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Introduction to NuMAD: A numerical manufacturing and design tool

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**INTRODUCTION TO NUMAD:
A NUMERICAL MANUFACTURING AND DESIGN TOOL[†]**

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Abstract

Given the complex geometry of most wind turbine blades, structural modeling using the finite element method is generally performed using a unique model for each particular blade analysis. Development time (often considerable) spent creating a model for one blade may not aid in the development of a model for a different blade. In an effort to reduce model development time and increase the usability of advanced finite element analysis capabilities, a new software tool, NuMAD, is being developed.

Introduction

Though the commercial finite element (FE) analysis packages currently available are powerful, they are generally difficult to use. Even users well-versed in the finite element method can spend significant amounts of time deciphering the correct format in which to input data relating to anisotropic materials (laminated composites), varying thicknesses, etc.¹ In addition, the minimum amount of information needed to properly define a wind turbine blade in three dimensions is non-trivial. As a result, experienced analysts may spend several weeks to develop a detailed finite element model of a turbine blade.

Other issues in model creation are reusability and design for manufacture. Depending on the methods used to develop the original model, subsequent modifications to the design may be relatively minor or quite time-consuming. Obviously, a process which maximizes model

reusability would be beneficial, especially for parametric studies. Throughout the design process, manufacturing constraints should be incorporated. A design which cannot actually be produced is generally of limited interest.

NuMAD is designed to address all of these issues and provide an improved FE model development environment for wind turbine blades.

Software Overview

NuMAD is a user-friendly, X-windows based (graphical) pre-processor and post-processor for the ANSYS^{®2} commercial finite element engine. It is designed to enable users to quickly and easily create a three-dimensional model of a turbine blade and perform structural and modal analyses. The parameters defining the blade may be provided by existing files (possibly from other design codes) or developed interactively using databases of airfoil shapes and materials.

Figure 1 shows a screen shot of NuMAD for the interactive input of blade parameters for a 3-D shell model. The blade is defined by a series of stations beginning at the root and ending with the blade tip. For each station, the user selects an airfoil profile from the database and inputs a chord length, twist, etc. Structural ribs may be defined between

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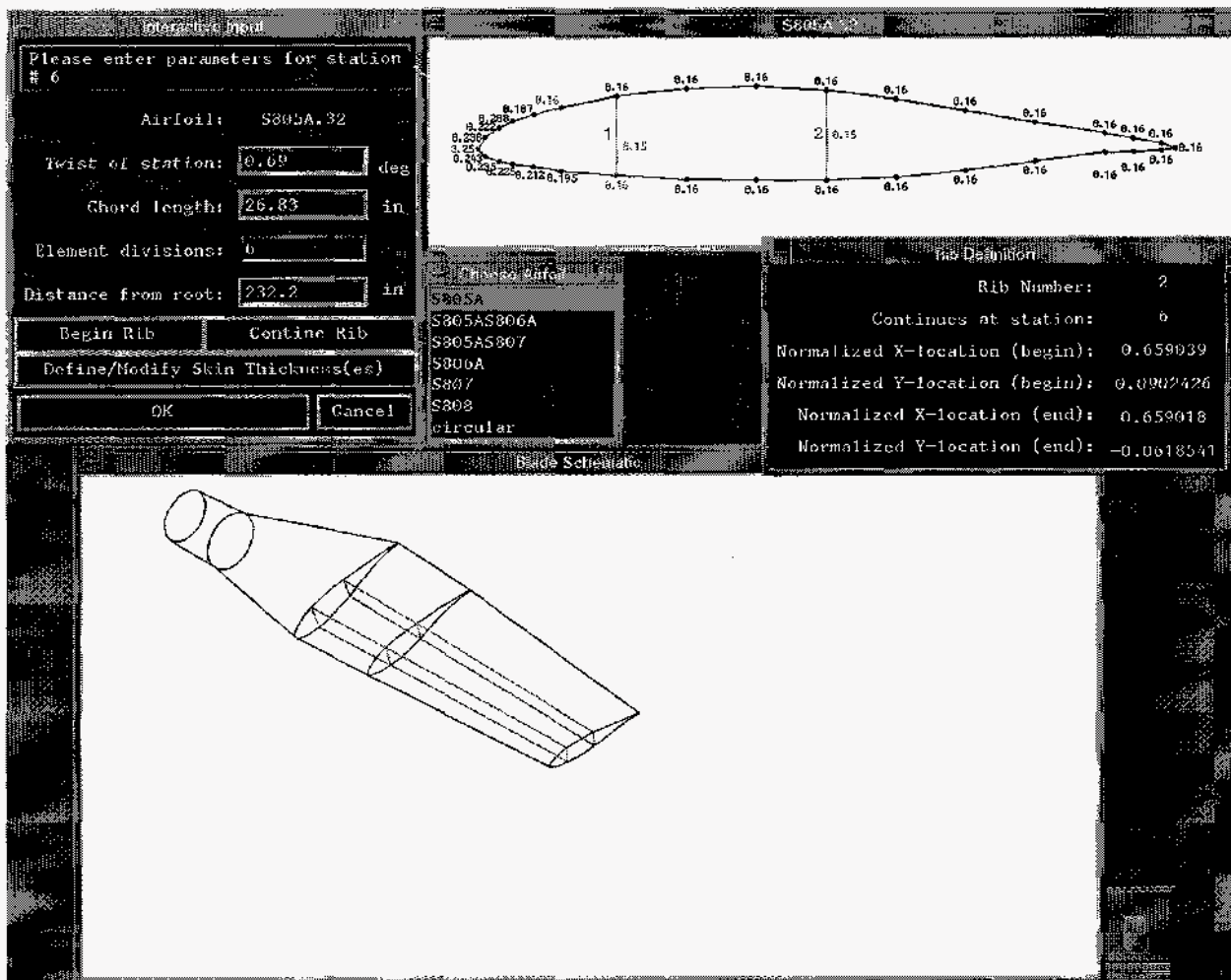


