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Impact of the fuselage damping characteristics and the blade rigidity on the stability of helicopter

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ABSTRACT

The aim of this work is to compare in the system of blade articulations, the hydraulic and elastomeric dampers in order to reduce the vibration level in the helicopter rotors. Based on an aerodynamic model, a three-dimensional model of the composite material blade was developed. Numerical calculations on the model developed taking into account the aeroelastic interaction prove that the elastomeric damper of viscoelastic type produces better results compared to other hydraulic damper. The study of the blade stability depending on the orientation of the composite fibers is an important factor to determine the rigidity of the structure.

1. Introduction

The frequent crashes helicopters are often linked to resonance phenomena such as "ground resonance" and aerodynamic forces related to the aeroelastic characteristics blades. The rigidity and geometry of the blade are the main aspects of helicopter stability [1]. Many studies were conducted to improve stability, in particular by modifying the geometry of the blades, Ganguli and Chopra [8]. Krishna Murty and Raman [13] used the finite element method to study the dynamic response of a blade with a rectangular cross section. The numerical results obtained showed the effect of geometrical nonlinearity on the first three normal frequencies of the rotor.

Among ensuing studies on the problems of flapping and lag, Ormiston and Hodges [14] who have used the approximation of a torsionally stiffness blade to show the influence of torsion–elastic coupling on the stability of the blade. Subsequently, the problem of complete stability of lag, flapping and torsion has been studied by Friedmann and Tong [6]. They examined the flapping and lag in a uniform blade. The results showed that it is important to consider the torsion. Stability depends on the deformation modes number. Another study on the nonlinear coupling of flapping, lag and torsion of a blade is given by Hodges and Dowell [9]. They used two methods: the variational method and Newton approach to draw the nonlinear equations of flap motion, lag and torsion for a nontwisted blade.

Xiong and Yu [16] have sought to define a new model of coupled helicopter rotor–fuselage using the partition–iteration method, leading to the prediction of the blade's structural response based on an aerodynamic two-dimensional quasi-stationary model. Subsequently Chakravarty [4] used the finite element method to study the influence of the number of DDL on the torsional rigidity and the shear stress. Optimal approaches to reduce vibration of the rotor blade were studied and discussed, using dampers in the articulations.

To reduce the lag induced vibration level in the helicopter blade, Hu Guo-Cai et al. [11] studied the influence of a damping elastomer with nonlinear properties and a kinematic coupling. The results showed that the damping elastomer increased the helicopter dynamic stability, though damping effect decreased with increasing displacement. According to Fort et al. [5], the design, analysis and modeling of elastomeric dampers for helicopters are becoming difficult. Elastomers are viscoelastic materials, which provide both stiffness and damping to the system. The characteristics of stiffness and damping elastomers are nonlinear functions of the amplitude and frequency for a blade in lag mode. Gandhi and Chopra [7] developed a model of nonlinear viscoelastic solid in which a nonlinear spring was used in series with a single linear chain of Kelvin. Using this model, the changes in complex analytic

