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Wing box transonic-flutter suppression using piezoelectric self-sensing diagonal-link actuators

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ABSTRACT

The main objective of this research is to study the capability of Piezoelectric (PE) self-sensing actuators to suppress the transonic wing-box flutter, which is a flow-structure interaction phenomenon. The unsteady general frequency modified Transonic Small Disturbance (TSD) equation is used to model the transonic flow about the wing. The wing-box structure and the piezoelectric actuators are modeled using the equivalent plate method, which is based on the first-order shear deformation plate theory (FSDPT). The piezoelectric actuators are used as diagonal-links. The optimal electromechanical-coupling conditions between the piezoelectric actuators and the wing are collected from previous work. Three main different control strategies; Linear Quadratic Gaussian (LQG) which combines the Linear Quadratic Regulator (LQR) with the Kalman Filter Estimator (KFE), Optimal Static Output Feedback (SOF), and Classic Feedback Controller (CFC); are studied and compared. The optimum actuators and sensors locations are determined using the Norm of Feedback Control Gains (NFCG) and Norm of Kalman Filter Estimator Gains (NKFEG), respectively. A genetic algorithm (GA) optimization technique is used to calculate the controller and estimator parameters to achieve a target response.

1. Introduction

Flying aircraft in the transonic regime is efficient because of the high lift-to-drag ratio. However, several undesirable phenomena occur in the transonic regime. From an aeroelastic point of view, the major concern is the presence of moving shock waves and rapid changes in the flow because of structural deflections. This flow-structure interaction under certain dynamic pressure leads to a phenomenon known as transonic flutter. Flutter can be defined as the onset of dynamic instability of the wing self-excited vibrations due to the interaction between the wing structure and the flow around the wing. This flutter may cause failure to the wing if not delayed or controlled. Flutter danger prevents flying above certain aerodynamic conditions, so recent research work is concerned with controlling flutter. Using smart materials like embedded or bonded piezoelectric material to the wing may provide proper sensing and damping to wing flutter. Loewy (1997) introduced a complete survey of recent developments in smart structures with aeronautical applications.

Studying the flutter suppression of fixed wings with smart structures is a complicated problem because of complexity of the aerodynamic and structural analyses. Many simplifications can be done in the aerodynamic or structural models. Most researchers simplify the wing to a cantilevered plate, and a few of them model the wing as a wing box structure. Also, most researchers use simplified analytic aerodynamic theories, and a few of them use complicated numerical techniques. Simplified techniques (analytic or numeric) can be found for subsonic and supersonic flow regimes, but the transonic flow regime is more complicated. Although a transonic flow model with a wing box structure is the most realistic flutter model, few researches take this approach.

The primary objectives of this study are: (1) to develop nonlinear equivalent plate tool for analyzing the wing box structure with bonded piezoelectric patches, (2) to develop an unsteady transonic flow solver to predict the flutter condition of the wing, (3) to design a practical control tool that suppresses transonic wing flutter using piezoelectric sensors and actuators, (4) using the genetic algorithm optimization technique to force the wing to track a target response

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