Vortex wake control via smart structures technology

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ABSTRACT

Control of trailing vortex wakes is an important challenge for both military and civilian applications. This paper summarizes an assessment of the feasibility of mitigating adverse vortex wake effects using control surfaces actuated via Shape Memory Alloy (SMA) technology. The assessment involved a combined computational/design analysis that identified methods for introducing small secondary vortices to promote the deintensification of vortex wakes of submarines and aircraft. Computational analyses of wake breakup using this "vortex leveraging" strategy were undertaken, and showed dramatic increases in the dissipation rate of concentrated vortex wakes. This paper briefly summarizes these results and describes the preliminary design of actuation mechanisms for the deflectable surfaces that effect the required time-varying wake perturbations. These surfaces, which build on the high-force, high-deflection capabilities of SMA materials, are shown to be well suited for the very low frequency actuation requirements of the wake deintensification mission. The paper outlines the assessment of device performance capabilities and describes the sizing studies undertaken for full-scale Vortex Leveraging Tabs (VLTs) designed for use in hydrodynamic and aerodynamic applications. Results obtained to date indicate that the proposed VLTs can accelerate wake breakup by over a factor of three and can be implemented using deflectable surfaces actuated using SMAs.

Keywords: Shape memory alloys; Vortex wake; Wake mitigation; Smart materials

1. INTRODUCTION

The ability to control the vortex wake structure downstream of lifting surfaces is a topic of continuing importance for a variety of applications. For example, minimizing the wake signature left by submarines is a crucial element in preventing potential threats to the stealthiness of the current U.S. sub fleet. In addition, the encounter of jet transports with the wakes of preceding aircraft produces a significant safety hazard, and the current conservative separation standards limit capacity at all major U.S. airports. The effort described here involved the extension of established vortex wake analysis tools in combination with recently-developed fluid dynamic and material design techniques to assess the feasibility of mitigating undesirable vortex wake behavior using control surfaces actuated via smart structures technology. A key focus of this work was to demonstrate how the strengths of Shape Memory Alloy (SMA)-based actuation technology can be exploited to yield the combination of high control force, compactness, and efficiency required in the design of wake deintensification devices.

The performance required of such vortex control surfaces has been defined by way of computational studies of the effect of the introduction of secondary vortices, vortices whose presence accelerates destructive wake-on-wake interactions (Fig. 1). These secondary vortices are generated by carefully phased unsteady loading on small surfaces or tabs installed on larger "primary" lifting surfaces (e.g., submarine sailplanes or aircraft wings). The overall strategy can be characterized as "vortex leveraging", an approach in which modifications to large-scale wake structures in the far field are effected using relatively modest, realistic levels of steady or time-varying deflections of Vortex Leveraging Tabs (VLTs). As will be seen, the results to date are very promising, and suggest that wake deintensification for representative lifting surfaces may be accelerated by over a factor of three. These reductions translate into significant potential reductions in the current separation standards for jet transport aircraft on approach or into significantly reduced submarine wake signature.

The role of smart structures technology in this context lies in the opportunity it presents to deal with several of the design challenges posed by real-world VLT installation requirements. As will be discussed below, one of the most promising installation strategies for VLTs is at the outboard or inboard edges of lifting surfaces; also, the tabs themselves should be thin to minimize drag penalties. Actuating slender aerodynamic surfaces in these spatially confined locations requires a compact device with a high control force-to-volume, ratio, a requirement that calls for the mix of characteristics available from Shape

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