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Thermally induced multistable configurations of variable stiffness composite plates: Semi-analytical and finite element investigation

Ayan Haldar*, José Reinoso†, Eelco Jansen*, Raimund Rolfes*

* *Institute of Structural Analysis, Leibniz Universität Hannover, Appelstrasse 9A, 30167 Hannover, Germany*

† *Elasticity and Strength of Materials Group, School of Engineering. University of Seville, Camino de los Descubrimientos s/n, 41092, Seville, Spain*

Abstract

Multistable structures used in morphing applications are conventionally achieved by using unsymmetric laminates with straight fibers. An ideal morphing system always calls for a structure with highly anisotropic internal architecture. With the advancement of fiber placement technology, it is possible to manufacture fibers even with curvilinear paths or so-called variable stiffness (VS) composites. The aim of this study is to explore the bistable shapes generated by changing various angle parameters that define a VS composite for elucidating novel morphing structures. A semi-analytical model based on the Rayleigh-Ritz method was developed to investigate the thermally induced multistable behavior particularly taking into account the curvilinear paths of VS composites. This approach provides a computationally efficient means to determine all the stable solutions with reasonable accuracy. The proposed methodology requires the definition of appropriate shape functions for the out-of-plane displacement and strain field. This is used to (i) identify the multiple potential solutions and (ii) to perform the subsequent stability assessment of the solutions obtained. To check the accuracy and robustness of the proposed method, the results for different cases are compared with a nonlinear finite element analysis. A parametric study is further conducted to analyze the effect of changing fiber orientation on the multistable shapes. A rich design space of VS composite is demonstrated with different bistable shapes having different values of out-of-plane displacements and curvatures.

Keywords: Multistability, Variable stiffness composites, Rayleigh Ritz, Residual thermal stresses

1. Introduction

In the recent years, multistable structures became a potential candidate for morphing applications and thus an active field of research in different engineering sectors. Few examples of multistability used in everyday life include snapping hair clip, slap-bracelet or flexible bistable display ([1]) that demonstrate the potential of achieving multiple stable shapes without the need of mechanical hinges.

In the field of aerospace and wind industry, multistable or bistable structures have showed great potential as morphing structures [2, 3, 4, 5, 6]. This is specially due to the existence of multiple stable shapes and their ability to remain in these stable states without any external forces. Several concepts have been investigated to include multistable components in morphing aerofoils. Diaconu et al. [7] explored three concepts using bistable elements in a morphing aerofoil by changing the camber, chord length of the section and also by using it as an adaptive flap. Arrieta et al. [8] studied several composites with different layups to obtain stiffness variability in order to achieve a distributed compliance for passive load alleviation in a morphing aerofoil. However, most of these studies are limited to theoretical concepts and still lack a fully functional prototype. The primary challenge for an efficient morphing in light-weight structure is the conflicting requirements of flexibility and stiffness. Additionally, the concept of bistable fiber-reinforced composite laminate is limited to only a few stable shapes and exploring further design space could lead to its incorporation into a wider