Figure 1. Screen shot of NuMAD during blade definition. Stations are defined by selecting an airfoil profile, chord length, twist, distance from root. Additionally, thickness values along the profile may be specified (for isotropic/orthotropic materials) and support ribs may be defined.

locations used in the definition of the airfoil profile. The user defines the rib by selecting the end locations of the rib on the display of the profile. A window providing information on rib definitions gives the rib number, current station, and an active display of the current position of the input device. The rib thickness is defined in an entry box. The thickness of the skin (applicable to isotropic and orthotropic materials) is determined by defining the thickness at any number of locations around the profile; undefined locations are interpolated. Thus if only one skin thickness value is defined, the airfoil profile would have a uniform thickness. As each station is defined, it is drawn in an isometric representation of the blade (lower portion of figure 1) so that the user may detect errors in the blade definition.

While users need no previous knowledge of the ANSYS® analysis package, experience with finite element methods is required to use NuMAD effectively. Model types accessible through NuMAD include three-dimensional beams, three-dimensional structural shells, and three-dimensional structural solids. No modification to the standard ANSYS® package is necessary.

Hardware Requirements

The hardware requirements of NuMAD are far less than those of ANSYS®. Thus any system capable of running ANSYS® can run NuMAD as well. The requirements for ANSYS® are a unix workstation or Windows® personal computer (PC) with at least 64 MB of random access memory (RAM) and at least 2 GB of hard disk space.

Databases

Materials

The materials database may contain isotropic, orthotropic, and composite materials. A user-defined name is associated with each material and this name is displayed in the materials selection box when assigning a material to a particular portion of a blade model. Different materials may be defined at each station, i.e. to capture the effects of stiffening materials near the root.

Facilities are provided within NuMAD to aid in the definition of new materials for the database. This prevents, for instance, problems with ply-orientation in the definition of new composite materials.

Airfoil Profiles

The airfoils database is comprised of text files in a specific directory (folder). NuMAD checks this directory and displays each profile in it when the user is asked to select an airfoil profile.

The database of airfoil profiles is also easily modified. Each profile is determined from a series of coordinate pairs. The leading edge of the profile is at the origin and the trailing edge is at the coordinates (1,0). The profile descriptions begin at the trailing edge and define the airfoil in a counter-clockwise direction going from trailing edge to leading edge to trailing edge. Each airfoil profile is described in a text file named after the airfoil and the coordinate pairs are space delimited. New airfoils may be added by simply creating a new file with the appropriate airfoil name. NuMAD will recognize the new airfoil and list it along with the previously defined profiles. Figure 2 shows the directory containing the airfoil profiles as well as the partial contents of one of the files. Note that the file names shown in Figure 2 correspond to the profiles listed in Figure 1 in the airfoil selection box. The particular profile names listed here correspond to some of the NREL airfoil families³.

