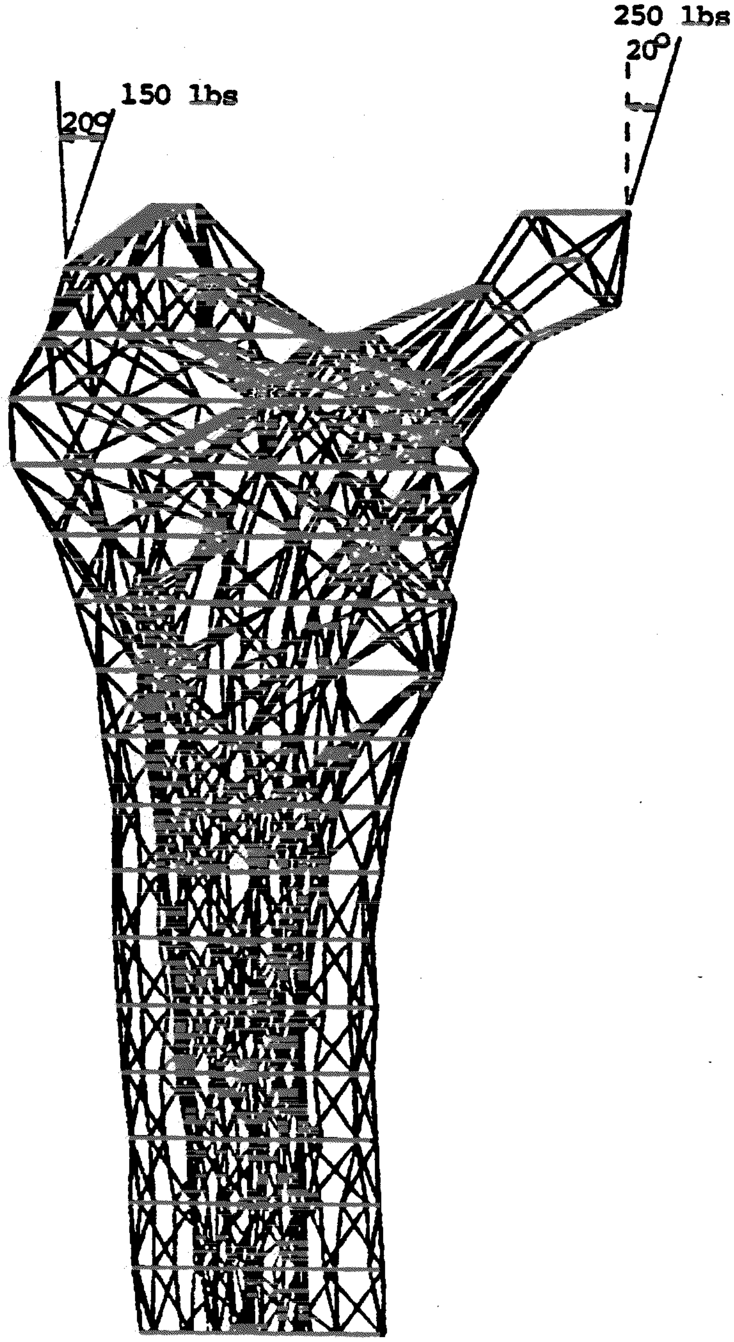

FIGURE 6. FINITE ELEMENT REPRESENTATION
OF THREE-DIMENSIONAL MESH

The design process involved iterations of the placement of the prosthesis relative to the bone, with the objective of determining stress distribution in the constitutive materials. The prosthesis was rotated clockwise and counterclockwise as shown in Figure 7 along with other variations in material properties.

