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THE DEVELOPMENT OF A CLOSED-LOOP FLIGHT CONTROLLER FOR LOCALIZED FLOW CONTROL AND GUST ALLEVIATION USING BIOMIMETIC FEATHERS ON AIRCRAFT WINGS

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ABSTRACT

On avian wings, significant flow control is accomplished using localized control loops, both active and passive, between leading- and trailing-edge feathers. Conversely, most man-made flight control systems respond to perturbations in inertial measurements (global states) rather than the flow itself (local states). This paper presents the design of a distributed, bio-mimetic flow control system and a characterization of its performance compared to a wing with traditional control surfaces relying on inertial measurements. This new design consists of a skeletal wing structure with a network of feather-like panels installed on the upper and lower surfaces, extending beyond the trailing edge and replacing leading- and trailing-edge flaps/ailerons. Each feather is able to deform into and out of the boundary layer, thus permitting local airflow manipulation and transpiration through the wing. For this study, two airfoil sections are compared – a standard wing section with a trailing-edge flap, and section with multiple trailing-edge feathers. COMSOL Multiphysics is used to model the flow field under various flight conditions and flap deflections. A dynamics model of the wing is also simulated in order to compute the disturbances caused by wind gusts. Continuous gusts are simulated, and the disturbance rejection capabilities of the baseline and feathered wing cases are compared.

INTRODUCTION

Since the Wright brothers' maiden voyage, flight systems and controllers have pushed aircraft flight capabilities into environments once thought impossible. The modern-day use of the Global Positioning System (GPS), stormscopes, and autopilot functions have reduced pilot workload and offered improvements in safety when operating in turbulent conditions. Each system is interlinked with the aircraft's central flight computer and enables the onboard flight crew to assess the target flight path. Consequently, preemptive measures can be taken prior to encountering bad weather and turbulent airflow to minimize gusting intensity, resulting in precautionary changes in heading and altitude.

The first recorded reference of a gust alleviation system (GAS) was in 1914 for a "stabilizing device for flying machines" [1]. Since the inception of this idea, many attempts have been made to develop an autonomous GAS, including projects performed by the Bristol Aeroplane Company 1949 [2], Douglas Corporation 1950 [3] and NACA 1952 [4]. Each system design was defined unsatisfactory or abandoned prior to their maiden voyage [5]. The technological advancements of modern day onboard sensing and automated control have aided in the reduction of gust loading. However, the presence of turbulent airflow remains a dominant factor for consideration during the aircraft design and development process [6]. Consequently, the implementation of a GAS from a new approach could offer increased stability and maneuverability, with the potential of additional structural weight savings that have yet to be achieved.

In military applications, the beneficial gains in surveillance and reconnaissance missions offered by Unmanned Aerial Vehicles (UAVs) has been demonstrated by a yearly growth in recorded missions during the last decade [7]. The removal of the pilot and the consequential onboard life support systems offers weight and size reduction potential that can be used for increased endurance and maneuverability capabilities. These advantages, along with removing the pilot from harm's way, have been key factors in the growth of UAVs during military operations in active war zones; however, turbulent weather conditions remain a major hazard to these aircraft when operating at low altitude [8, 9]. Military reports have stated the loss of multiple UAVs as a result of insufficient sensory feedback from onboard sensors to the pilot. The limitations of the visual data displayed at the pilot base station have led to accidents during approach due to sudden changes in position and orientation from gusts [8].

