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Large amplitude (nonlinear) oscillations of rotor blades due to self-excitation (flutter) or external excitation (mechanical or aerodynamic) frequently occur and are often design critical for rotorcraft. The present work is a combined theoretical-experimental study to develop improved understanding and mathematical models for enhanced design and performance.

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SUMMARY OF RESEARCH FINDINGS

For our research program on nonlinear dynamics and aeroelasticity of rotorcraft in forward flight, the early research findings (before December 31, 1992) have been summarized in Ref.[1]. During the period of this grant, two major subjects were pursued. One is the rotor blade response to a periodic or random gust with both theoretical modeling and experimental simulation based on a rotating slotted cylinder (RSC) gust generator mounted in the Duke University low speed wind tunnel, see Ref.[2] and [3]. The other subject considered is damping prediction for a stalled rotor including correlation with experimental data obtained at the Ames Research Center Army Laboratory, see Ref.[4]. The main research findings are as follows:

For the theoretical and experimental study of the nonlinear response of a *nonrotating* blade to single harmonic, two harmonic, and swept frequency, gust excitation, it is found that the assumptions of a uniform chordwise gust angle of attack and a simple representation for lift forces (strip theory) in a gust flow field are allowable for a large aspect ratio rotor blade. The effects of geometric structural nonlinearity and aerodynamic nonlinearity on dynamic aeroelastic behavior are significant when stall occurs. When this nonlinear system undergoes a two harmonic gust excitation, theory predicts a "quenching" phenomenon or response reduction may occur for a certain combination of parameters. The effect of the second harmonic gust excitation is to decrease the response amplitude under these circumstances. Generally good quantitative agreement between theory and experiment is obtained.

A new experimental method based on a RSC/vane gust generator and a nonrotating blade model in a wind tunnel environment has been developed to simulate the gust response of a *rotating* rotor blade in forward flight. The theoretical variance responses of the flapping and torsional motions, as functions of the azimuth position of a rotor blade under the excitation of lateral and longitudinal gusts, have been computed and compared to the experimental results. The quantitative results are very similar to those obtained from an actual helicopter in forward flight and/or a rotational blade model in the wind tunnel. The major advantage of the present experimental method is to simplify the configuration of the experimental model and hence the relative convenience of the experimental measurement. This new experimental method is especially suitable for a small wind tunnel. The principal limitation of this method is the lack of velocity variation along the blade span and the absence of the effect of a reversed flow region near the blade root.

The modified linear ONERA aerodynamic model was used in a direct time domain numerical simulation method. The calculated gust response results using this aerodynamic model are also in reasonable agreement with the experimental results obtained in the present study.

Turning now to another important subject, the conventional frequency domain Floquet solution scheme for a flap-lag stability analysis of a rotor has been used by previous investigators for determining the response of a weakly nonlinear system and small or moderate degrees of freedom (DOF) of the rotor system. However, it is known that the results from such calculations show poorer agreement with the available experimental data (McNulty experiment at the Ames Research Center) when the advance ratio increases into the stall regime of the rotor blade system. Therefore, in the present work we have used a direct numerical time marching integration to compute the transient response (free oscillation) of the flap-lag motion. A regressing motion response with frequency with frequency $\Omega - \omega$ of the rotor in the nonrotating system is obtained through a numerical coordinate transformation. A time-domain quasilinear model identification technique is applied to identify the damping and frequency for the regressing mode. This is similar to the method used by McNulty in analyzing the time histories of the experimental data. It is found that the results from the present theoretical method demonstrate complex, sometime chaotic, responses where the agreement between results from the Floquet analysis and experiment deteriorates.

For the present flap-lag model, the necessary and sufficient condition for the onset of chaotic or aperiodic oscillations in flap-lag stall response is that not only that the section angle of attack be larger than the static stall angle, ($\alpha > \alpha_{ss}$), but also that the variation of the angle of attack with azimuth angle of the blade be aperiodic. When the flap-lag response is a limited amplitude aperiodic or chaotic oscillation, the prediction of lag damping and estimation of the flap-lag stability margin for a rotor system is complex and needs further study. However the results from the present study strongly suggest that distinctly nonlinear effects are responsible for the previously observed differences between theory and experiment in the stalled flow regime.