

SENSITIVITY ANALYSIS OF STRUCTURAL-AERODYNAMIC SENSOR FUSION CONFIGURATION FOR ACTIVE FLUTTER SUPPRESSION

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Abstract

Flutter is a dynamic aeroelastic instability of a lifting body that causes divergent oscillations. Due to the potential structural failure associated with these oscillations, regulations require that aircraft be free from flutter within the flight envelope by a stability margin^{1,2}. However, by employing closed-loop control, active flutter suppression (AFS) systems³ have been shown to delay the onset of flutter, allowing operation past the open-loop flutter point.

AFS combats flutter by outputting commands that are anti-phase to the divergent oscillation, such as through flow control⁴ or deflections of control surfaces⁵ and spoilers⁶. These systems typically rely on structural response variables as the controller inputs, measured through inertial sensors (e.g., accelerometers^{7,8}, gyros⁹) or force sensors (e.g., strain gages¹⁰). Previous efforts have also explored the feasibility of using aerodynamic response variables as inputs to AFS systems by characterizing the unsteady aerodynamics through leading-edge hot-film sensors^{11,12}. Recent experiments¹³ indicate that incorporating the aerodynamic information into the AFS loop using measurements from a differential pressure sensor more effectively delays flutter onset than based on inertial sensors alone.

This paper investigates the effectiveness of AFS based on structural-aerodynamic sensor fusion, combining information from multiple configurations of inertial and pressure sensors. The study builds on a validated time-domain aeroservoelastic numerical model that can simulate pressure sensor measurements. The test case is based on the control-surface (CS) wing, a rectangular wing for wind-tunnel aeroservoelastic experiments in incompressible flow¹⁴. The study focuses on the AFS performance, measured as the flutter speed increment relative to the open-loop configuration, of various chordwise and spanwise sensor distributions, including different weights applied to inertial and pressure sensors.

The final paper will include: (i) a description of the aeroservoelastic numerical model, including the simulation of aerodynamic pressure sensor outputs; (ii) the definition of candidate inertial-pressure sensor configurations, including different chordwise and spanwise distributions of the pressure sensors; (iii) simulation of the unsteady aerodynamic behavior at each local pressure sensor for the examined configurations and analysis of their AFS capability; (iv) insights for choosing optimal sensor configurations that maximize the closed-loop flutter speed while minimizing the number of sensors used and ensuring robustness to malfunctioning or failure of selected sensors.

The paper is anticipated to advance knowledge of how structural-aerodynamic sensor fusion can enhance the effectiveness, reliability, and safety of AFS systems. The ultimate goal of this research is to facilitate the adoption of AFS in future commercial transport aircraft.

¹Anon., *14 C.F.R. § 25.629*, 2024.

²EASA, *CS 25.269 Amendment 28*, 2023.

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⁴De Breuker et al., *SDM Conference*, 2007.

⁵Bergmann and Severt, *J. Aircr.*, 1975.

⁶Bradshaw et al., *Trans. Inst. Meas. Control*, 1988.

⁷Liebst, *J.Guid. Control Dyn.*, 1987.

⁸Grauer and Waite, *AIAA SciTech Forum*, 2024.

⁹Doggett and Townsend, *Proc. of the SCAR Conf.*, 1976.

¹⁰Klepl, *Dynamics Specialists Conference*, 1992.

¹¹Mangalam et al., *AIAA Meeting Paper*, 2010.

¹²Suryakumar et al., *AIAA AVIATION Forum*, 2015.

¹³Szymanski et al., *J. Aircr.*, 2025.

¹⁴Simbuerger et al., *J. Aircr.*, 2022.