Two-Dimensional Localized Flow Control Using Distributed, Biomimetic Feather Structures: A Comparative Study

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ABSTRACT

This paper presents the development of a bioinspired flight control system and a characterization of its performance when operating in turbulent and gusting airflow conditions. This design consists of a skeletal structure with a network of feather-like panels installed on the upper and lower surfaces, extending beyond the trailing edge. Each feather is able to deform into and out of the boundary layer, thus permitting local airflow manipulation. The gust load sensing is predominately performed near the leading edge of the airfoil, and the reaction forces are generated by the feathers located at the trailing edge. For this study, the focus presents a benchmark case of the NACA 4412 airfoil with the standard 20% trailing edge flap design operating in a gusting, turbulent airflow. COMSOL Multiphysics is used to model the flow field and the fluid-structure interactions using Direct Numerical Simulation. The dynamics of the gusting model are developed using MATLAB and LiveLink connected to COMSOL to enable unsteady, turbulent simulations to be performed. Discrete and continuous gusts are simulated at various airfoil angles of attack. Additionally, the airfoils' aerodynamic performance is comparatively analyzed between time-varying and steady-state turbulence models. This paper discusses how these two-dimensional, time-varying turbulent and gusting airflow simulation results can be developed and integrated into a LQR closed-loop feed back flight control system.

Keywords: morphing, hierarchical control, bio-inspired, gust alleviation

1. INTRODUCTION

Since the first manned flight, onboard systems have extended aircrafts' ability to operate in unfamiliar environments. The introduction of the Global Positioning System (GPS), stormscopes and autopilot functions have aided pilots with their work load and offered safety when operating in turbulent conditions. Each of these systems is interlinked with the aircraft's main flight computer and allows the aircraft and the pilot to access the flight path and therefore take the necessary precautions for inbound turbulent conditions. Despite advances in sensing and automatic control, turbulent airflow has been identified as a dominant factor that requires considerable analysis during aircraft design[1]. Consequently, an improved gust alleviation system could offer increased stability and maneuverability, with the potential of additional structural weight savings.

In military applications, the benefit of using Unmanned Aerial Vehicles (UAVs) has been demonstrated by a yearly growth in missions undertaken during the last decade. The benefits include the removal of pilots from war-zones, removal of onboard life support systems, and increased endurance and maneuverability capabilities. Although these advantages lead to the increased use of UAVs in military applications, turbulent weather conditions remain a significant hazard to these aircraft[2–3]. The cause of these incidents is a lack of sensory feedback to the pilots through the visual display screens available, where live video footage and flight data are presented. The limitations of the data displayed have lead to accidents during low-level flight where turbulence causes sudden changes in the aircrafts' altitude and orientation[2].

UAVs have been used for reconnaissance missions due to their capability to operate over the target location for extended periods of time. To optimize the quantity and quality of the data collected during reconnaissance, low-level flight is required. However, natural and manmade structures on the Earth's surface can induce turbulent characteristics in the airflow[4]. In turn, the aircraft operating in these regions experience sudden and severe gusts that can result in rapid

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