A Three Dimensional Unsteady Iterative Panel Method with Vortex Particle Wakes and Boundary Layer Model for Bio-Inspired Multi-Flap Wings

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ABSTRACT

The ability of UAVs to operate in complex and hostile environments makes them useful in military and civil operations concerning surveillance and reconnaissance. However, limitations in size of UAVs and communication delays prohibit their operation close to the ground and in cluttered environments, which increase risks associated with turbulence and wind gusts that cause trajectory deviations and potential loss of the vehicle. In the last decade, scientists and engineers have turned towards bio-inspiration to solve these issues by developing innovative flow control methods that offer better stability, controllability, and maneuverability. This paper presents an aerodynamic load solver for bio-inspired wings that consist of an array of feather-like flaps installed across the upper and lower surfaces in both the chord- and span-wise directions, mimicking the feathers of an avian wing. Each flap has the ability to rotate into both the wing body and the inbound airflow, generating complex flap configurations unobtainable by traditional wings that offer improved aerodynamic stability against gusting flows and turbulence. The solver discussed is an unsteady three-dimensional iterative doublet panel method with vortex particle wakes. This panel method models the wake-body interactions between multiple flaps effectively without the need to define specific wake geometries, thereby eliminating the need to manually model the wake for each configuration. To incorporate viscous flow characteristics, an iterative boundary layer theory is employed, modeling laminar, transitional and turbulent regions over the wing's surfaces, in addition to flow separation and reattachment locations. This technique enables the boundary layer to influence the wake strength and geometry both within the wing and aft of the trailing edge. The results obtained from this solver are validated using experimental data from a low-speed suction wind tunnel operating at Reynolds Number 300,000. This method enables fast and accurate assessment of aerodynamic loads for initial design of complex wing configurations compared to other methods available.

1. INTRODUCTION

The rapid growth of Unmanned Aerial Vehicle (UAV) use in defense and civil applications has increased focus towards development of aerodynamic systems which can improve their maneuverability and controllability [1-5]. Smaller and lighter weight UAVs are more susceptible to wind gusts, which make the vehicles especially vulnerable near the ground and near obstacles [1-2]. In last decade researchers have turned towards bio-inspiration to design more stable aerodynamic systems [3-6]. One of such design developed by Blower et al., shown in Figs. 1–2, consists of a series of feather-like flaps that are installed over the upper and lower surface of a standard wing [6]. The flaps mimic avian wing design and flow manipulation characteristics to overcome the gust-induced turbulence and maintain flight stability. The flap deflections are denoted δ_{ij}, where index i defines the span-wise station number (1 or 2), and index j identifies the flap number: 1-4 are the upper flaps and 5-8 are the lower flaps. A rigidly fixed leading edge element enables the airfoil to mimic the geometry of a NACA 4412 airfoil when in the rest configuration, thereby ensuring the wing remains efficient during cruise.

The increase in availability of high speed computing resources in the last decade has opened new avenues for detailed design and analysis of complex engineering systems, resulting in the development of high fidelity computational algorithms for fluid dynamics investigation. One of the most significant contributions of this technology is in the development of viscous-inviscid panel method solvers for high speed aerodynamic analysis of complex wing geometries for preliminary design stages [6-9]. These methods offer faster assessment of flow variables over the surface of the wing in comparison to traditional Computational Fluid Dynamic (CFD) solvers and thus can be used for initial analysis of a multi-flap wing.

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