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ANALYSIS OF ROTATING FLEXIBLE BLADES USING MSC/NASTRAN

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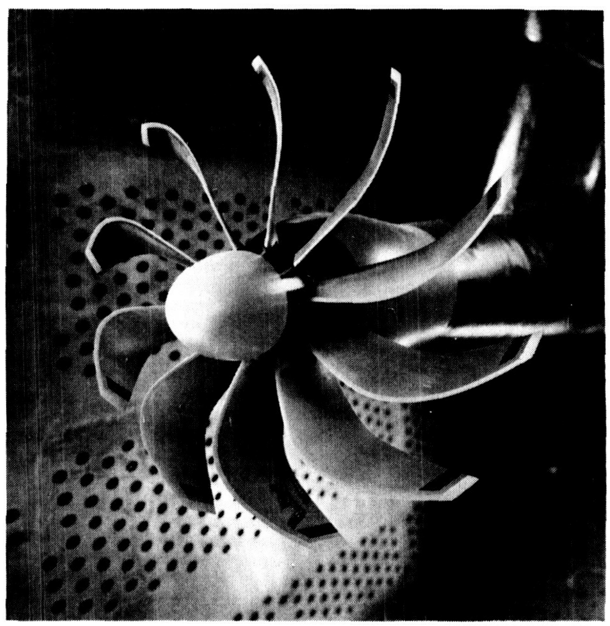
ABSTRACT

This presentation gives an overview of the use of MSC/NASTRAN in the analysis of rotating flexible blades (Lawrence, et al., 1987). The geometrically non-linear analysis using NASTRAN Solution Sequence 64 is discussed along with the determination of frequencies and mode shapes using Solution Sequence 63. Items unique to rotating blade analyses, such as setting angle, centrifugal softening effects, and hub flexibility, are emphasized.

PROPFAN

Because of the potential for very high propulsive efficiency at cruise speeds up to Mach 0.8, advanced forms of the propeller, called propfans, are being seriously considered for aircraft propulsion. To obtain maximum aerodynamic and acoustic performance, the trend in advanced high speed propeller design has been toward thin, swept blades of complicated structural design. A research program to establish the required technology for successful design of propfans is in progress at the NASA Lewis Research Center (Mikkelson, et al, 1984 and Strack, et al, 1981).



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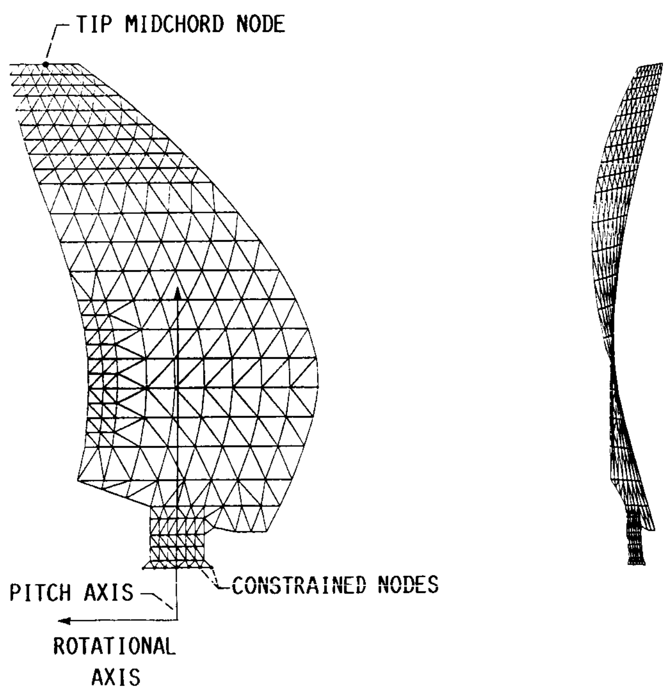
STRUCTURAL MODEL

Part of the Advanced Turboprop Program effort is to understand and predict the structural and dynamic behavior of these blades. The analysis of rotating flexible blades, such as compressor and turboprop blades, often requires complex procedures, including geometrically nonlinear (large-displacement) analysis and frequency and mode shape determination. In performing these analyses, and in modeling the complex geometries and material properties of the blades, finite element (F.E.) computer programs typically are used.



