N93-32189 49242U S40-52 p. 10

FINITE ELEMENT ANALYSIS OF A COMPOSITE ARTIFICIAL ANKLE

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ABSTRACT

Ultra-light carbon fiber composite materials are being utilized in artificial limbs with increasing frequency in recent years. Dr. Arthur Copes, an orthotist from Baton Rouge, Louisiana, has developed a graphite epoxy composite material artifical ankle (Copes/Bionic Ankle) that is intended to be used by amputees who require the most advanced above-and-below-the-knee prosthetic devices. The Copes/Bionic Ankle is designed to reproduce the function of the natural ankle joint by allowing the composite material to act as a spring mechanism without the use of metal mechanical parts. NASA Marshall Space Flight Center has agreed to participate in the design effort by providing the structural analysis of the artificial ankle design.

INTRODUCTION

This paper presents the structural analysis that was required to define the composite members of the Copes/Bionic Ankle. The finite element modeling expertise and extensive computer facility that resides at NASA Marshall Space Flight Center (NASA MSFC) were essential to ensure a good design of the Copes/Bionic Ankle. The utilization of this resident technology demonstrates the engineering potential that will soon become available through similar computer systems within many private companies to improve the quality of life for many people. Some of the potential uses of this technology are development of self-propelled vehicles for paraplegics, knee prosthetics, robotic structures for machine shops, and customized exoskeleton load carrying frames to be used by persons who must lift heavy loads. A thorough knowledge of structural and materials engineering is required to utilize the computer finite element codes for design engineering analyses. Material strength, ductility, stiffness, and fatigue life are primary areas of understanding to produce a suitable product of this nature.

STRUCTURAL ANALYSIS

The drawings of the design depict the foot adapter and ankle made of graphite epoxy composite material that is attached to an aluminum alloy vertical post. The interface of the ankle to the post is a spherical ball joint which provides for ankle rotations about all three mutually orthogonal axes.

The modeling of the Copes/Bionic Ankle was initiated by the interactive development of the ankle geometry by Blaise Czekalski. This interactive model was then converted to the ANSYS computer code. A 3-D finite element model (FEM) of the ankle was then developed from ANSYS layered shell elements for the composite material, isotropic shell elements for the aluminum support plate, and isoparametric 20-node solid elements for the aluminum post. This FEM is described in Figure 1. It is comprised of 2300 elements with 45,400 total degrees of freedom.

The composite material system for the design is T300/5208, which has Union Carbide Thornel 300 graphite filaments that are impregnated in Narmco 5208 epoxy resin. The orientation of the filament layup for the ankle is ±30 degrees. The structural properties for this material that were used in the analysis are shown in Figure 2. Fatigue life predictions were determined from the fatigue curves for the calculated maximum stresses in the composite material [1]. For fatigue life of approximately one million cycles, the maximum calculated bending stress in the composite material should not exceed 50,000 psi.

The Copes/Bionic Ankle assembly is installed into a foot structure. The foot adapter of the Ankle is restrained from flexing by the foot structure. The ankle flexes about the three mutually orthogonal axes like a human ankle. The ankle must be capable of rotating 20 degrees about the Y axis and 10 degrees about the X and Z axes, separately or simultaneously, with moments not to exceed 60 inch pounds. The number of the graphite layers and the orientation of the fibers in the composite elements must be adjusted to achieve the proper stiffness.

