Dynamic Stall Modeling and Its Effect on Airfoil Response

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ABSTRACT

The field of rotary-wing aeroelasticity has been a very active area of research during the last four decades [1]. There are still several unresolved issues relating to blade loads and fuselage response in forward flight [2] and [3]. Analysis of rotary-wing aeroelasticity requires a proper structural, inertial and aerodynamic modeling. The rotor blade aerodynamic modeling is highly complex due to time varying pitch, heave, pulsating oncoming flow, dynamic stall and wake effect. Modeling of instantaneous sectional lift, drag and moment as a function of pitching, plunging motion of the blade, variation in oncoming velocity and inflow velocity is of paramount importance in evaluating rotor aerodynamic loads.

Dynamic stall is a strong nonlinear unsteady aerodynamic effect associated with flow separation and reattachment. It is difficult to predict stall and all its effects using theoretical unsteady aerodynamic tools. So researchers are depending on the empirical or semi-empirical models. Several mathematical models that attempt to predict the effects of dynamic stall are available in the literature [4] - [8]. ONERA dynamic stall model is a relatively simple and efficient model to incorporate in aeroelastic analysis.

The ONERA dynamic stall model developed by Petot is modified by incorporating a higher order rational approximation [9] of Theodorsen's lift deficiency function [10]. This improved model is shown to provide a better correlation with experimental stall data [11] (Fig. 1). The response characteristics of a 2-D airfoil undergoing pitching and plunging motion in a pulsating oncoming flow, simulating the response of a cross-section of a helicopter rotor blade in forward flight are analysed (Fig. 2). This study shows significant difference in the response characteristics of the airfoil for unsteady (dynamic stall model) and quasi-steady aerodynamic models (Fig. 3).

It has been observed that introduction of heave-pitch coupling by shifting the mass centre from the elastic centre results in the appearance of several sub and super harmonics in heave as well as in pitch response of the airfoil under dynamic stall conditions. The results pertaining to this analysis and also additional results of correlation will be presented in the final version of the paper.

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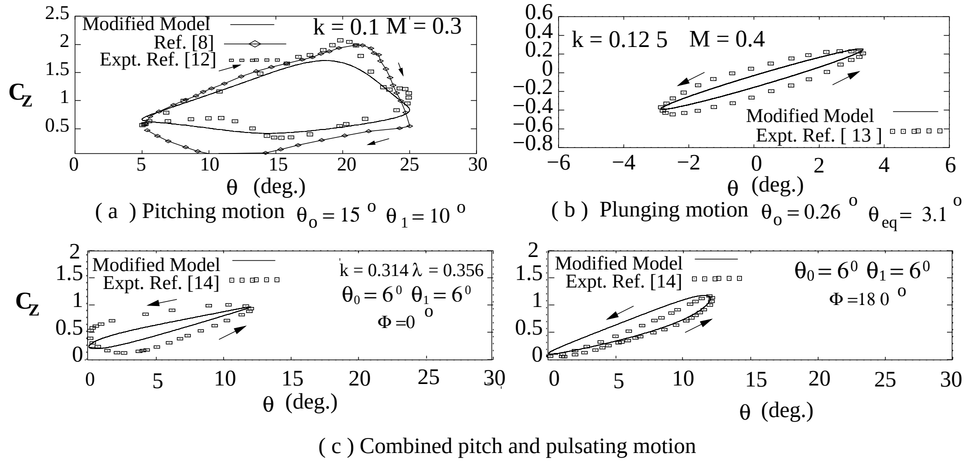


Figure 1: Lift hysteresis loops

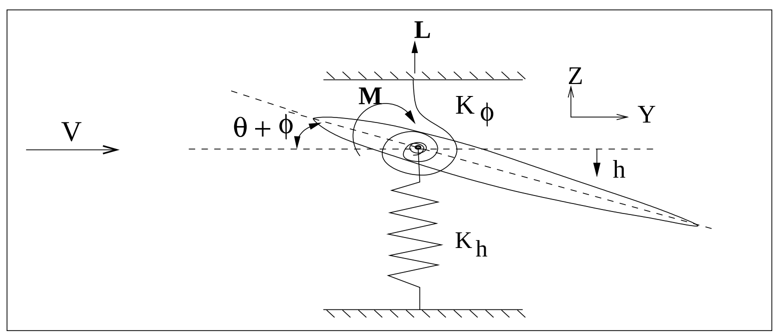
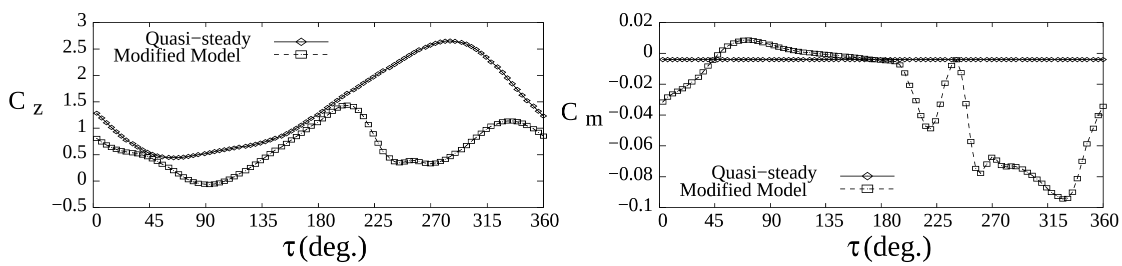


Figure 2: 2−D airfoil model



(a) Lift variation (b) Moment variation

Figure 3: Comparison of quasi−steady lift and moment with modified stall model lift and moment

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