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OBJECTIVE

The objectives in performing such analyses include the prediction of steady-state deflections and stresses under centrifugal forces, the generation of data for constructing Campbell diagrams (plots of frequency with respect to rotational speed), and the provision of modal data for use in flutter calculations.

- **STRUCTURAL ANALYSIS OF TURBOPROP BLADES**
  - **STEADY-STATE DISPLACEMENTS**
  - **FREQUENCIES**
  - **MODE SHAPES**

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APPROACH

NASTRAN is particularly well-suited to this purpose because of its ability to compute steady-state displacements with its geometrically nonlinear analysis capabilities, and to use those results for subsequent normal-modes analyses (McCormick, 1983).

- **FINITE ELEMENT ANALYSIS USING NASTRAN**
  - **STEADY-STATE DISPLACEMENT (SOLUTION SEQUENCE 64)**
  - **EIGENSOLUTION (SOLUTION SEQUENCE 63)**

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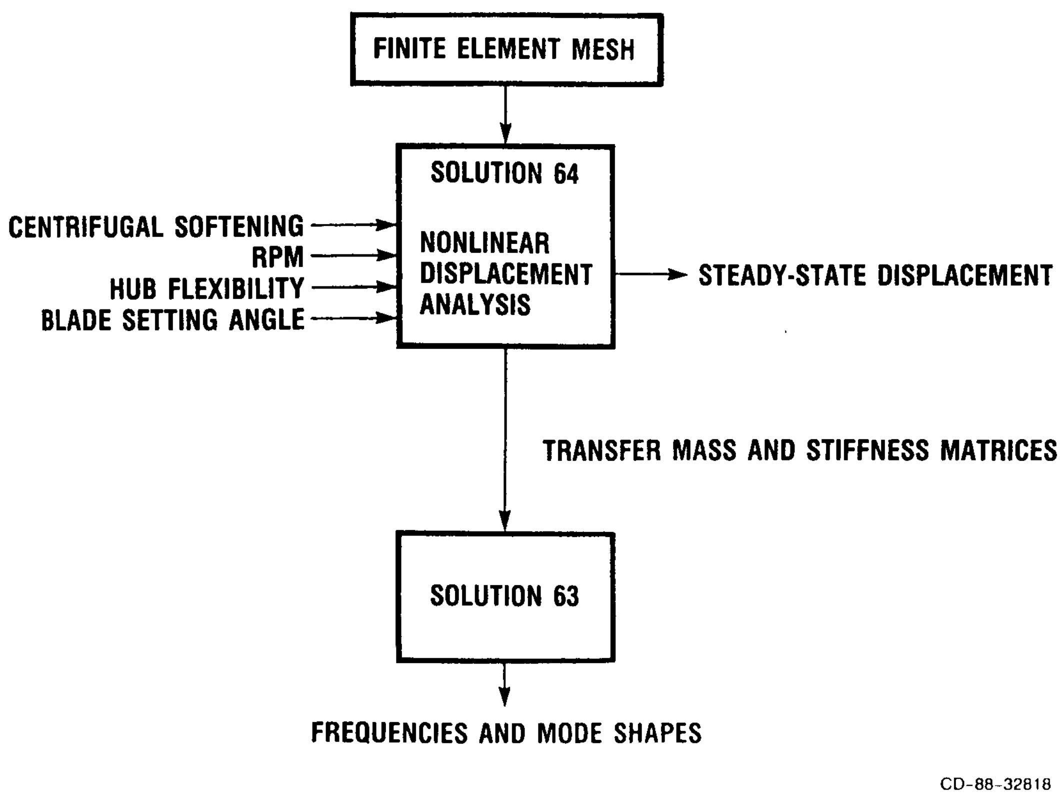
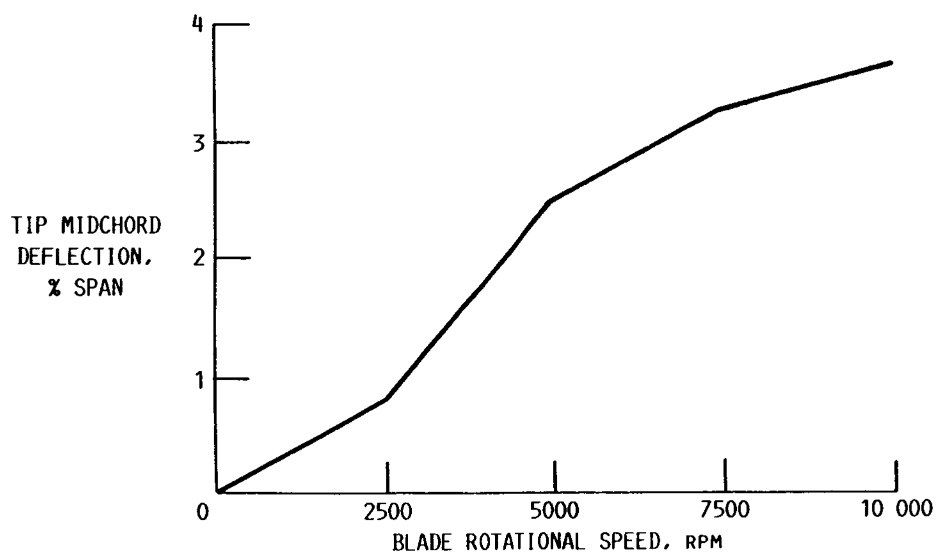
PROCEDURE

