Methodology for Design of an Active Rigidity Joint

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ABSTRACT: Active control of composite structures has primarily focused on vibration control and other small-scale deformations. For use in morphing aircraft structures, a composite "smart joint" is proposed, employing both shape memory alloy and shape memory polymer to replace a conventional rotary actuator. This joint functions as a discrete member capable of both actuation and structural rigidity in user programmable states, with large-scale tip deflections on the order of 10–20% camber. A strain energy model is used to prescribe joint deflection in terms of thermally varying material properties across the thickness of the joint, allowing the designer of a morphing system to select electrical power input and element composition as based on deflection, response speed, and load capacity. This model discretizes the transformation into a multiple step shape change maneuver using the tri-phase process to determine deflection both when heated and when set into its cooled state. Comparison with a finite element model confirms thermodynamics analysis as well as deflection accurate within 2% of analytically predicted behavior.

Key Words: shape memory alloy, morphing, active composites, piezoelectric, shape memory polymer, compliant joint.

INTRODUCTION

WITHIN the realm of airframe design, there falls a class of vehicles known as 'morphing aircraft'. This type of aircraft is capable of macro-scale shape change in flight, aimed at creating multiple, highly functional operating points. Many devices, including adjustable ailerons, flaps, and slats, fall into this category. With the aid of modern engineering materials however, new attention has been given to more radical morphing maneuvers such as span, wing twist, and camber change, all in an attempt to more efficiently control aerodynamic parameters than can current-day commercial aircraft. The Wright Brothers knew that much could be gained by borrowing shape change concepts from biological fliers such as bats and birds, and as such designed wings that could twist in order to experiment with different flight parameters. Now, with better materials technology, this concept can be extended beyond determination of operating points for single mission vehicles, and instead to expanding a flight envelope to cover multiple aerodynamic regimes. This may allow a vehicle to be designed capable of functioning not just as a high-endurance or fast-dash vehicle but perhaps as both, depending on mission demands.

Many concepts have been proposed for actuating these morphing vehicles. Variable geometry truss mechanisms have been developed in bench models, along with tensegrity structures and devices employing both linear and rotary DC actuators (Abdulrahim and Lind, 2004; Wiggins et al., 2004; Moored and Bart-Smith, 2005). These mechanisms are generally complex due to their redundant coupling of actuators and structural members, their mechanical linkages, and their design methodologies, the latter especially true for tensegrity structures. Morphing mechanisms are generally weight-intensive, expanding geometric capabilities but compromising flight-worthiness in terms of payload capacity or range. This tradeoff typically results in designs that perform shape change well in bench-top models, but that are completely impractical. Further, the mechanisms generally rely on a very simple basic physics principle: apply a force about a large enough moment arm to cause a rotation or torque with some consequent movement. This concept is demonstrated in the design of the HECS wing as well as the Lockheed Martin morphing concept vehicle, among countless others (Love et al., 2004; Manzo et al., 2005). Morphing often requires the use of tendons or bulky rotational actuators to accomplish this, and although mechanisms can be highly effective at prescribing shape change, their drawbacks in terms of flightworthiness provide few practical applications.

Because the morphing actuator doubles as both rigid load-bearing element and structural manipulator, energy demands on morphing structures are both high and constant, as power is constantly required even to keep a

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