Loadings

For static analyses, options include tip loads in the flapwise and edgewise directions as well as pressure loads in the flapwise direction (hurricane load). For modal analyses, a spin rate may be defined for the blade so that stress stiffening

effects may be included. An example of this capability may be seen in Figure 3 and Figure 4. A typical blade geometry was used but for this example an arbitrary material was selected. Figure 3 shows the fundamental flapwise bending mode for the stationary, cantilevered blade while Figure 4 shows the same blade with a spin rate of 1.0 Hz. The legend gives information concerning relative deflection. The fundamental frequency changes from 0.607 Hz in the stationary blade to 0.724 Hz in the spinning blade. While the particular values of these frequencies are not important, it demonstrates the potentially substantial increase in natural frequencies due to spin rates.

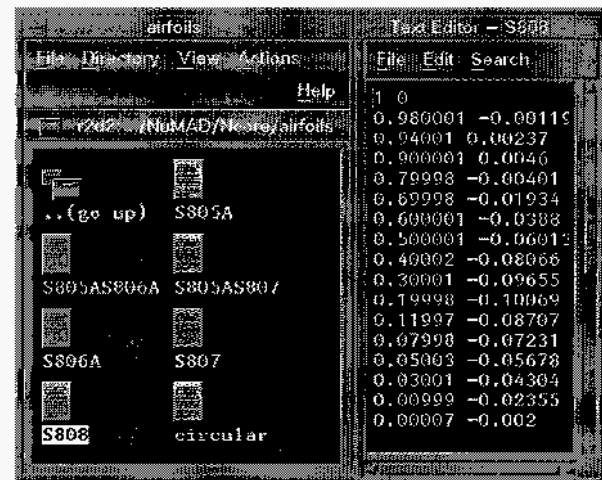


Figure 2. Airfoil profiles defined as simple text files in airfoils directory (folder).

Analysis Types and Output

Both structural and modal analyses may be performed. After defining the blade geometry, the user is asked to choose an analysis type. Based on the type chosen, additional information is required such as tip load magnitudes for a static structural analysis or the number of modes desired for a modal analysis.

Next, output preferences are chosen by the user concerning which results will be saved to images and which images will be automatically printed when the analysis is completed. Users may select plots of deflections, stresses, and strains for structural analyses. In a modal analysis, natural frequencies may be listed in tabular form or plots of each individual mode shape may be produced.

