# SHAPE MEMORY ALLOY ACTUATION FOR ASYMMETRIC BISTABLE COMPOSITES

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## Introduction

Asymmetric composite laminates can exhibit interesting bistable characteristics due to their anisotropic response to temperature change that leads to a curved deformation [1]. Such a laminate configuration is of interest since a large deflection can be achieved through an equilibrium state change. As a continuous energy input is not required to maintain the deformation, asymmetric composites have been considered for a range of applications such as aerospace engineering [2].
The bistable behaviour of the $[0_n/90_n]$ family of laminates has been characterised in a numerical model, where there exists three equilibrium states at room temperature: two stable and one unstable state,, as shown in fig. 1. The large deflection is attributed to 'snap-through' between two stable states achieved by applying an in-plane stain.

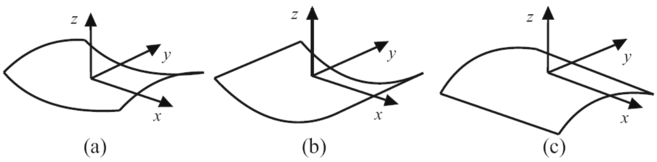


Fig. 1 Laminate shapes: (a) unstable saddle shape, (b) cylindrical state I, (c) cylindrical state II.

Piezoelectric materials have been used to control the deformation and 'snap-through' between states by inducing an in-plane strain and an analytical model has been developed to describe the actuation characteristics [3]. Whilst piezoelectric materials can generate a high force at high frequency, it is only capable of inducing a relatively low strain. Since bi-stable laminates typically require a greater strain to reverse the state change the use of a low strain piezoelectric material can be limiting. Previous studies have shown that the reverse actuation required an additional mechanical load input [4] or a voltage input outside the recommended operating range into the piezoelectric actuator [5].
An alternative material to induce a strain is a Shape Memory Alloy (SMA). SMAs have been incorporated for a range of aerospace applications due to its high force and high recoverable strain [6]. SMA wires have also been applied to induce the cylindrical state change by in-plane force attached above the surface of the cylindrical shape with bridge-like supports [7]. The concept of attaching SMA on the curved surface of asymmetric laminates has been introduced [8], although experimental or numerical investigations of such a configuration are limited.
This paper investigates SMA wires as an actuation mechanism for asymmetric bi-stable laminates to achieve a reversible state change and introduces a numerical model to describe this behaviour.

## Investigation of SMA Actuation

*Introduction to Multistable Equilibria in Asymmetric Composites*
It has been established that an asymmetrical laminate, which has been cured at elevated temperature whilst held flat has three possible equilibrium states when cooled, as shown in Fig. 1 [1]. For a thin laminate, the saddle shape of Fig. 1(a) is unstable hence the bistability, with cylindrical states I and II of Fig. 1(b) and (c). Previous studies have shown that in-plane strain can induce a snap-through between these states, as shown in Fig. 2.
It can be seen from Fig. 2 that the laminate will snap-through from cylindrical state I to II following the path **AB**. However the state change from state II to I follows path **CD** due to the unstable equilibrium of the saddle shape. It is this different in-plane strain requirement between state changes that presents challenges in achieving the reversible state change.

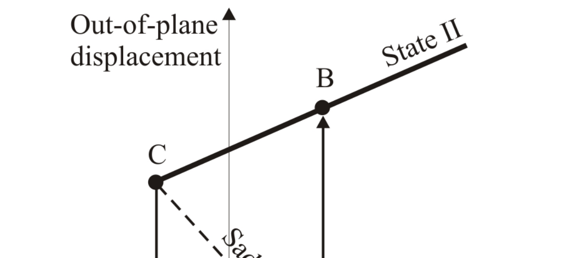


Fig. 2 Multi-equilibria of an asymmetric composite and its response to in-plane strain.

