Coupled nonlinear aeroelastic stability of wing-propeller systems

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One of the current main goals in aeronautics developments is to design more environmentally friendly aircraft. Aircraft electrification is one of the promising concepts that has attracted many attentions in the past decade. The next generation of electric aircraft incorporates one or more electric propulsors to power up the aircraft, since electric motors significantly increase the vehicle efficiency as compared to internal combustion engines[1]. For instance, the NASA's X-57 Maxwell is a full electric demonstration aircraft which uses one tip propulsors and 6 high-lift motors distrusted along the wing span [1]. However, realizing those benefits relies on wing and pylon structure design to enable higher aspect ratio wings to increase the aircraft efficiency more. One of the main design considerations for propeller driven aircraft is the prevention of whirl flutter in which the propeller hub executes a whirling motion [2]. This instability is a result of interactions between the rotor and flexible wing-pylon. This dynamic instability can happen at a specific aircraft and rotor speed and may lead to growing amplitudes in the whirling motion and can pose a risk to flight safety. Another aeroelastic instability is the wing flutter which can limit the flight envelope of the aircraft [3].

In this paper, a fundamental nonlinear aeroelastic model is developed to investigate the transition from wing flutter to whirl flutter as well as the post-instability investigation of this coupled system. The structural dynamics of the wing is simulated using a nonlinear 2-DOF typical section which undergoes pitch and heave (plunge) motions to capture the influence of the wing large deformation. Furthermore, a rigid rotor is connected to the wing through a flexible attachment which has two degree of freedom in the pitch and yaw directions. Two types of structural nonlinearities are present within the system which are stiffness hardening of the wing and free-play stiffness in the pylon. The latter is considered to take into account the possible effects of wear of the pylon attachments on the overall system behaviour. Furthermore, the unsteady aerodynamic loads applied on the wing are simulated using Wagner's unsteady aerodynamic theory. Also, the aerodynamic forces acting on the propeller are expressed in terms of propeller stability derivatives. The effects of rotor wakes on the wing are considered through a simple perturbation of the wing local angle of attack. The resulting nonlinear aeroelastic system is solved to find the stability charts of the system as well as the nonlinear dynamics of the system in the post-instability region. Several studies have concerned with the effects of propeller on wing aeroelasticity [2] as well as the effect of wing deformation on rotor whirl flutter [4]. However the post-instability of this coupled system in the presence of wing and pylon nonlinearities has received less attention which may bring more insight into more efficient design of such configurations.

A four degree of freedom wing-propeller system as shown in Figure 1 is considered. The bending and torsional stiffnesses of the wing are simulated using two nonlinear springs which are attached to the elastic axis of the wing (e.a). Also, the total mass of the wing is concentrated on the wing mass centre (c.g.). The rotor-wing arrangement is shown below, and the rotor adds two additional degrees of freedom in pitch (θ) and yaw (ψ) directions. The wing aerodynamic lift and moment are determined using an unsteady aerodynamic theory, while the rotor aerodynamic forces are expressed in terms of propeller stability derivatives.

Figure 2 shows the comparison of whirl flutter instability boundaries of a rotor with flexible pylon for various pitch and yaw stiffness values with those reported by [2], using a quasi-steady aerodynamics. The results are in very good agreement, indicating that the developed aeroelastic model of the rotor only can predict its dynamic behaviour accurately. Furthermore, the nonlinear aeroelastic model of the wing has already been developed and the details are available in [5]. The final version of the paper will coupled these two models to investigate the effects of system parameters on the transition from wing flutter to whirl flutter. Furthermore, stability charts of the system will be determined and the nonlinear dynamics of the system in the post-instability regions will be investigated. Finally, the developed model will then be applied to a more realistic high aspect ratio wing with rotors.

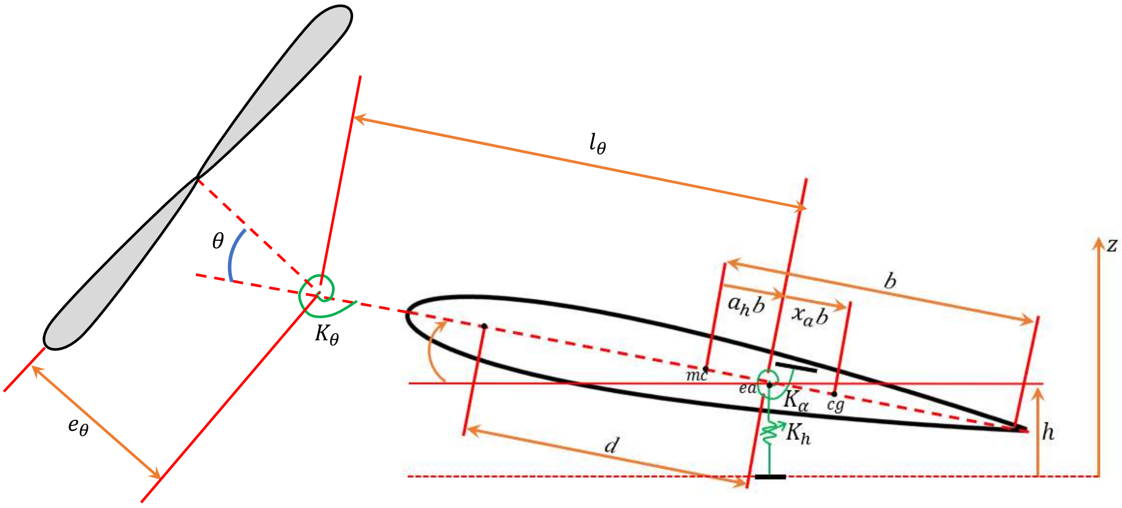

Figure 1: Schematic of the wing-propeller system (side view)

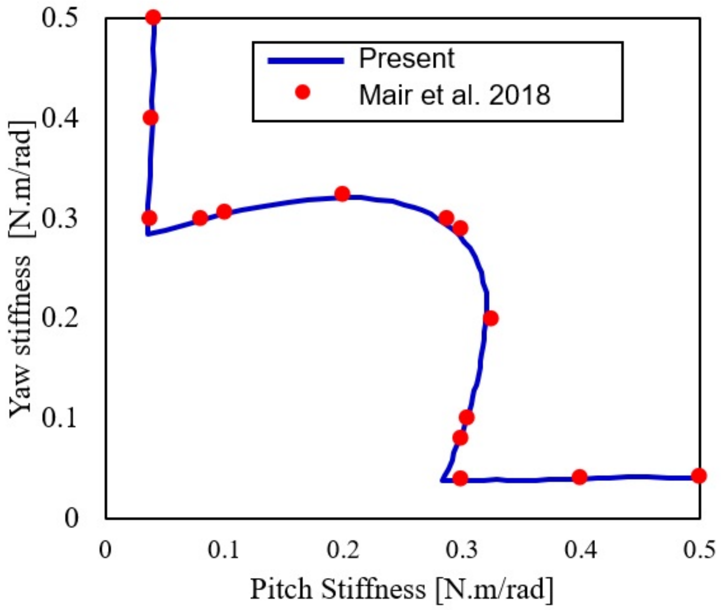

Figure 2: Comparison of the whirl flutter stability boundaries

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