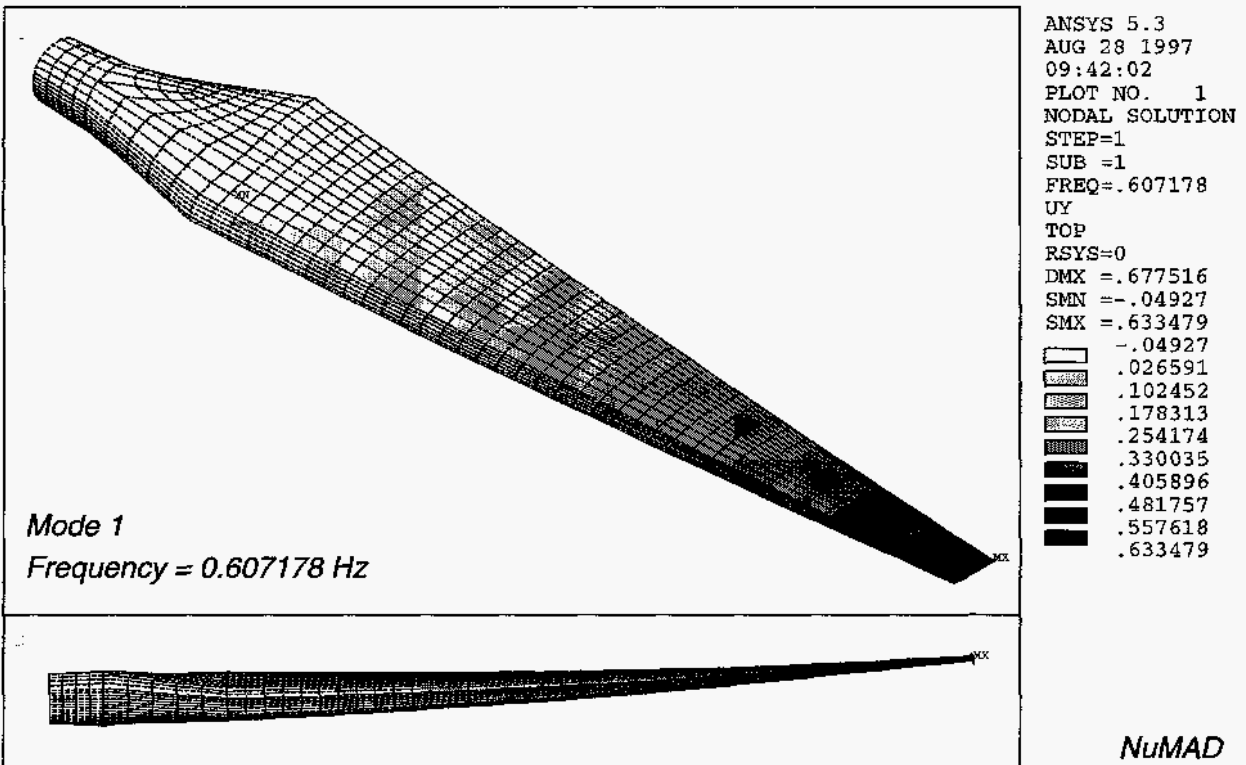


Figure 3. Fundamental flapwise mode shape. Contours indicate relative transverse motion.

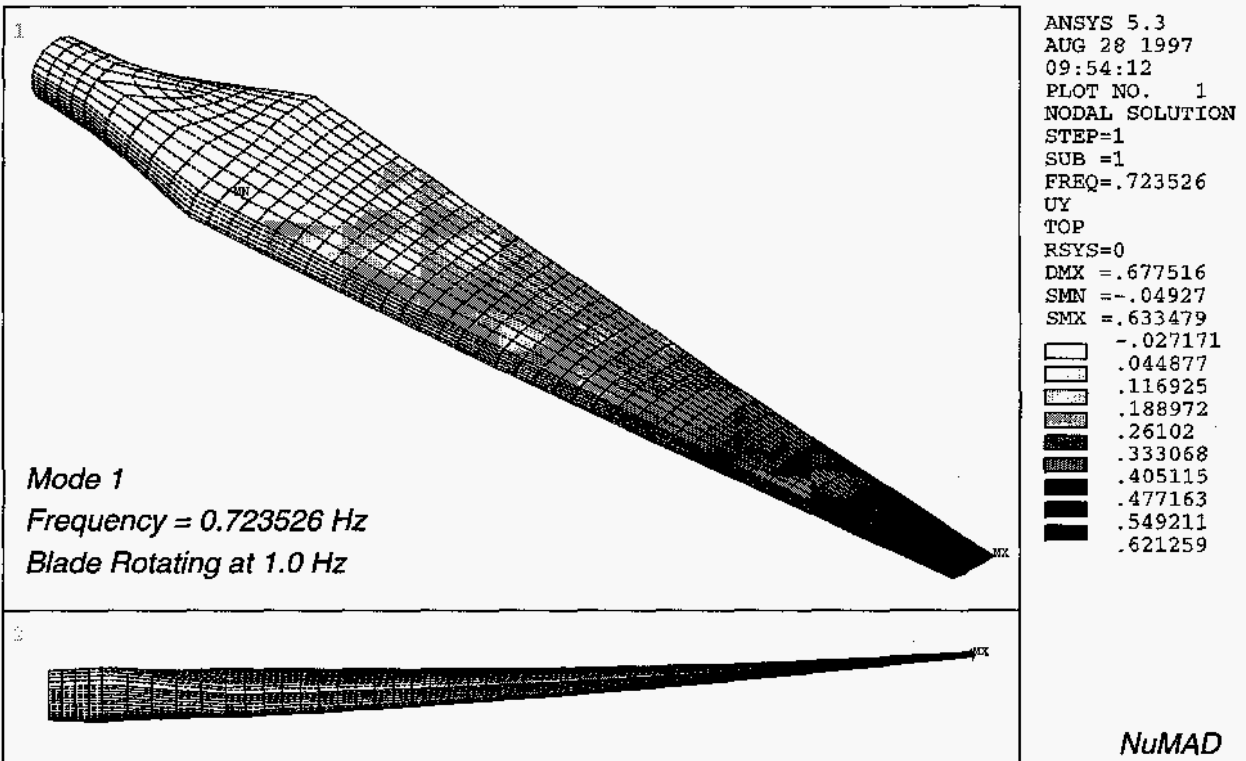


Figure 4. Fundamental flapwise mode shape for blade rotating at 1.0 Hz. Contours indicate relative transverse motion.

