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Analysis of thermally activated fluid-structure interaction for a morphing plate immersed in turbulent flow

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ABSTRACT

In the framework of vehicle aerodynamics, new integrated systems can be developed based on shape memory metal alloys (SMAs) capability to perform surface morphing. Such systems can be exploited to create appendices containing active composites that change shape in response to variable thermal inputs, in relation to the desired aerodynamic behavior. The purpose of these systems is to offer benefits in terms of vehicle's performance and fuel consumption rate. Even the design of the simplest geometry appendix, a finite horizontal plate aligned with a turbulent air flow, is nevertheless affected by three intertwined and nonlinear phenomena - namely the solid/fluid/thermal interactions. In order to approach the definition of appropriate design parameters, the space of operating variables must be explored by devising a numerical simulation encompassing the equation of structural motion and the energy and Reynolds Averaged Navier Stokes equations, complemented by a viable turbulence model. In this paper, a fully-coupled model encompassing all phenomena involved is tested by implementing a sensitivity analysis for a thermally activated morphing surface. Temperature, stress and velocity distributions are presented and discussed for a given geometry case. A new metrics leading to aerodynamic lift calculations is then proposed and demonstrated, that will simplify the preliminary design procedures.

1. Introduction

Improved performance and reduced fuel consumption reflecting on environmental impact of vehicles represent two important goals that must nowadays be taken into account when addressing automotive transportation. For these reasons, all major vehicle manufacturers have invested efforts in R&D to identify the most performing solutions, systems and materials.

Aerodynamics is the major aspect influencing body design and, as Jacob [1] and Pern and Jacob [2] first speculated, the application and exercise of discrete adaptive surfaces can represent a viable solution to reach this goal, while improving overall handling. Conceptual design, prototype fabrication, and evaluation of shape morphing wings were classified by Sofla et al. [3]. As with other engineering fields, the computational research dealing with active load control airfoil appendices can be purposeful [4]. In the past some segments of the car body were realized by means of retractable spoilers, flexible deflectors and movable flaps. In some cases, such surfaces were realized requiring mechanical actuators providing the specific degree of freedom, with the weight and structure performance affecting their efficiency and cost; moreover, they could just assume few discrete positions, only. The development of active aerodynamic surfaces, capable of improving aerodynamics performance by autonomous morphing and continuous adaptation to specific inputs while keeping added weight at a minimum (lean morphing), is therefore a relatively new and interesting area of investigation.

Shape memory alloys (SMAs) have been long known to be profitably employed to cast composite materials and reach the lean morphing goals. A comprehensive reviews were performed by Barbarino et al. [5], Bashir et al. [6,7]. SMAs exist in two crystalline structures: Martensite is present at lower temperatures, whereas Austenite is present at higher ones. The transition from one phase to the other is the cause of the specific structural behavior of a SMA segment: following a temperature increase due to an electrical stimulus (Joule heating), this transition is initiated generating a force that can achieve segment morphing, or smooth and continuous geometry variation, to accomplish a desired operating condition [8]. Meanwhile, the embedding matrix ensures all other specifications such as color endurance and corrosion resistance.

Design and realization of dynamic SMA systems relies on structural computations: for example, Scalet et al. [9] provided the necessary insights. Its applications in the automotive sector was first

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