Numerical Prediction of Typical Articulated Rotor Impedance

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Abstract

The authors proposed a rotor impedance calculation procedure for articulated rotors in hovering and in forward flight, respectively, in Refs. 1 and 2. Sample calculations in these papers, however, used a rather simplified blade model, since the purpose was to show the essential characteristics of the rotor impedances. This paper conducts a more detailed numerical study of the rotor impedances for a typical articulated blade in practical use. The intent of this paper is to show that the detailed numerical analysis results in essentially the same characteristics as those obtained in Refs. 1 and 2 with a simplified blade model, and also that the effects of collective pitch on the impedances are not so significant in the practical articulated rotors.

Contents

IN the numerical calculations in Refs. 1 and 2, the chordwise center of gravity of the blade was assumed to be located on the elastic axis and that no elastic coupling existed between the flapwise bending, chordwise bending, and torsion. Moreover, when solving blade motion, a nonzero collective pitch, as well as a coning angle, were assumed in the generalized force calculations. Although this was done intentionally to estimate the effects of the steady thrust and the in-plane Coriolis force, it is inconsistent with the assumption of no elastic coupling.

To remove these ambiguities, the exact mode shapes corresponding to each specific collective pitch setting are used with a consistent coning angle in the blade aeroelastic response calculations. The standard Holzer-Mykelstad method is used to conduct modal analysis. Major assumptions contained in the impedance analyses are:

1) The airloads are based on the linearized two-dimensional quasisteady theory and are integrated with the strip theory.

2) The effects of preceding and returning wakes are neglected.

3) The radial displacements of a blade are caused by the blade segments' flapping (around a steady coning) projected on a radial axis.

4) The blade spatial deformations are composed of l coupled natural modes (a total of $l \times 3$ modes), where $l = 8$ in this study.

5) The blade motions are represented in terms of the complex Fourier expansions of the generalized coordinates, and are truncated at the hth harmonic, where $h = 5$ in this study.

The H-34 helicopter rotor is selected as a sample. This is a four-bladed rotor having fully articulated rectangular blades of 28.0-ft radius and 1.366-ft chord. The spanwise characteristics are given in Ref. 3 in 18 spanwise segments.

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Figures 1 and 2 show some results of numerical calculations and show the amplitude ratios of three impedances in hover and in forward flight ($\mu = 0.39$), respectively. The notations $\Delta T/\Delta W$, $\Delta H/\Delta \bar{U}$, and $\Delta H/\Delta Q$ express the impedance of the thrust variation due to hub plunging, the H-force variation due to hub fore-and-aft velocity, and the H-force variation due to hub pitching rate, respectively. The abscissa denotes hub forcing frequency ω nondimensionalized by rotor rotational speed Ω.

Figure 2 shows the results for forward flight; only the impedance components with forcing frequency ω are shown. Those components with frequencies $\omega \pm kN\Omega$ ($N=4$, $k=1,2,\ldots$) are generally small and are not shown here. Figures 1 and 2 also indicate the effects of collective pitch settings. The steady rotor thrust levels are varied by $\pm 50\%$ from a nominal value by means of varying collective pitch angle, and are noted as 150% C_T, 100% C_T, and 50% C_T in the figures.

The results of these numerical studies can be summarized as follows:

1) The change of collective pitch setting causes slight mode changes only in the minor bending modes, not in the major bending or torsional modes. Collective pitch change, as well as blade twist, has negligible effects on the aeroelastic responses in the case of articulated blades.