The computation of steady-state displacements, frequencies, and mode shapes of flexible rotating blades requires that two NASTRAN Solution sequences be run. First, a large-displacement analysis is run using NASTRAN Solution Sequence 64. This solution sequence performs a large-displacement analysis on the rotating blade, computes steady-state displacements and stresses, and then stores the blade final stiffness and mass matrices in a database. Following the large-displacement analysis, the frequencies and mode shapes are computed using Solution Sequence 63. This solution sequence computes the modal parameters from the final mass and stiffness matrices which were computed during the Solution 64 run (Lawrence, et al, 1987).



TYPICAL NONLINEAR DEFLECTION CURVE FOR FLEXIBLE BLADE

Experience has shown that a large-displacement analysis is required because the blades are relatively flexible and normally deflect considerably under centrifugal forces (Lawrence and Kielb, 1984).



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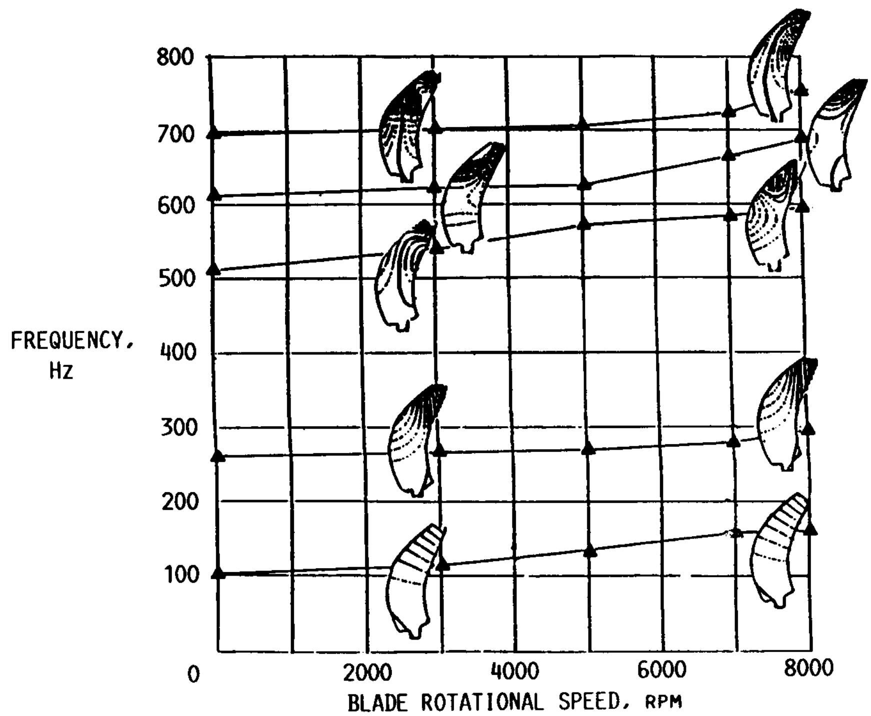
TYPICAL FLEXIBLE BLADE CAMPBELL DIAGRAM