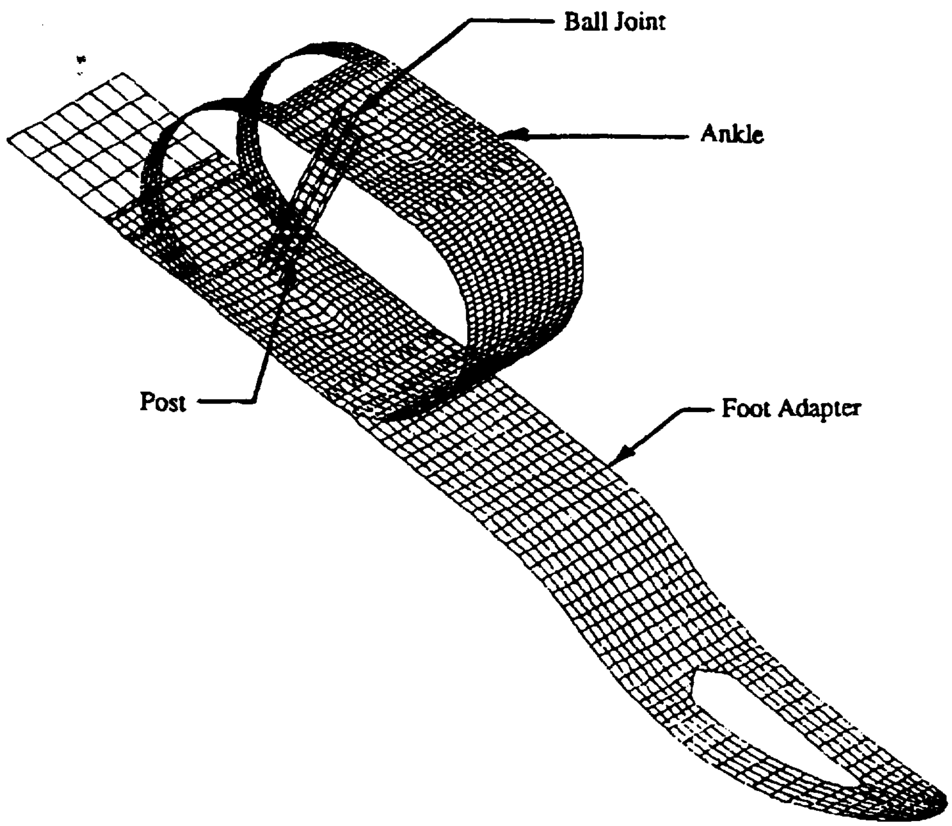

Figure 1. ANSYS Finite Element Model of Copes/Bionic Ankle

Elastic Moduli	$EX = 33\ (10)^6$ PSI
	$EY = EZ = 2.1\ (10)^6$ PSI
	$GXY = 2.1\ (10)^6$ PSI
	$GYZ = GXZ = 3.3\ (10)^6$ PSI
Poisson's Ratios	$NUYZ = 2.7\ (10)^{-1}$
	$NUXY = NUXZ = 2.7\ (10)^{-2}$

Thickness of Thornel 300 graphite ply = 0.005 inch

Figure 2. Structural Properties for the T300/5208 Composite Material [2]

ANALYTICAL RESULTS

The front surface of the initial design of the ankle acted like a shear beam for rotations about the vertical and longitudinal axes and was therefore much too stiff to allow rotations of 10 degrees about these axes.

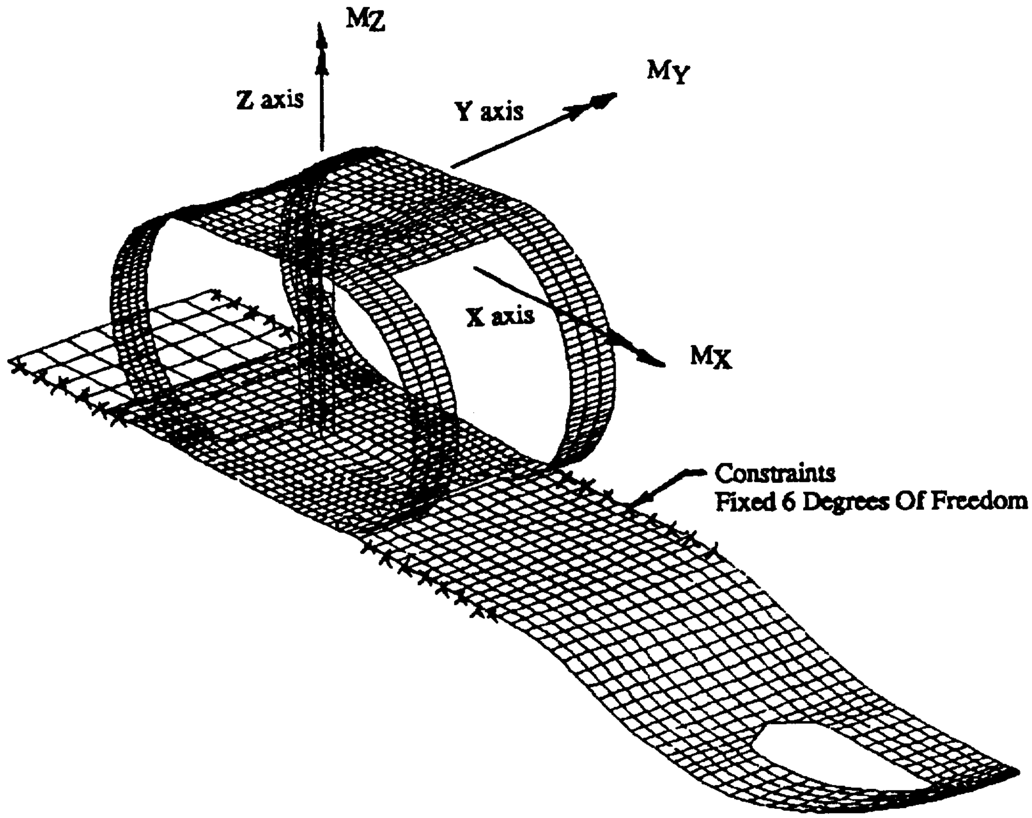

Figure 3. ANSYS FEM of the Modified Copes/Bionic Ankle, Showing Applied Loads and Constraints

The FEM of the Copes/Bionic Ankle was therefore modified to delete the center of the front curved part of the ankle so that it will resemble the aft curved part. The FEM of the proposed modification of the Copes/Bionic Ankle is shown in Figure 3. To employ an iterative approach, the 24 graphite filaments were reduced to 8 for all of the ankle to approximate the desired flexibilities. The purpose of this modification was to allow the required rotations of the ankle within the moment restraints.

The required 20 degree rotation about the Y axis was imposed on the FEM of the modified Copes/Bionic Ankle. The resultant bending moment about the Y axis was calculated to be about 670 inch pounds, which is an order of magnitude too high. The bending stresses were also about an order of magnitude too high. Additional design iterations will be explored to hopefully achieve a level of the proper stiffness and stresses.

CONCLUSIONS

The Computer Aided Design application of the ANSYS structural code at the NASA Marshall Space Flight Center is providing valuable and essential assistance in the development of the Copes/Bionic Ankle. The proof of the concept is greatly helped, and may result in the desired stiffness and adequate useful life.

References

1. Tsai, S.W., "Composites Design, 4th edition," Think Composites, 1988
2. Material Properties from Dr. Copes on 6-23-92