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Nomenclature

A	Cross-sectional area
a	Airfoil lift-curve slope
b	Number of blades
B_1^*	Blade cross-sectional integral
B_2^*	Blade cross-sectional integral
c	Blade chord
c_{d0}	Airfoil profile drag coefficient
C_1	Blade cross-sectional integral
C_1^*	Blade cross-sectional integral
G	Shear modulus
$[I]$	Identity matrix
Iy', Iz'	Cross-sectional area moments of inertia about y' and z'
J	Torsional stiffness constant
k_A	Cross-sectional polar radius of gyration
k_m	Mass radius of gyration
k_{m1}, k_{m2}	Principal mass radius of gyration
K	Non-dimensional parameter
$[K]$	Modal stiffness matrix
$[K^s]$	Modal stiffness matrix due to the structural terms
$[K^a]$	Modal stiffness matrix due to the aerodynamic terms
L_u, L_v, L_w	Generalized aerodynamic forces per unit length in the u, v and w directions, respectively
$[M]$	Modal mass matrix
M_ϕ	Generalized aerodynamic moment per unit length
$M_{x'}$	Twisting moment about x' axis
$M_{y'} M_{z'}$	Bending moments about y' and z' axes
$[M_m]$	Modal mass matrix made diagonal
m	Mass per unit length
m_1, m_2, m_s	Masses per unit length of tuning bars and the host spar
$[P], [P^*]$	State space matrices in the perturbation equations
Px'	Warp term in the strain energy expression
$[Q]$	Transition matrix
R	Length of the blade
$\Re$	Flap–lag structural coupling parameter
t	Time [s]
r	Distance along the deformed elastic
S'_x	Twisting moment due to shear stress
T	Kinetic energy, and blade tension
$T_{x'}$	Twisting moment due to longitudinal stress
U	Strain energy
$[U]$	Matrix of eigenvectors for free vibration case
u, v, w	Elastic axis displacements along the x, y, z directions, respectively
v_i	Induced inflow velocity
$\vec{V}$	Velocity of a point in the blade
$V_{x'}$	Axial force (tension) in the x' direction
$V_{y'}, V_{z'}$	Shear forces in the y' and z' directions, respectively
V_j, W_j, V_{0j}, W_{0j}	Lead-lag and flap bending generalized coordinates and equilibrium deflections, respectively
x, y, z	Undeformed coordinate system (x is the elastic axis)
x_1, y_1, z_1	Coordinates of the point in the deformed blade
x', y', z'	Deformed coordinate system
x_p	Axis, which rotates about the Z axis with angular velocity Ω
$\{X\}$	Vector of generalized perturbation modal coordinates
$\alpha j, \beta j, \gamma j$	Constants used in the expressions for assumed mode shapes
γ	Lock number
δW	Virtual work of the non-conservative forces
ε	Small parameter
$\varepsilon_{xx}, \varepsilon_{x\eta}, \varepsilon_{x\zeta}$	Strain components
η, ζ	Principle coordinates of the blade cross section
$\hat{\eta}, \hat{\zeta}$	Equal to $\eta - \partial\lambda/\partial\zeta$, $\zeta + \partial\lambda/\partial\eta$, respectively
$\Theta(\bar{x})$	Non-rotating torsional mode shape
θ	Blade pitch angle
κ	Non-dimensional torsional rigidity
$\lambda(\zeta\eta)$	Warp function
Λ_1, Λ_2	Non-dimensional bending stiffnesses
μ, μ_1, μ_2	Non-dimensional radius of gyration
ν	Poisson's ratio
ρ	Structural mass density
σ	Solidity, $bc/\pi R$
$\sigma_{xx}, \sigma_{x\eta}, \sigma_{x\zeta}$	Stress components
φ	Torsional displacement about the elastic axis
φ_{0j}	Equilibrium torsional displacements
φ_j	Torsional generalized coordinates
$\Psi_j(\bar{x})$	Non-rotating lead-lag and flap bending mode shapes
ψ	Azimuth angle (dimensionless time)
Ω	Rotor angular velocity

modules with various amplitudes match closely experimental data. They proved that the parameters in these models were identified using the complex modulus-amplitude dependence data. Thus conducted researches have shown that the stability was observed for most of the configurations of blades without articulations with a zero pre-cone angle. However, a positive pre-cone angle was considered destabilizing. For current helicopter blades analysis, it is necessary to consider the coupling of the torsion motion, flap and lag to configure the articulated blades.

2. Formulation and equation setting

2.1. Description of the blade model

The coordinate system $OXYZ$, attached between the hub and the root of the blade is attached to the inertial reference of the movement $\Re$. Orthogonal axes x_p, y, z turn respectively with respect to $\Re$, with a constant angular velocity Ω. For a non-deformed blade in Fig. 1(a), a Cartesian coordinate system $Oxyz$ is chosen, where the x axis coincides with the elastic axis of the blade, and then tilted towards the axes x_p by the angle of pre-cone β_{pc}. The displacement of each point according to the elastic axes in the x, y and z directions, are designated u, v and w, respectively. During the deformation, the blade sustained the extensions and the moments in lag, flapping and torsional rotation ϕ. The section of the blade before and after deformation is shown in Fig. 1(b) [15]. The blade is composed of a flapping articulation modeled by a spring and a damper, the lag articulation is modeled by a spring and a damper, the guide arm pitch is modeled by a spring (Fig. 1(c)). The connection between the blade and the hub of the rotor consists of flapping articulation, a lag articulation and a pitch control link (Fig. 1(c)).

The pitch link has stiffness of $K_{\text{pitch}} = 1.25 \times 10^6\ \text{N}\,\text{m}^{-1}$.

The characteristics of the flap hinge are

$$K_{\text{flap}} = 1.85 \times 10^6\ \text{N}\,\text{m}^{-1}, \qquad c_{\text{flap}} = 1.25 \times 10^6\ \text{N}\,\text{m}^{-1}\,\text{s}^{-1}$$

The choice of damper type for the lag loads is very important. For this, a comparison was made between an elastomeric damper (Fig. 1(d)) [2] and the hydraulic damper type (Fig. 1(e)) [3] reinforced with a torsional spring.