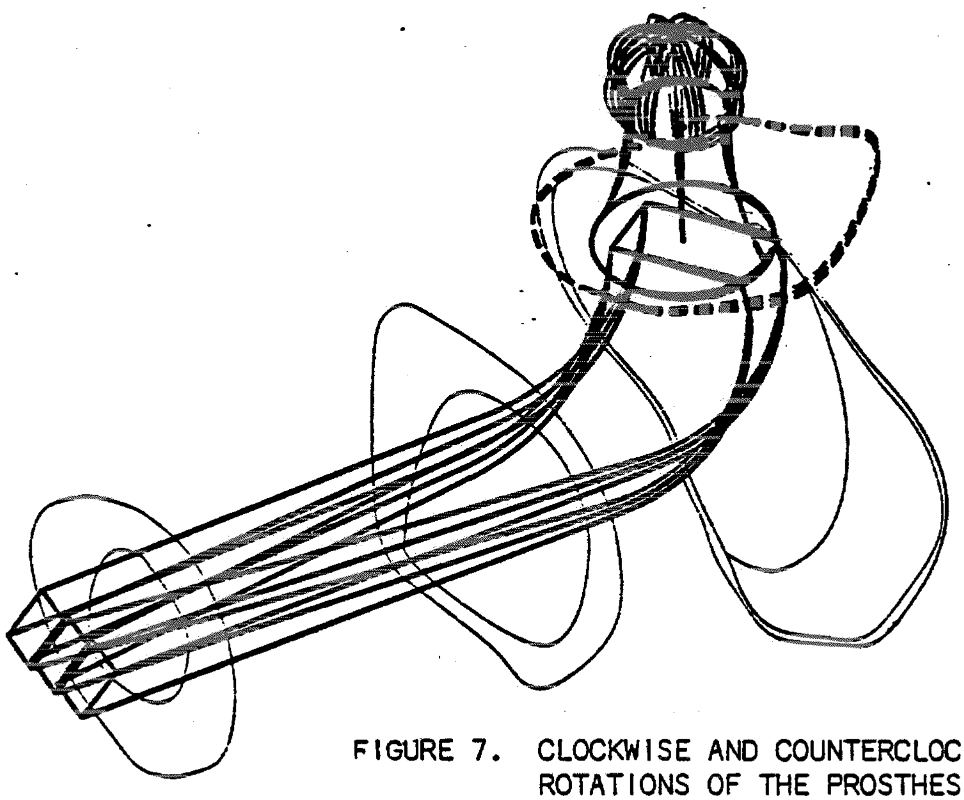

FIGURE 7. CLOCKWISE AND COUNTERCLOCKWISE ROTATIONS OF THE PROSTHESIS

Each iteration was performed with the interactive graphics system, each iteration resulting in somewhat altered finite element mesh, and each mesh leading to the bulk data for a new MSC/NASTRAN stress analysis. The stress analysis results were summarized using AOS/GRAFAX to identify stress and strain distributions.

From the three-dimensional analysis model it was found that generally the maximum stress distribution occurred in a vertical plane through the middle of the prothesis. Figure 8 shows the Hencky-von Mises equivalent stresses at several locations in the model and the approximate neutral axis of bending.