A typical plot demonstrating the variation in natural frequencies with rotational speed is shown.



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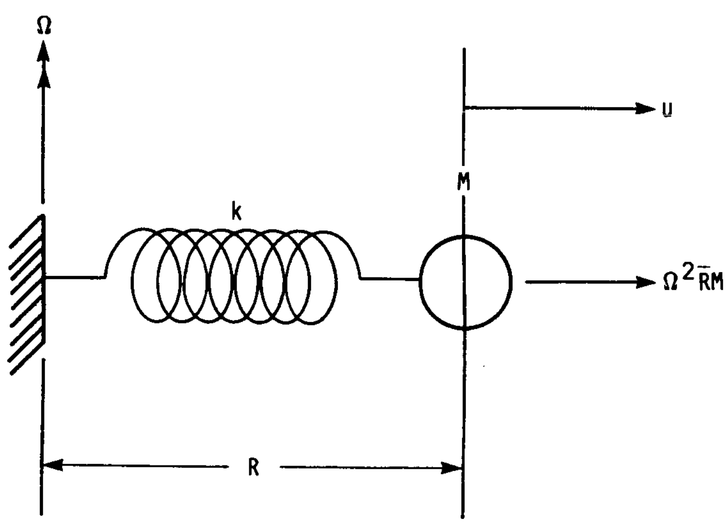
CENTRIFUGAL SOFTENING

When performing the large-displacement analysis, NASTRAN will automatically consider the increment in load by updating the centrifugal loads based on the deformed position of the blade. Although this approach will work for the large-displacement analysis, the softening terms must still be inserted into the stiffness matrix when a subsequent normal-modes analysis is performed. If the softening term $-\Omega^2 M$ is not included in the stiffness matrix that is transferred from the Solution 64 to the Solution 63 analysis, the frequencies will be computed incorrectly.



$$ku = \Omega^2 \bar{R} M$$
$$ku = \Omega^2 (R + u) M$$
$$(k - \Omega^2 M) u = \Omega^2 R M$$

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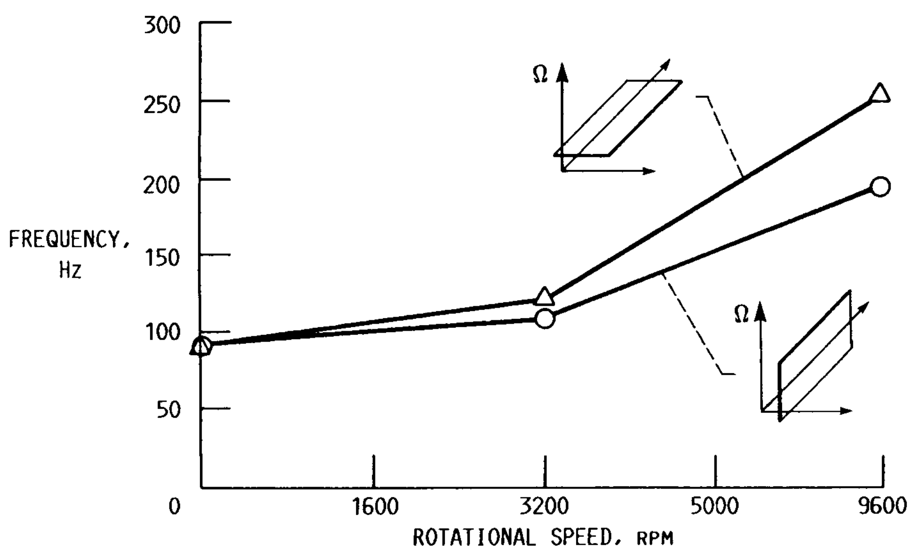
EFFECT ON NATURAL FREQUENCIES DUE TO CENTRIFUGAL SOFTENING

