DESIGN OF MORPHING SMA AEROSTRUCTURES BY COMPUTATIONAL MODELING

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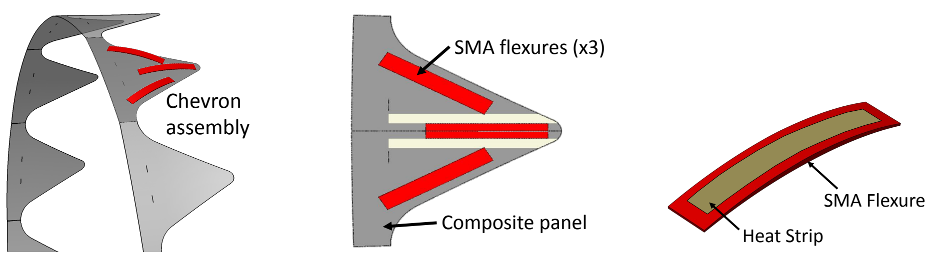
Summary In the following work, a method for designing optimized SMA morphing structures using iterative computational analysis techniques is described. The general framework for design optimization is demonstrated with an academic engineering problem inspired by an actual morphing aerostructure that was successfully developed and flight-tested. Two facets of the design space are explored: 1.) subsystem actuator placement and 2.) component material distribution.

INTRODUCTION

Modern advancements in computational power are prompting investigations into time- and cost-efficient methods for design optimization of morphing structures. Historically, legacy methods for design optimization of any active structure relied on empirically derived graphical methods or experimental trial and error. However, with the introduction of high-speed computational modeling and large-scale parallel processing, a variety of design optimization techniques based on iterative analysis were developed to solve engineering problems in a more efficient manner.

The following work demonstrates the use of these techniques to determine optimized design configurations of the Boeing Variable Geometry Chevron (VGC) [1] morphing aerostructure. Multiple VGCs, shown in Fig. 1(a), are installed around the nozzle exit of a jet engine. Each VGC, illustrated in Fig. 1(b), consists of a composite panel thermally actuated by three SMA flexures fastened onto the panel surface. Each flexure is covered with thin film heaters, seen in Fig. 1(c), to thermally induce transformation. Upon takeoff, the heat strips activate and the flexures begin reverse transformation, causing the



(a) Aeroacoustic control system. (b) Morphing structural subsystem. (c) Highly thermomechanically coupled active component.

Figure 1. Illustration of the VGC system and its components.

panel to deflect into the engine outlet flow, thereby reducing engine noise. These chevrons are deactivated during the cruise condition, restoring engine efficiency. This work consists of two objectives. The first objective is to determine optimal placement of the flexures, with respect to the composite panel, such that the actuated deflection profile of the panel matches an ideal profile provided by aeroacoustics engineers. This is accomplished by treating flexure location and orientation as design variables in an optimization study and attempting to minimize a cost function that measures the error between the predicted and ideal deflection profiles. The second objective is to increase the frequency of flexure actuation. This is accomplished in a second, independent study in which thermally conductive material is layered inside an I-beam configuration of the "hybrid" SMA flexure cross-section to increase heat flux. Here the evaluated cost function to be minimized is chosen to represent the predicted full-cycle actuation time.

Analysis Framework

A combination of commercially available analysis tools and a numerically implemented SMA constitutive model developed at Texas A&M University [2] is utilized to automate the iterative optimization process for the VGC seen in Fig. 2. The ModelCenter software package provides an interface for the integration of optimization and analysis processes, and is used to conduct Designs of Experiments (DOE) and to execute optimization algorithms [3]. For each analysis, the Abaqus FEA software suite [4] is called and used to generate the model and predict the actuation response of component(s) of interest. A full 3-D SMA constitutive model, based on the Boyd-Lagoudas model [5] that accounts for stress- and thermally-induced transformation of SMAs, is numerically implemented as a user-defined material subroutine (UMAT) [6] in the given FEA framework. For the secondary study regarding flexure actuation speed, the UMAT is specially tailored to account for latent heat effects of transformation for use in the thermomechanically coupled analysis.

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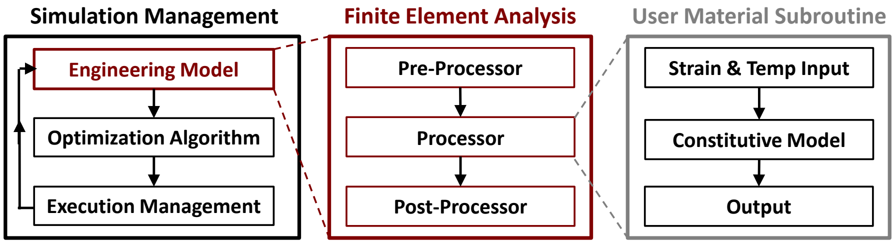
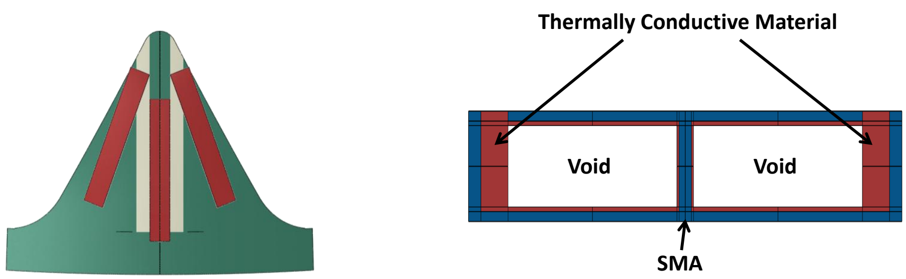


Figure 2. Hierarchy of analysis tools for iterative optimization.

Results and Discussion

The optimized flexure configuration for the subsystem is shown in Fig. 3(a) and the optimized thermally conductive material distribution is illustrated in Fig. 3(b). The flexure configuration seen in Fig. 3(a) results in the closest match between the ideal profile and the predicted profile along the centerline of the panel. It is also interesting to note that, in Fig. 3(a), a significant portion of the SMA can be removed without affecting the overall response of the flexure. With the exception of the thickened portion of the thermally conductive material, very little thermally conductive layering is necessary to adequately increase heat flux throughout the body. With this material distribution, the analysis reports an actuation rate of $\sim$10 minutes.



(a) Final panel configuration. (b) Final flexure material distribution.

Figure 3. Optimized design solutions for the VGC subsystem and flexures.

CONCLUSIONS

Design optimization of the subsystem and actuator components of the Boeing Variable Geometry Chevron (VGC), an example morphing aerostructure, was performed through automated iterative analyses. In the first study, the positions of three SMA flexures were optimized such that the active structural response matched the computed deflection profile with an ideal profile. In the second study, the optimized distribution of thermally conductive material relative to SMA was determined to maximize actuation frequency. Future efforts will involve further development of the analysis framework for use in designing other morphing structures.

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