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Improving Tiltrotor Whirl-Mode Stability with Rotor Design Variations

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Abstract

Further increases in tiltrotor speeds are limited by coupled wing/rotor whirl-mode aeroelastic instability. Increased power, thrust, and rotor efficiency are not enough: the whirl-mode stability boundary must also be improved. With current technology, very stiff, thick wings of limited aspect ratio are essential to meet the stability requirements, which severely limits cruise efficiency and maximum speed. Larger and more efficient tiltrotors will need longer and lighter wings, for which whirl-mode flutter is a serious design issue.

Numerous approaches to improving the whirl-mode airspeed boundary have been investigated, including tailored stiffness wings (Refs. 1-3), active stability augmentation (Ref. 4), variable geometry rotors (Ref. 5), highly swept tips (Ref. 6), and at one extreme, folding rotors (Ref. 7). The research reported herein began with the much simpler approach of adjusting the chordwise positions of the rotor blade aerodynamic center and center of gravity, effected by offsetting the airfoil quarter chord or structural mass with respect to the elastic axis (Ref. 8). The research was recently extended to include variations in blade sweep, control system stiffness, and pitch-flap coupling (δ_3).

As an introduction to the subject, and to establish a baseline against which to measure stability improvements, this report will first summarize the results of Reference 8. The paper will then discuss more advanced studies of swept blades and control-system modifications. The paper will include material not published in Reference 8.

Example results

The XV-15 was conceptually redesigned with a thinner (15% thickness-to-chord) wing. While lighter and more efficient, the new wing had no provisions for aeroelastic stability. The resulting whirl-flutter boundary was some 100 knots lower than the standard XV-15. Hence, the studies reported here had a goal of increasing the stability boundary by 100 knots, thereby restoring the original flight envelope.

Initial studies divided the blade into four radial segments (Fig. 1). The center of gravity (CG) and quarter-chord (QC) loci were shifted step-wise in increments of 5% chord over one segment at a time. These designs gave best results for offsets at the tip, and greater improvements for QC offsets than for CG offsets. Moreover, the least stable modes were improved the most. Figure 2 illustrates the improvement in stability provided by QC offsets, which strongly affected the symmetric chord-wise and antisymmetric beam-bending modes.

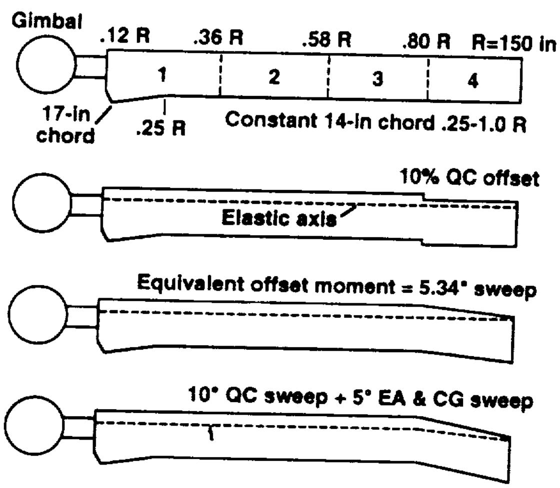

Fig. 1. XV-15 rotor blade planform (45-deg twist and 1-deg baseline sweep not shown).

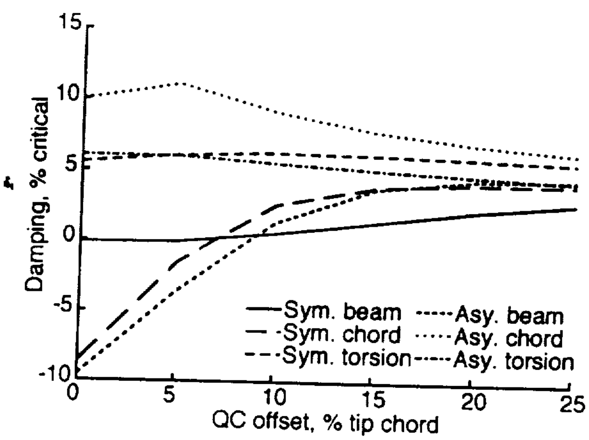

Fig. 2. Variation of damping with quarter-chord offset for blade segment #4 at 350 knots.

The stepped-offset blade was refined into a swept-tip blade (Fig. 1), which is of course a more practical design. Note that this design has a lower value of sweep extending over a larger span than is typical for modern helicopter rotors. Variations in sweep gave stability improvements similar to those for stepped offsets (Fig. 2).

The rotor control system also has a major impact on whirl flutter. Pitch-flap coupling, or δ_3, is a critical design parameter. The geometric constraints of a gimbaled hub force δ_3 to be larger than desirable for aeroelastic stability. The paper will show that a swept-bladed rotor would permit hub geometries with much larger values of δ_3 than are possible with conventional blades.

The paper will conclude with a discussion of rotor loads, which were increased only a modest amount, at most, for the modified blades.

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