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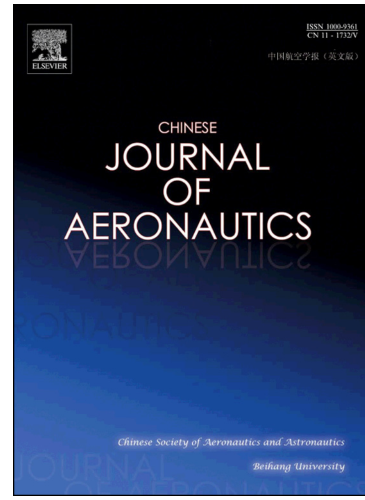

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Abstract

A flight dynamics model based on elastic blades for helicopters is developed. Modal shape analysis is used to describe the rotating elastic blades for the purpose of reducing the elastic degrees of freedom for blades. The analytical result is employed to predict the rotor forces and moments. The equilibrium equation of the flight dynamics model is then constructed for the elastic motion for blades and the rigid motion for other parts. The nonlinear equation is further simplified, and the gradient descent algorithm is adopted to implement the trim simulation. The trim analysis shows that the effect of blade elasticity on the accuracy of rotor forces and moments is apparent at high speed, and the proposed method presents good accuracy for trim performance. The time-domain response is realized by a combination of the Newmark method and the adaptive Runge-Kutta method. The helicopter control responses of collective pitch show that the response accuracy of the model at a yaw-and-pitch attitude is improved. Finally, the influence of blade elasticity on the helicopter dynamic response in low-altitude wind shear is investigated. An increase in blade elasticity reduces the oscillation amplitude of the yaw angle and the vertical speed by more than 70%. Compared with a rigid blade, an elastic blade reduces the vibration frequency of the angular velocity and results in a fast return of the helicopter to its stable flight.

Keywords: Helicopter; Dynamic model; Elastic; Time domain analysis; Trimming; Wind shear

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1. Introduction

When a helicopter encounters atmospheric disturbances, the flapping motion of the rotor blade causes a hysteresis effect on the response of the aircraft fuselage.[1] This phenomenon affects the judgment of the pilot on the helicopter's flight attitude and endangers the helicopter's flight safety seriously. Helicopter movement exhibits obvious nonlinear features because of the coupling characteristics among the helicopter rotor, fuselage, lifting surface, and other components, such as inertia coupling, structure coupling, motion coupling, and aerodynamic coupling.[2] In fact, the helicopter rotor blade rotates at high speed with high-order nonlinear flapping motion and elastic deformation. Therefore, a helicopter nonlinear dynamics model that considers blade elasticity and exhibits a high level of simulation fidelity can precisely estimate the characteristics of blade flapping. This model is meaningful for research on helicopters under atmospheric disturbances, especially in assessment of flying quality, design of control systems, and analysis of stability and maneuverability.

Crocco[3] and Hohenemser[4] used an initial dynamics model of helicopters for the analysis of trim and stability. This model considers six degrees of freedom of a rigid body motion fuselage only. With the development of high-speed helicopters, the need for a reliable design of flight control systems has prompted interest in improving the accuracy of a flight dynamics model coupled with a sophisticated rotor model. The typical models are the ARMCOP general mathematical model proposed by the AMES Research Center[5, 6], the GENHEL model designed by Sikorsky Aircraft Corporation[7], the affine nonlinear model established by Yang [8], and the helicopter nonlinear dynamics model estab-