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SMA-actuated, Compliant Mechanism-based Morphing Flap

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Project Summary: This project seeks to implement shape memory alloy (SMA) technology into the actuator component of wing flaps. Actuators deflect, or extend, wing flaps during takeoff and landing sequences. Successful wing flap deflection is vital because it increases effective camber line slope of the airfoil, substantially increasing the lift and drag. Because of this increase, the airfoil will require less runway length to takeoff, or alternatively, land, which increases the overall efficiency of the takeoff and landing sequences. By the same token, the actuators must be able to contract wing flaps to disengage deflection. If wing flaps were deflected during cruising flight, the non-streamlined wing profile would produce a high amount of drag. This would greatly reduce the plane's fuel efficiency and thereby limit its flying capacity. Thus, wing flap actuators serve a crucial role in the overall efficiency of airfoil. This project, in turn, seeks to optimize the efficiency of the actuators themselves through the integration of SMA technology.

SMAs differ from current actuator technologies primarily because they rely on a much simpler, more efficient process. Whereas current technologies operate through a complex series of interacting systems, SMAs operate solely by sending electrical current through singular wires whose chemical and physical properties enable them to retain a set, pre-programmed shape. The molecular composition of SMAs is such that the molecules change crystal structure in response to load and heat applied, producing the shape-memory effect. The parent phase structure, or "Austenite" phase, is rectangular and uniform. When cooled, the molecular structure shifts into the Martensitic twinned phase, wherein the structure resembles a rhombus crystal. Under strain, the molecular structure shifts into the Martensitic detwinned phase, wherein the structure resembles a lateral parallelogram. Once heated, the Martensitic detwinned structure shifts back into the Austenite phase (parent phase). This particular cycle of shifts in molecular composition enables SMAs to contract efficiently when a load is applied; this is the shape-memory effect.

This project will explore the capabilities of shape-memory alloy wires as potential candidates for the actuation system for the flap of a wing. It will also test the structural behavior of the morphing flap under static and dynamic loading. The actuation system will be put through numerous cycles of deflection and release in order to understand the long-term effects of integrating the SMA wire as the actuator. Since SMAs interact with varying materials and structures very differently, each particular use of SMAs requires a different mathematical model to predict the behavior of this interaction. Therefore, this project provides a balance of experimentation, documentation, and computational analysis, respectively. With the mentor's guidance and assistance, the student will acquire useful experience in research, experimentation, data collection and analysis, technical documentation, and other skills involved in the process which will contribute to the student's success in later, more advanced research.

Also, results from this proposed research will provide critical preliminary data for external funding and potential internal/external collaboration for the student and the mentor.

The RCEU student's tasks in the project include:

i.) Conduct shape optimization to define the optimal deformation and wing actuation (MATLAB-Modeling)

ii.) Compute optimal points of actuation and respective maximum deflection of 3D printed flap. (50% hands-on and 50% modeling)

iii.) Wing model shape optimization & validation using XFLR5 (Computational analysis) iv.) Integrate the SMA actuator into the wind tunnel wing model and conduct wind tunnel testing experiments ((Hands-on experience)

Student Prerequisites

The student will be required to have the following skills:

i.) Thorough understanding of fundamental aerodynamics concepts and related sciences (Aerospace Major-Junior year)

ii.) Sufficient knowledge and experience in MATLAB, Solid Edge/ SolidWorks, and Latex

iii.)Experience XFLR5 and 3D printing

iv.)Minimum GPA of 3.5

Student Duties and Deliverable

This project requires the student to use analytical and observation skills in a laboratory setting. One big aspect of the project will entail the use of software to simulate and manipulate data. The student must document experimental results and draw conclusions based upon the data collected. In order to ensure repeatability, the final wind tunnel model will undergo numerous cycles of actuation, the results of which will be tested. In weekly meetings, the student will give progress reports to the mentor and discuss current results. A final report will be submitted during the 10^{th} week for the mentor to evaluate. Provided is a tentative 10-week project schedule:

Week 1: Introduction to both labs, equipment, and background.

Week 2: Review literature on SMA's and present a design and a design alternative.

Weeks 3-4: Test methods of securing the SMA to a variety of 3D printed flap molds.

Weeks 5-6: Calculate optimal number of wires and location of actuation points **Week 7:** Shape optimization and performance validation using XFLR5 software **Weeks 8-9:** Integrate SMA actuator on wind tunnel model and conduct wind tunnel testing **Week 10:** Analysis and documentation of the results

Mentor Supervision and Interaction

The research mentor will have regular interactions with the RCEU student during the project period. Undergraduate students will also interact with graduate research assistants to facilitate a more productive environment. The instructor/research mentor will confer with the student in regularly scheduled, weekly meetings to supervise, mentor, evaluate progress and assess student's general project development and work product.