*Experimental Set-up*
We consider a cantilever beam where the previous work has shown that large deflections could be achieved using a piezoelectric patch but that the state change was not reversible [4]. The cantilever beam is a [0/0/90/90] lay-

up measuring 300×60×0.52mm manufactured using HTA (12k) 913 prepreg sheet. The laminate was run through a standard cure cycle to a maximum cure temperature of 125°C and a pressure of 85psi. The material properties are: $E_{11}$ = 135GPa; $E_{22}$ = 18.5GPa; $\nu_{12}$ = 0.29; $\alpha_1$ = 30×10$^{-6}$/°C. An MFC patch with an active area of 28x14mm and a thickness of 0.3mm is bonded to the top surface using a two-part epoxy.
In order to clamp the cantilever beam and to attach the SMA wire, four 20×20mm corners were removed. One single SMA wire (radius of wire diameter 0.175mm), insulated by a series of thin ceramic tubes, was then wrapped around one of the resulting tabs at the end of the cantilever beam and was clamped at the opposite end. The two ends of the wire were then fixed behind the clamping point to tighten and remove any slack.
It was observed that the clamping eliminates the bistable characteristics and that only one stable configuration existed, as was reported in [4]. This was remedied by adding a small weight of 4g to the tip of the cantilever beam. This was found to be sufficient to regain the bistability of the cantilever beam.

*Characterisation of Reverse State Change*

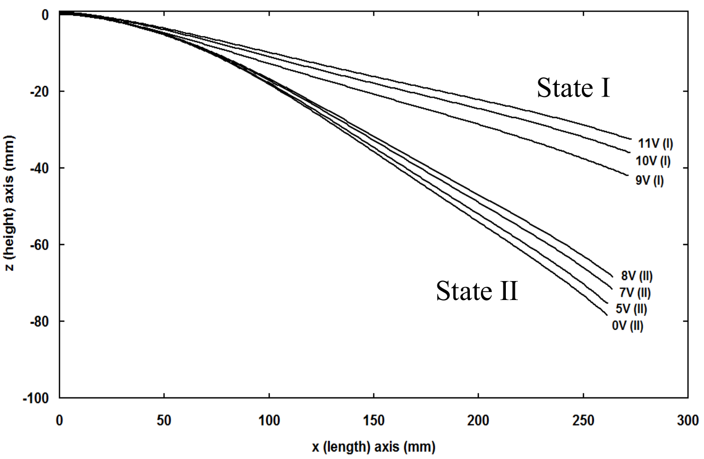


Fig. 3 Shape profile of the cantilever beam at varying applied SMA voltages.

The piezoelectric patch was able to snap the structure form state I to state II. The SMA was used to reset the structure and return the composite to state I. Starting in state II, the cantilever beam profile was videotaped and analysed in similar fashion as in [4] with zero voltage in the SMA, repeated at 1V intervals from 0-11V. The results obtained at 0, 5, 7, 8, 9, 10 and 11V are shown in Fig. 3. It was seen that between 0 and 5V there was very little deflection as the temperature in the wire had not reached the transition temperature. Between 5 and 8V there was a more marked change in the deflection but the cantilever beam remained in state II. At 9V the reverse snap-through to state I was observed. As the applied voltage was increased further to 11V the changes in deflection were small. Upon removal of the applied SMA voltage the cantilever beam returned to its original zero volt state I profile. It was found that this reversible actuation was completely repeatable.

## Numerical Model

The numerical model for asymmetric bistable composites is based on a Rayleigh-Ritz method of minimisation of the total strain energy of the laminate, where the out-of-plane deflection is approximated to a quadratic polynomial [9]. The SMA actuation is added to the model by embedding SMA wires in epoxy resin attached to the surface of the laminate. The details of the model will be presented at the conference.

## Conclusion

This paper achieves the reverse state change for an asymmetric bistable composite using a SMA wire with its high force and high strain actuation. This is demonstrated using a simple cantilever beam which was shown in the previous study that the snap-through from state I to II was achievable by a piezoelectric actuation but the reverse state change from state II to I could not be obtained. A preliminary numerical model is developed based on the minimisation of the total strain energy of the laminate.

## Acknowledgement

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