Flutter Analysis of Advanced Turbopropellers

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Abstract

PREVIOUS work by the authors on the modal flutter analysis of tuned bladed-shrouded disks with NASTRAN has been modified and applied to investigate the subsonic unstalled flutter of advanced turbopropellers. Generalized oscillatory aerodynamic forces for varying sweep turbopropeller blades are based on the two-dimensional subsonic cascade unsteady aerodynamic theory of W.P. Jones and B.M. Rao applied in a strip theory manner with appropriate modifications for the sweep effects. These modifications consider the blade to be spanned by a number of nonintersecting chords selected normal to a suitable spanwise reference curve, such as the blade leading edge, and are similar to those of Barmby, Cunningham, and Garrick for swept wings. The stability of three operating conditions of a ten-bladed propeller is investigated using the KE method of flutter analysis. Each condition is iterated once to determine the flutter boundary. A five-bladed propeller is also analyzed at one operating condition to investigate stability. Analytical results are in good agreement with tunnel tests.

Contents

Under the sponsorship of NASA's Lewis Research Center, a series of new capabilities has been developed and added to the general-purpose finite element structural analysis program NASTRAN.[1-7] A variety of problems, including static aerothermoelastic and dynamic aeroelastic analyses of tuned cyclic structures and modal analysis of mistuned cyclic structures such as bladed disks of turbomachines and advanced turbopropellers, has been addressed. State-of-the-art three-dimensional steady and two-dimensional unsteady cascade aerodynamic theories have been integrated with the structural analysis capabilities of NASTRAN. This is a synopsis of Refs. 6 and 7 and addresses the subsonic unstalled flutter analysis of advanced turbopropellers.

Multibladed advanced turbopropellers are geometrically cyclic structures with thin blades of low aspect ratio and varying sweep. The hub is relatively rigid, so that blades can be considered to be structurally independent. Modal analysis of one root-fixed blade suffices without recourse to special techniques for cyclic structures. For structural modeling, the NASTRAN general-purpose finite element program is used. To facilitate the use of a two-dimensional cascade unsteady aerodynamic theory,[8] the aerodynamic "grid" is defined by the intersection of a series of chords and "computing stations" (the thick solid lines in Fig. 1). To apply the strip theory in a manner similar to that of Ref. 9, the chords are selected normal to any spanwise reference curve such as the blade leading edge. The choice of the number and location of the chords and the computing stations is dictated by the variation of the relative flow properties across the blade span and the complexity of the blade mode shapes. The aerodynamic model may generally be defined as a subset of the structural model as shown in Fig. 1.

Figure 2 illustrates some of the definitions pertinent to incorporating sweep effects in the two-dimensional cascade program. Within the program, a local coordinate system $\bar{x}\bar{y}\bar{z}$ is defined at the leading edge point A of the chord AB such that $\bar{x}$ is directed along AB. $\bar{y}$ is defined normal to the "mean" surface containing the points A_-, A, A_+, B_+, B, and B_-. Modal translations along $\bar{y}$ and rotations about $\bar{x}$ at user-selected points along the chord are used in deriving the generalized air force matrix. For the opposite sense of rotation, $\bar{x}\bar{y}\bar{z}$ is defined to be left handed with $\bar{y}$ reversing direction. The shaded area about the chord AB represents the strip of integration associated with AB. Quantities, such as

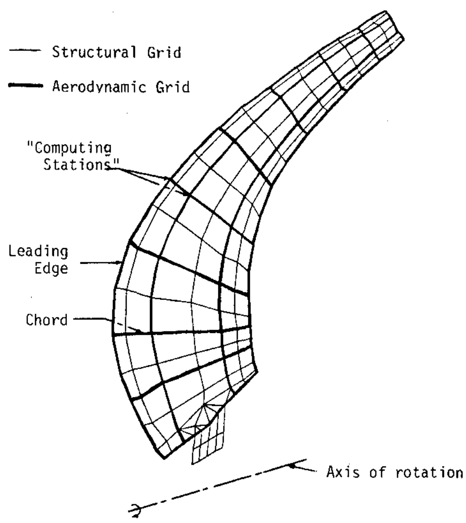

Fig. 1 NASTRAN structural and aerodynamic models of the advanced turbopropeller for flutter analysis.

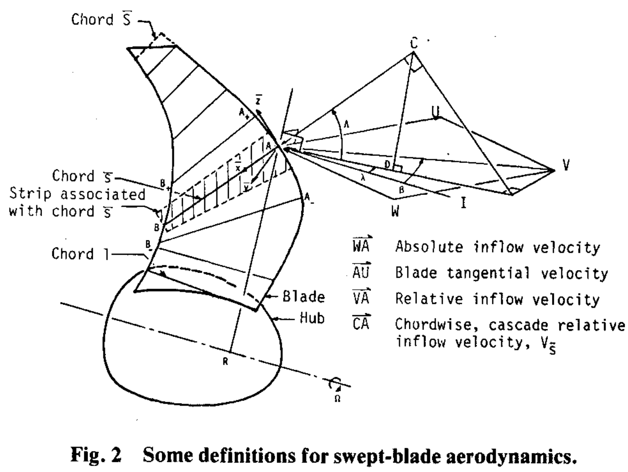

Fig. 2 Some definitions for swept-blade aerodynamics.

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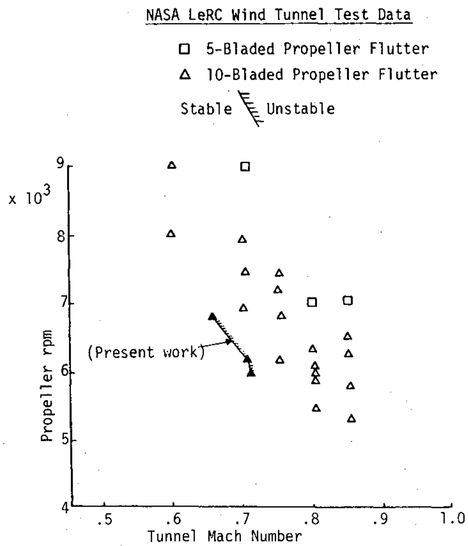

Fig. 3 SR-5 classical flutter summary.

reduced frequency, associated with the propeller (as a whole) are assigned to a user-selected reference chord and scaled appropriately to other chords.

To investigate flutter, the following steps were taken at each of the operating conditions:

1) Centrifugal loads at the operating rpm were applied to the as-manufactured (pretwisted) blade shape to compute the differential stiffness.

2) The displacements at the end of the differential stiffness calculations were added to the pretwisted blade shape to define the deformed blade shape. The elastic and differential stiffnesses were then used to determine the natural frequencies and mode shapes of the deformed blade.

3) The first six structural modes of the deformed blades were used in flutter calculations. For the unstable modes, the root locus plots with interblade phase angle as the parameter were analyzed to determine the dominant flutter interblade phase angle.

For the ten-bladed propeller, step 3 was repeated once in order to locate the neutrally stable operating conditions (flutter boundary). In order to retain the structural modes computed in step 2, the rpm's were unchanged while varying the freestream Mach numbers. Figure 3 compares the analytical predictions of the present work with the experimental results of NASA Lewis. In this study, no attempt was made to determine the sensitivity of the flutter boundary to the structural and aerodynamic models.

Acknowledgment

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