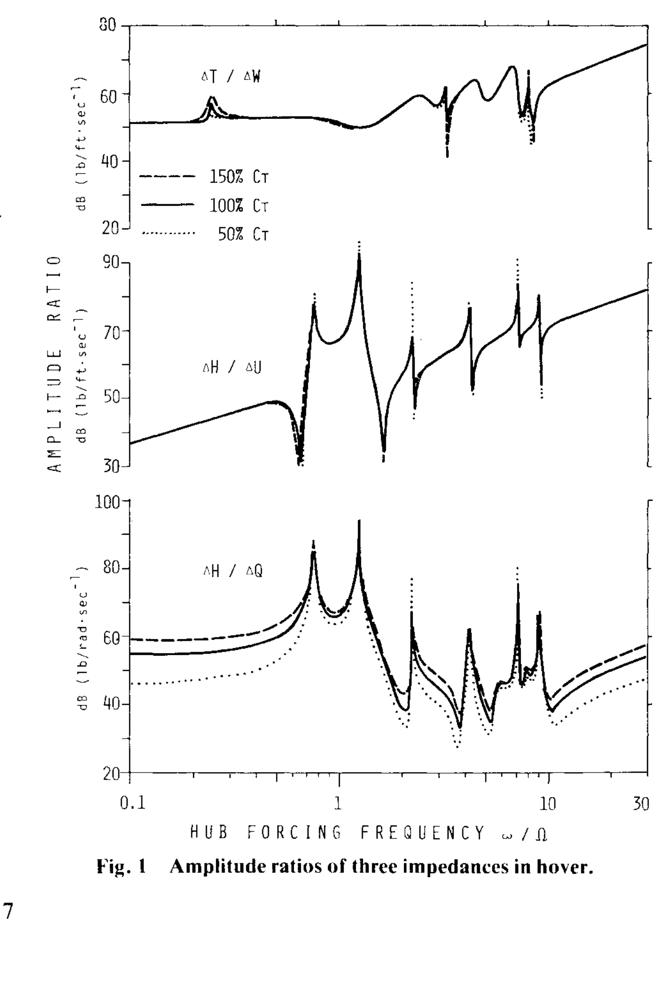

Fig. 1 Amplitude ratios of three impedances in hover.

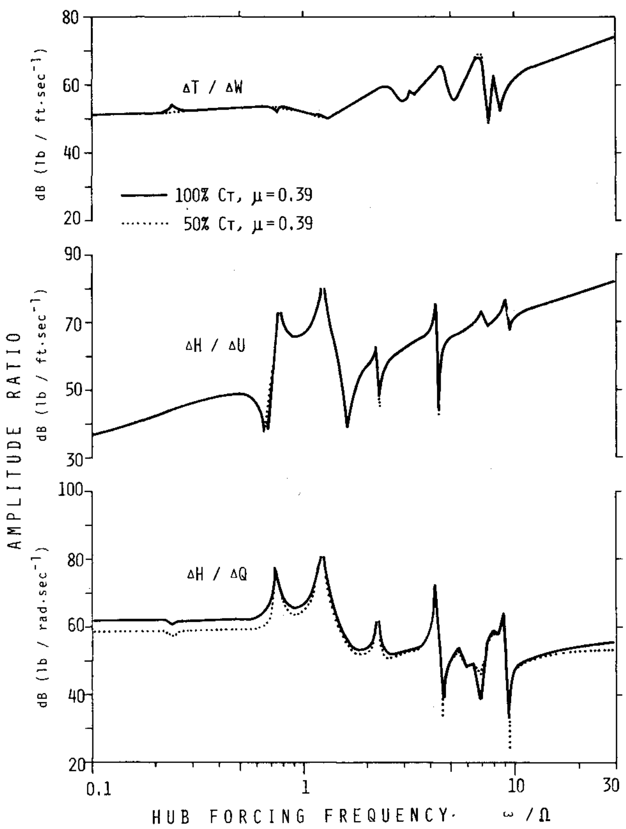

Fig. 2 Amplitude ratios of three impedances in a forward flight.

2) Collective pitch setting can have considerable effect on those impedances that are implicated in the steady thrust. The $\Delta H/\Delta Q$ is such an example. The $\Delta H/\Delta Q$ characteristics are mainly attributed to the fact that the thrust vector follows the shaft tilt when the shaft pitches with a low frequency, while the steady thrust vector is fixed in space when the shaft teeters with a high frequency.

3) The basic impedance characteristics described in Refs. 1 and 2 are still retained: The major impedances (responses with forcing frequency ω) predominate over other impedance components owing to the interharmonic coupling (responses with frequencies $\omega \pm kN\Omega$), and each major impedance resembles the corresponding hover impedance.

4) In the case of the forward flight impedance $\Delta H/\Delta Q$, as also occurred in Ref. 2, the major impedance does not necessarily tend to the corresponding hover impedance when $\omega/\Omega \rightarrow 0$. This originates primarily because the hub generally has a translational velocity v in forward flight; this velocity causes an acceleration $\omega \times v$ in the shaft axis system, where ω is a hub angular velocity, resulting in the inertial loads that did not appear in hover.

References

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