To demonstrate the effect that the softening terms have on the natural frequencies, a steel plate (6 in. by 2 in. by 0.10 in.) was analyzed. In this figure, two sets of frequencies are plotted; one for the plate lying in the plane of rotation, and the other lying perpendicular to the plane of rotation. For the latter case the softening terms have a significant effect on the plate's first bending mode frequency. This is understandable since both the softening terms and the bending mode motion are in the plane of rotation. For actual blades, which have more complexity in their geometries than the steel plate, the centrifugal softening will have some influence on all of the modes, and therefore, will need to be included in all of the normal-modes analyses.



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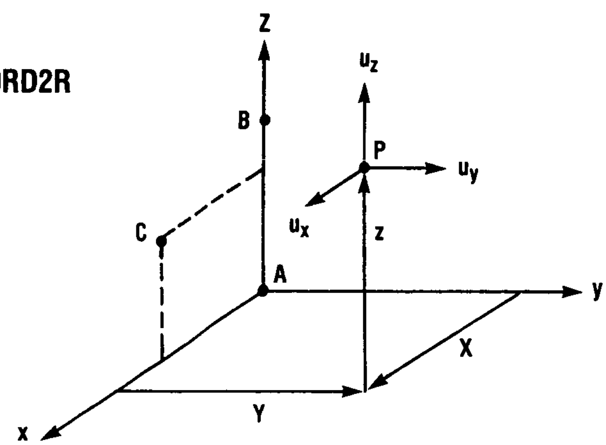
ALTERING BLADE SETTING ANGLE

To obtain the steady-state displacements, frequencies, and mode shapes when the blade is rotating at a new speed, both the large-displacement and normal-modes analysis need to be rerun. In addition to changing the blade rotational speed, the blade setting angle generally has to be adjusted. To implement a change in the setting angle, the entire blade can be rotated by defining the blade geometry in a new coordinate system via the CORD2R card.

INPUT DATA CARD CORD2R

(McCORMICK, 1983)