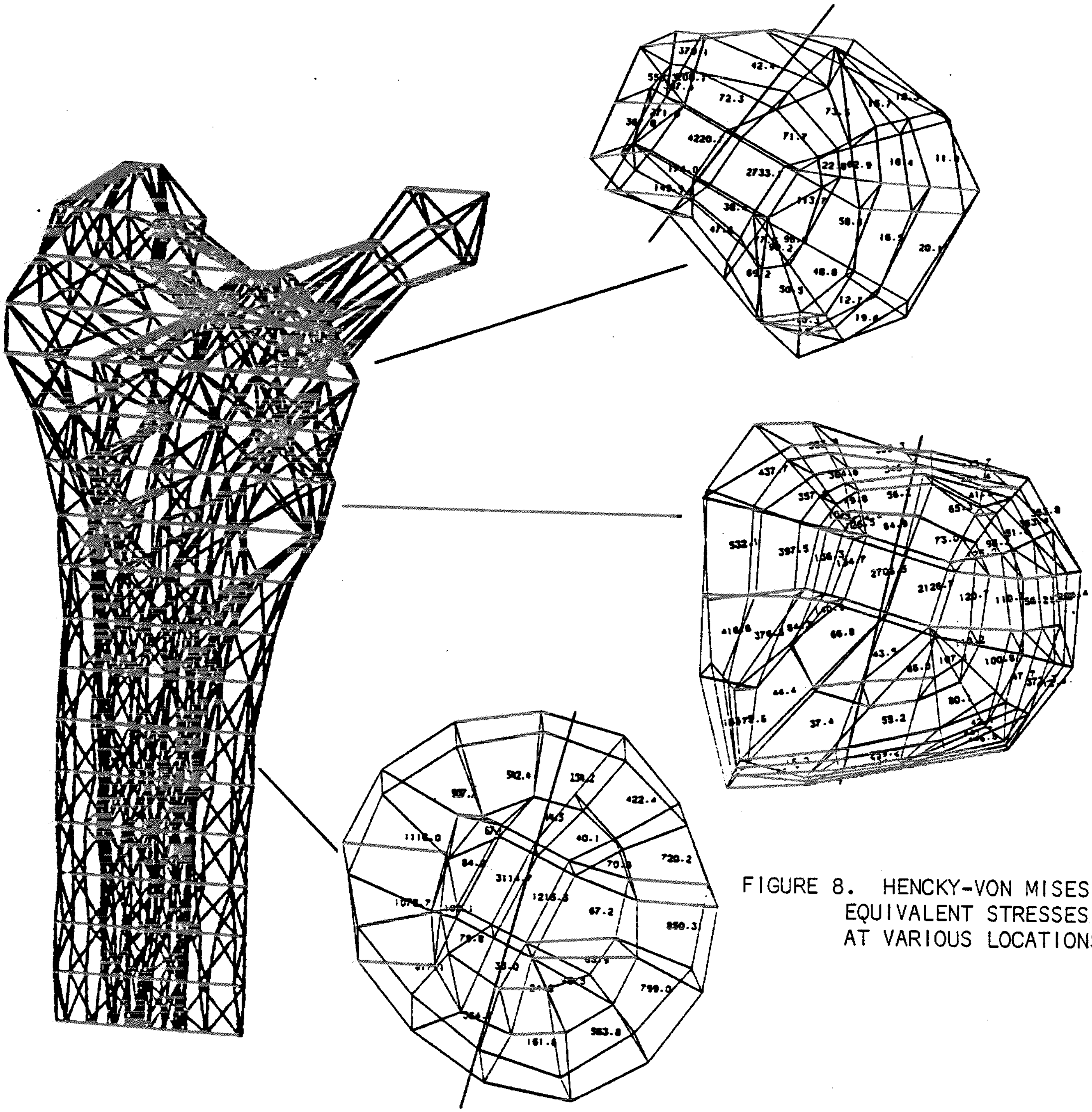

FIGURE 8. HENCKY-VON MISES EQUIVALENT STRESSES AT VARIOUS LOCATIONS

With emphasis in the design stage of being able to quickly and easily modify the analysis model a simplified model of a vertical slice through the prosthesis and bone was developed. Figure 9 shows the plane of the vertical slice. This allows design iterations to be accomplished in a most economical manner. Once a promising design is identified in the two-dimensional model, it can then be incorporated into the three-dimensional model.

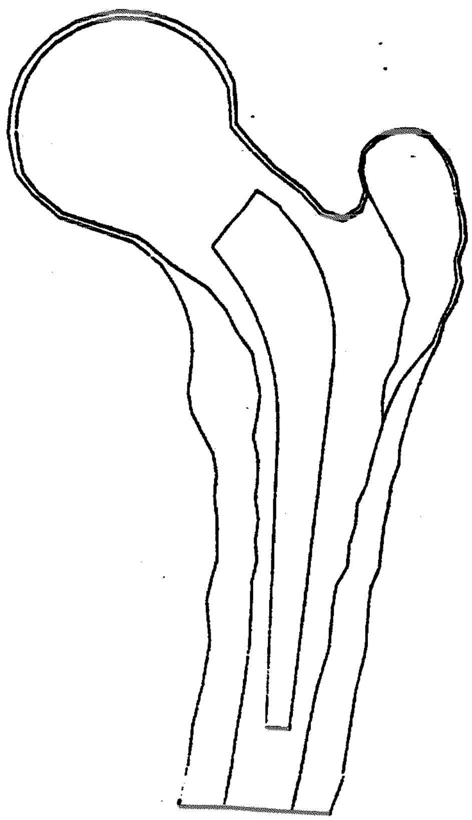

FIGURE 9. PLANE OF THE VERTICAL SLICE

On the analysis results it is significant to look at both the stress and strain distributions due to the composite materials. Figure 10 is a color contour display of the stress distribution. Figure 11 is similarly a color contour display of the strain distribution produced by AOS/ GRAFAX.