All plots are produced in the PostScript® format. In addition to the standard annotation provided by ANSYS®, NuMAD adds some additional relevant information such as the blade rotation speed displayed in Figure 4. NuMAD also includes an image viewer so that users can review results without printing.

Design for Manufacture

NuMAD contains a tutorial of recommended practices for composite manufacturing. Numerous rules-of-thumb and simple drawings are used to educate the user with regard to manufacturable design. In addition, error checking is employed throughout the package to warn or prevent users from specifying unmanufacturable blades or blades of obviously poor design. For instance, the warning shown in Figure 5 might appear as a NuMAD user attempted to assign a particular material to a portion of the blade. In this case, the warning could be ignored or the material could be redefined.



Figure 5. Example of a manufacturing/design related warning.

Enhancements to ANSYS®

A few features not present in the core ANSYS® package were added via the ANSYS® Parametric Design Language (APDL). For instance, a command to mesh an area with the thickness varying across the area is not present in the standard ANSYS® distribution. Such a feature is desired because a tremendous amount of development time can be spent simply capturing the varying panel thickness in a real structure. A new command to accomplish such a task was created with APDL and is used extensively by NuMAD. A simple example is shown in Figure 6. The upper image shows a rectangular area meshed with elements of equal thickness. This meshed area was then manipulated with the new command to define corner thicknesses for the area. Each element was redefined to have the

appropriate thickness value at each element corner. New real constant sets (ANSYS® mechanism to define certain element properties such as thicknesses etc.) are created and labeled appropriately. The lower image in Figure 6 shows the same area with four different corner thickness values defined. The shading of the elements indicate that each one now has a unique real constant set associated with it. While the example area was flat, the command works equally well for areas curved and warped in 3-D space. Enhancements such as the variable thickness mesh generator are internal to NuMAD and do not directly affect the NuMAD user.

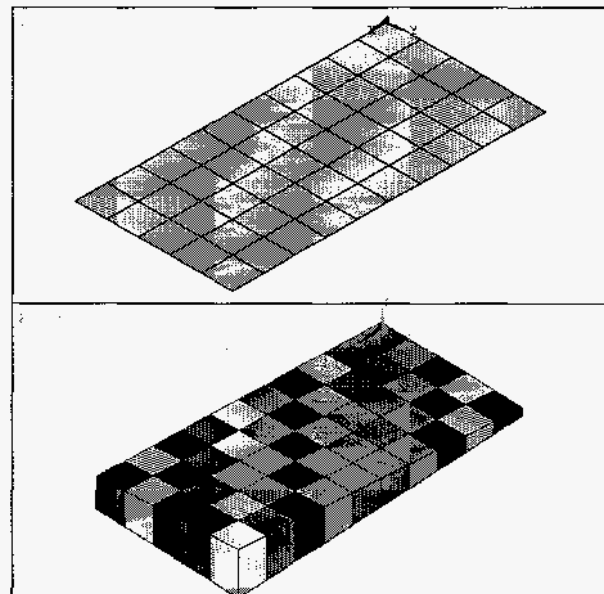


Figure 6. Example of element thickness definition capability for areas. The original meshed area is shown above with the modified area shown below.

Case Study

To give some quantification of the time savings possible, a blade model was developed with NuMAD which used the geometry of a model previously created with the traditional development method. As expected, NuMAD allowed for the creation of an identical model with much less development time.

The original model simulated a simple blade of constant cross section. The time spent creating the model was approximately 15 hours (for the author). This did not include the time required for

solution of the model. More recently, a finite element model for the same blade was created using NuMAD. In this case, the model creation process took 32 minutes. Of this time, 17 minutes were required to create the new airfoil profile and add it to the airfoils database. Future analyses using this profile would not need to repeat this step. Additionally, 5 minutes were spent in defining the orthotropic materials needed for the analysis. Had both the materials and airfoil profile been present in the original databases, the model development time would have been 10 minutes. This represents, obviously, a significant time savings when compared to the 15 hours of development time mentioned previously. It should also be mentioned that this particular blade geometry was relatively simple. The time savings possible for twisted and tapered blades should be significantly greater.