FORMAT

1	2	3	4	5	6	7	8	9	10
CORD2R	CID	RID	AI	A2	A3	B1	B2	B3	ABC
CORD2R	3	17	−2.9	1.0	0.0	3.6	0.0	1.0	123

+BC	C1	C2	C3						
+23	5.2	1.0	−2.9						

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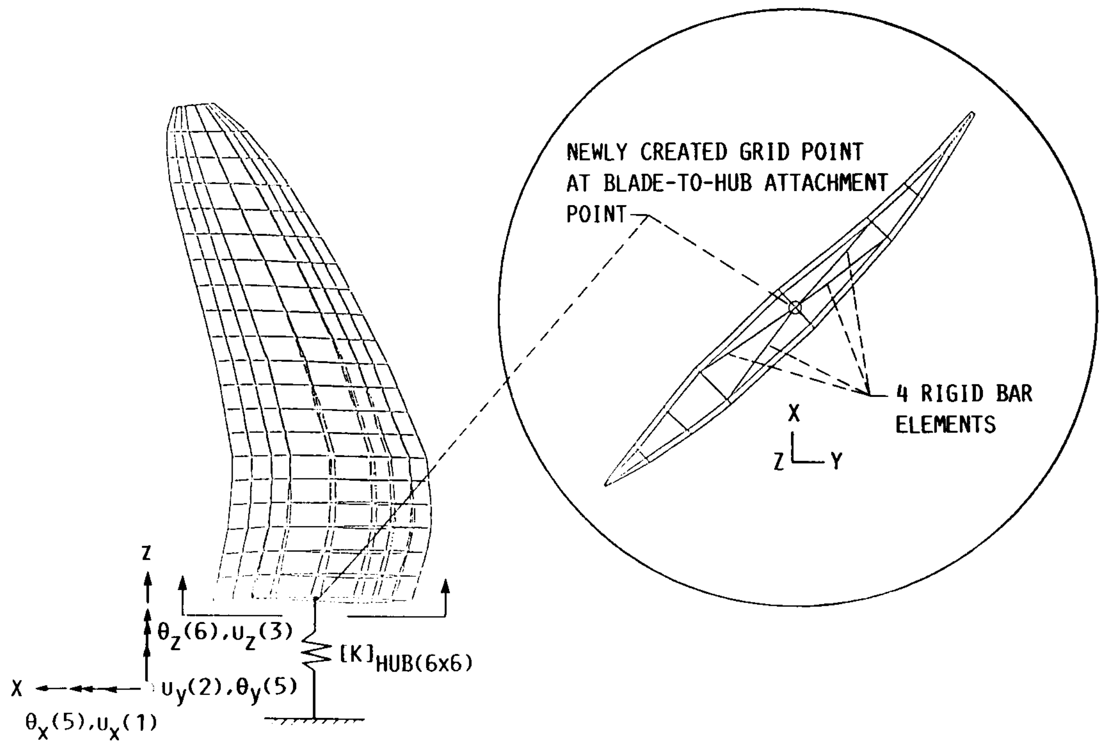
HUB FLEXIBILITY

Ernst and Lawrence, 1987, have shown that base flexibility can have a significant effect on steady-state displacements, frequencies, and mode shapes. The blade chosen for their study was the 0.175 scale model of the GE-A7-B4, shown below. A series of nonlinear static and dynamic analyses were conducted on the blade for both rigid and flexible hub configurations. Results indicated that hub flexibility is significant in the nonlinear static and dynamic analyses of the GE-A7-B4, and that in order to insure accuracy in analyses of other blades, hub flexibility should always be considered.



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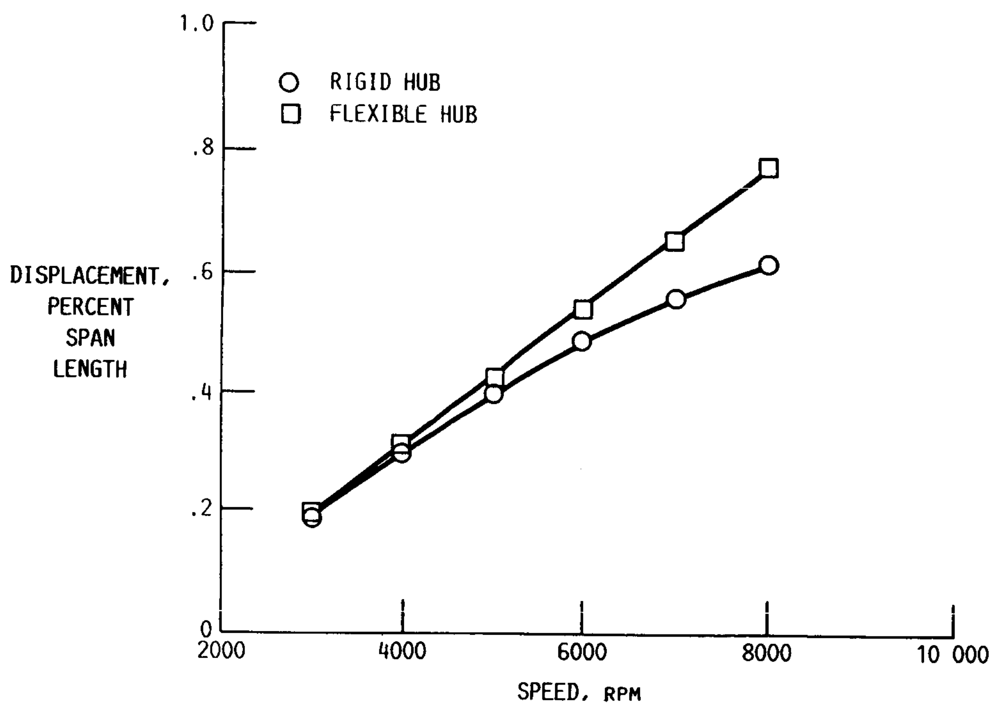
EFFECT OF HUB FLEXIBILITY ON LEADING-EDGE TIP DISPLACEMENTS

