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Flow Sensory Actuators for MAVs

V. Kumar[†], M. Hays[¤], E. Fernandez[‡], W. Oates[¥] and F. S. Alvi[§]
Florida Center for Advanced Aero Propulsion (FCAAP)
Florida A & M University and Florida State University, Tallahassee, FL 32310

A macro fiber piezoelectric composite has been studied for boundary layer management in Micro-Air Vehicles (MAVs). Specifically, self-sensing piezoelectric composite structures have been designed, fabricated, and tested in wind tunnel studies to quantify performance characteristics, such as the velocity field response to actuation, relevant for actively managing boundary layers (laminar and transition flow control). The dynamic properties of these Flow Sensory Actuators (FSA) were also evaluated in-situ. Results based on velocity field measurements and unsteady pressure measurements show that these macro fiber composites can sense the state of flow above the surface and have sufficient authority to manipulate the flow conditions. Control authority using open loop and closed loop control designs have also been investigated in trade-off studies to quantify performance enhancements versus power input and weight requirements (a critical driver in MAVs) relevant to this application.

I. Introduction & Background

Active flow control (AFC) has been shown to enhance an aircraft performance substantially and is considered to be critical to future advances in aerospace technologies. One such area that can benefit from AFC is the next generation of micro-air vehicles (MAV's). An AFC approach that allows one to actively manage the state of the boundary layer over MAVs would yield substantial performance benefits by providing enhanced agility (i.e, laminar to turbulent transition and turbulent to laminar transition). Additionally, the use of practical AFC approaches in MAVs is constrained by the significant size and weight limitations imposed by these smaller vehicles. Thus, multifunctional systems that can adapt to their flow environment through distributed sensing and actuation is highly desirable to simplify control strategies to enhance agility of next generation MAV platforms.

Towards this end, a macro fiber piezoelectric composite has been characterized to quantify its electro-mechanical (i.e., flow sensory-actuator) characteristics for boundary layer management of micro air vehicles. Whereas the use of piezoelectric composite actuators is well-known, the design and integration of a multifunctional structure that can simultaneously sense flow and modify the flow through structural changes will provide new opportunities for MAV applications. The piezoelectric material employed in these experiments is a lead zirconate titanate (PZT) composition designed in a macro fiber composite (Smart Material Corp.) which have larger piezoelectric coupling through the d_{333} coupling relative to conventional d_{311} composite actuators[1-3]. This piezoelectric actuator has been integrated into an aerodynamic model in order to evaluate its effect on the flow field properties in terms of transition control and sensing. Current research and development is focused on characterizing the flowfield (and its response to actuation) and on fluid-structural control designs. The objective of this study is to leverage past and on-going active flow control and active material research to develop an integrated flow sensory-actuator system for boundary layer management, which can sense the state of flow above the surface and adapt autonomously to the changing flow conditions.

As discussed in the following sections, the Flow Sensory Actuator (FSA) illustrates the requisite control authority for laminar and transition flow control and significant sensing output (voltage) in a low Reynolds number environment. This concept has been previously exploited in vibration control using collocated control concepts[3]; however, we demonstrate for the first time that such designs have the potential for flow control (i.e., flow

[†] Research Associate, Department of Mechanical Engineering, Member AIAA

[¤] Research Assistant, Department of Mechanical Engineering

[‡] Research Assistant, Department of Mechanical Engineering, Student Member AIAA

[¥] Assistant Professor, Department of Mechanical Engineering

[§] Professor, Department of Mechanical Engineering, AIAA Associate Fellow