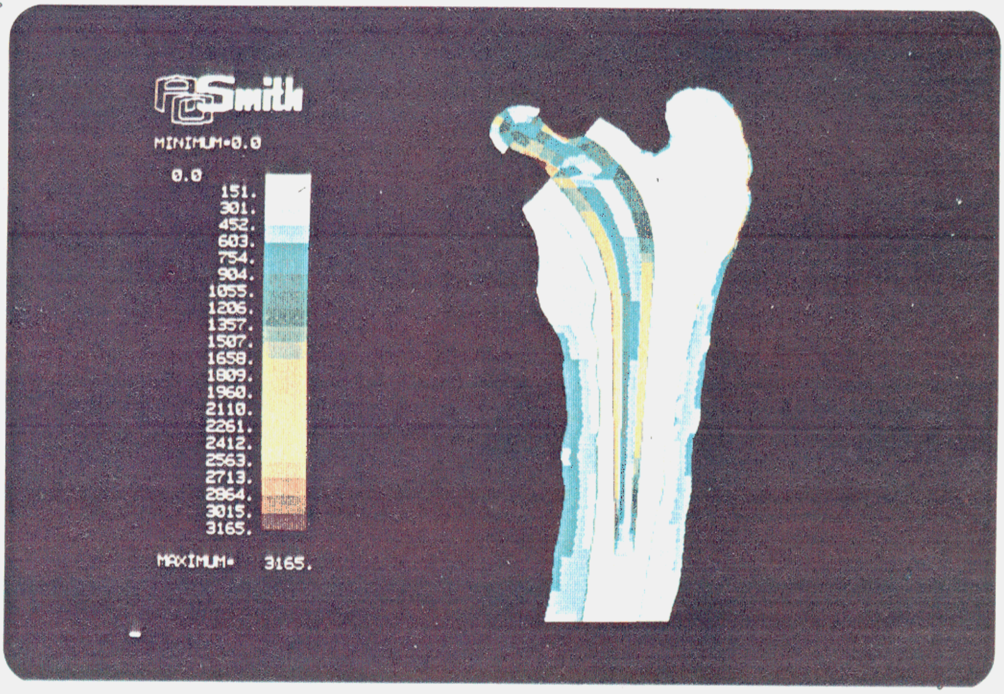

FIGURE 10. STRESS DISTRIBUTION

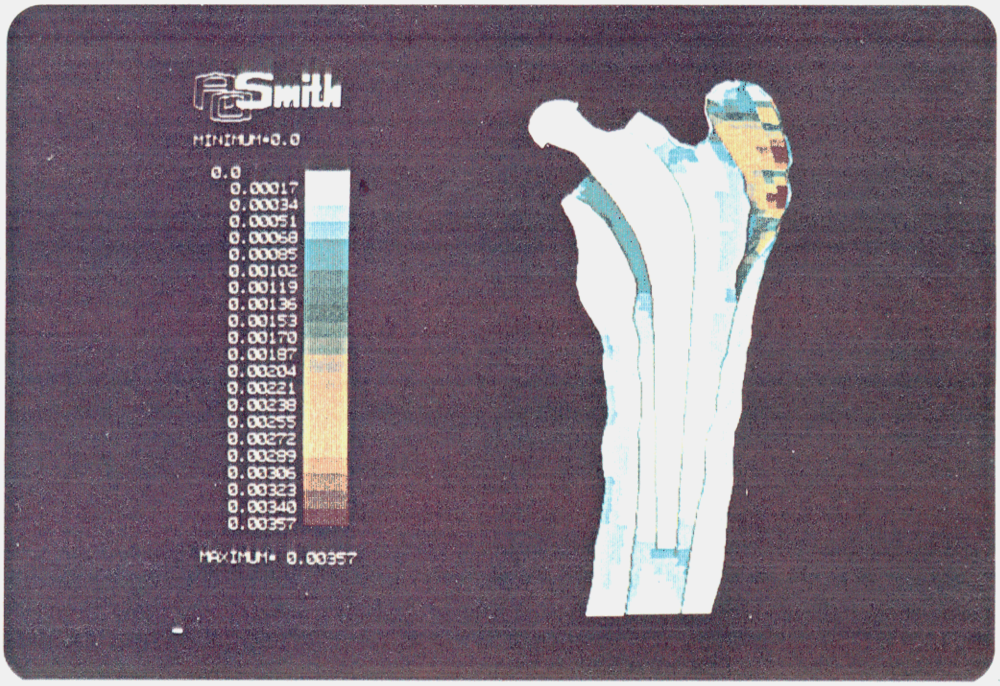

FIGURE 11. STRAIN DISTRIBUTION

It has been shown that the finite element technique integrated with a CAD system provides a useful tool for the combined design and analyze of structures. As implants become designed for a life-time of service, this will require sophisticated materials and better design.