The fundamental mode of the blade model just described is shown in Figure 7. Results match the original analysis. For this analysis, the boundary

conditions were free-free to match an experimental set-up.

Conclusions

A new design-for-manufacturing software tool is now available. NuMAD provides a user-friendly finite element model development environment tailored to wind turbine blades. It allows easier access to advanced finite element analysis capabilities and reduces model development time. Additionally, NuMAD has access to all of the visual capabilities of ANSYS® such as 3-D color graphics and animation.

Due to the utilization of a commercial finite element package, ANSYS®, state-of-the-art finite element analysis capabilities may be incorporated into NuMAD rather than developed from scratch. Future capabilities and improvements in ANSYS® may be quickly added into NuMAD.

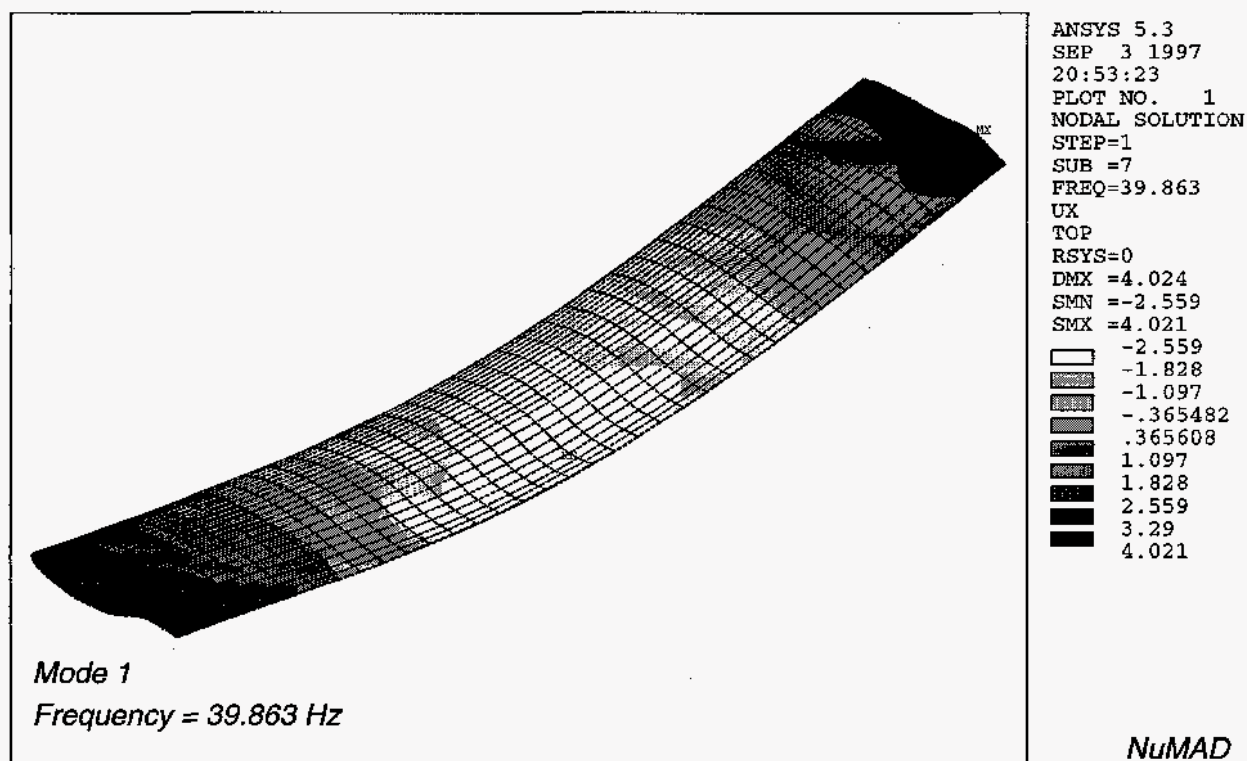


Figure 7. Fundamental flapwise bending mode for the case study. This blade uses a constant cross section.

Availability

NuMAD is available through Sandia National Laboratories. While current versions run only on unix operating systems, a PC/Windows version of NuMAD is currently being developed. Please contact

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