

THE DEVELOPMENT OF A CLOSED-LOOP FLIGHT CONTROLLER WITH PANEL METHOD INTEGRATION FOR GUST ALLEVIATION USING BIOMIMETIC FEATHERS ON AIRCRAFT WINGS

Christopher J. Blower^{*a}, Woody Lee^a and Adam M. Wickenheiser^a

^aDepartment of Mechanical & Aerospace Engineering,
The George Washington University, Washington, District of Columbia, 20052, USA

ABSTRACT

This paper presents the development of a biomimetic closed-loop flight controller that integrates gust alleviation and flight control into a single distributed system. Modern flight controllers predominantly rely on and respond to perturbations in the global states, resulting in rotation or displacement of the entire aircraft prior to the response. This bio-inspired gust alleviation system (GAS) employs active deflection of electromechanical feathers that react to changes in the airflow, i.e. the local states. The GAS design is a skeletal wing structure with a network of feather-like panels installed on the wing's surfaces, creating the airfoil profile and replacing the trailing-edge flaps. In this study, a dynamic model of the GAS-integrated wing is simulated to compute gust-induced disturbances. The system implements continuous adjustment to flap orientation to perform corrective responses to inbound gusts. MATLAB simulations, using a closed-loop LQR integrated with a 2D adaptive panel method, allow analysis of the morphing structure's aerodynamic data. Non-linear and linear dynamic models of the GAS are compared to a traditional single control surface baseline wing. The feedback loops synthesized rely on inertial changes in the global states; however, variations in number and location of feather actuation are compared. The bio-inspired system's distributed control effort allows the flight controller to interchange between the single and dual trailing edge flap profiles, thereby offering an improved efficiency to gust response in comparison to the traditional wing configuration. The introduction of aero-braking during continuous gusting flows offers a 25% reduction in x-velocity deviation; other flight parameters can be reduced in magnitude and deviation through control weighting optimization. Consequently, the GAS demonstrates enhancements to maneuverability and stability in turbulent intensive environments.

Keywords: morphing, LQR, adaptive panel method, bio-inspired, gust alleviation

INTRODUCTION

Atmospheric turbulence and gusts have plagued manmade flight since its inception, requiring feedback control systems to stabilize and pilot all manner of aircraft. From the Wright Flyer's wing warping to the highly sophisticated flight control systems of today's fighter jets, the need for controlled maneuvering in unsteady conditions has driven significant development in sensors, controllers, and flight control surfaces. Indeed, modern-day systems, including the Global Positioning System (GPS), stormscoopes and autopilot functions have improved flight safety in a wide range of flight conditions, while simultaneously reducing pilot workload. Each onboard system is interlinked with the aircraft's central flight computer and enables risk assessment to be undertaken, by the flight crew, on the target flight path. The pilot continuously assesses the flight data and weather reports of the flight path en route to their destination; consequently adjustments can be undertaken ahead of adverse weather conditions to minimize the safety risk of the vehicle, passengers and crew.

The development and implementation of a fully functioning GAS could reduce the deviation in position or orientation caused while operating in regions where turbulent conditions exist. Consequently, the overall stability and maneuverability of the aircraft could be enhanced thereby extending the vehicles range into locations that were once deemed hazardous; examples include low altitude flight over mountainous regions, in close proximity to jungle canopy and in cluttered urban environments ¹. The first published patent discussing the development of a gust alleviation system (GAS) was in 1914 for a "stabilizing device for flying machines" ². During the last century, technological advancements in onboard sensing and automated control have assisted in the reduction of gust loading. Currently, multiple gust alleviation systems and vortex generators are present on a range of commercial and military aircraft; however, to date no GAS has been identified that mimics the techniques implemented by avian