The figure below presents the magnitude of leading-edge tip displacements versus rotational speed for the 2-ft diameter GE-A7-B4 blade model, with both rigid and flexible hubs. At low rpm, the flexible hub has little effect on the static displacement. However, at greater than 4000 rpm, the influence of the flexible hub becomes notable.



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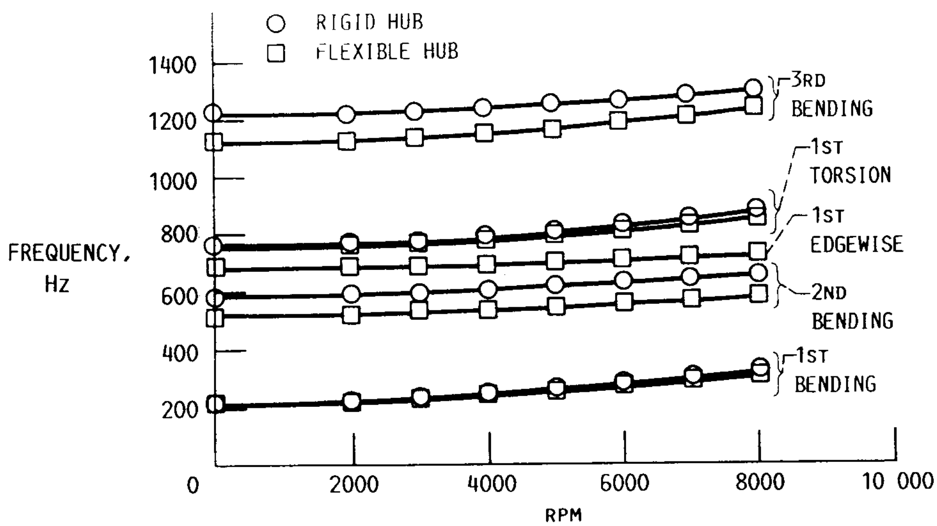
EFFECT OF HUB FLEXIBILITY ON MODAL FREQUENCIES

The figure below presents the first bending, second bending, first torsional, and third bending eigenvalues for the 2-ft diameter GE-A7-B4 blade model at various rpm, in both rigid hub and flexible hub configurations. Although the first bending and first torsional frequencies seem to be unaffected by the flexible hub, there is an appreciable discrepancy between the flexible hub and the rigid hub configurations relating to the second bending and third bending frequencies. Also, the first edgewise mode was seen between the second bending and first torsional modes of the flexible hub, whereas the first edgewise mode was not seen for the rigid hub in lower frequency range.



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SUMMARY

NASTRAN is a valuable tool in the large-displacement and dynamic analyses of Propfan blades. However, in order to insure accurate results, the user must account for the following: an updated global stiffness matrix with the appropriate centrifugal softening terms before proceeding with the Solution 63 dynamic analysis; a proper blade setting angle for each of the respective rotational speeds at which the blade is being analyzed; and the effects due to hub flexibility.

NASTRAN IS AN EFFECTIVE TOOL FOR THE ANALYSIS OF PROPFAN BLADES.

CENTRIFUGAL SOFTENING TERMS ARE IMPORTANT IN THE STIFFNESS MATRIX OF NASTRAN'S SOLUTION SEQUENCE 63.

PROPFAN BLADES NEED TO BE MODELED WITH THE APPROPRIATE BLADE SETTING ANGLE.

IN ORDER TO INSURE ACCURACY IN THE ANALYSES OF PROPFAN BLADES, HUB FLEXIBILITY SHOULD ALWAYS BE CONSIDERED.

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