Sequential Instabilities for Actuating Aerodynamic Surfaces

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Introduction

Resilience to gust loading is a major consideration for aircraft design [1]. Extreme gust loads can cause damage to aircraft structures, necessitating a conservative structural design philosophy which adds mass and thus reduces fuel efficiency [2]. Conventional wing spoilers can be used to alleviate aerodynamic loads during a gust, thereby reducing airframe stresses. However, such control surfaces utilise conventional, active actuation mechanisms such as hydraulic or electro-mechanical actuators [3]. These mechanisms introduce significant mass and complexity to aircraft which results in a decrease to fuel efficiency and an increase in cost and manufacture time.

A proposed solution is a passively-actuated spoiler. This device would utilise structural instabilities to deploy rapidly once the strain in a section of the wing exceeds a triggering level. Before this level is reached, the spoiler must remain conformed to the surface of the wing to minimise drag. Such a spoiler negates the need for heavy, complex and costly systems that are seen in current conventional wing spoilers.

Background

Structural instabilities have traditionally been considered a failure mechanism; thus, current design methods can be viewed as an example of ‘*buckliphobia*’ [4]. However, by deliberately designing a structure to become unstable in predictable ways, useful functionality can be achieved, such as large and rapid deflections in shape morphing structures. A novel concept for a passively-actuated spoiler proposed by Wheatcroft *et al.* exploits sequential, interacting instabilities to produce a large post buckling deflection in a bistable, constant curvature, composite laminate [5]. A pair of instabilities can be considered sequential when an instability in one system triggers a subsequent instability in another, an approach which enables more refined control over the device deployment.

For this investigation, the pop-up spoiler concept is extended to consist of a clamped-clamped Euler strut and a composite laminate shaped to the upper surface of an aerofoil. The strut buckles into a mode that subsequently causes the laminate to buckle, creating a sequential instability. To date, this has only been studied through numerical modelling [5]. In our work, we use the finite element software ABAQUS to predict the nonlinear structural behaviour of the proposed device [6]. Fig. 1 shows the predicted deflection of the laminate, u_{out}, as a function of the enforced axial compressive deformation of the Euler strut, u_{in}. Once u_{in} reaches a critical value it results in the system traversing an unstable region, resulting in a dynamic deflection. An experimental setup is proposed to validate the models and demonstrate the feasibility of this novel concept.

Experimental method

The experimental setup is shown in Fig. 2. The composite laminate profile matches the leading two thirds of the upper surface of a NACA4312 aerofoil with a chord length of 300 mm. The spanwise width of the laminate is 150 mm. The Euler strut is a 5x16mm rectangular section, 600mm in length, produced from steel. These materials and dimensions provide the desired buckling response in the ABAQUS model.

The compressed strut is fixed in a Shimadzu mechanical tester and its ends are restrained by the grips of the machine. The laminate is fixed to an aerofoil shaped mount and includes a rectangular channel in which the Euler strut sits. The mount is fixed to an L-bracket that is designed to allow for position adjustment to ensure the alignment of the laminate and that the strut is centred. The Shimadzu compresses the strut, causing it to buckle (the first instability of the sequential pair). The buckling of the beam triggers instability in the laminate, which causes a rapid and large deflection as the laminate undergoes snap-through (the second instability). The resulting deformation of the laminate is observed using high-speed stereoscopic Digital Image Correlation (DIC), a method for capturing out-of-plane motion [7]. Stereo imaging allows for measurement of the out-of-plane displacement of the laminate to capture both pre- and post-buckled configurations. The use of high-speed imaging enables the observation of the dynamic buckling behaviour.

From these measurements, it will be possible to determine whether sequential buckling has taken place, as well as if the desired input-output behaviour has occurred. This includes sufficient deployment and actuation *only* once a threshold input value has been reached. The full-field strain map captured using DIC will allow for a comparison with the strain map predicted by the ABAQUS model.

The captured results will validate our numerical models and will ultimately provide a greater understanding of the feasibility of exploiting sequential instabilities in other practical applications. Specifically demonstrating the feasibility of the concept first proposed by Wheatcroft et al. for a novel, passively actuated wing spoiler, which exploits sequential instabilities to achieve deployment [5].

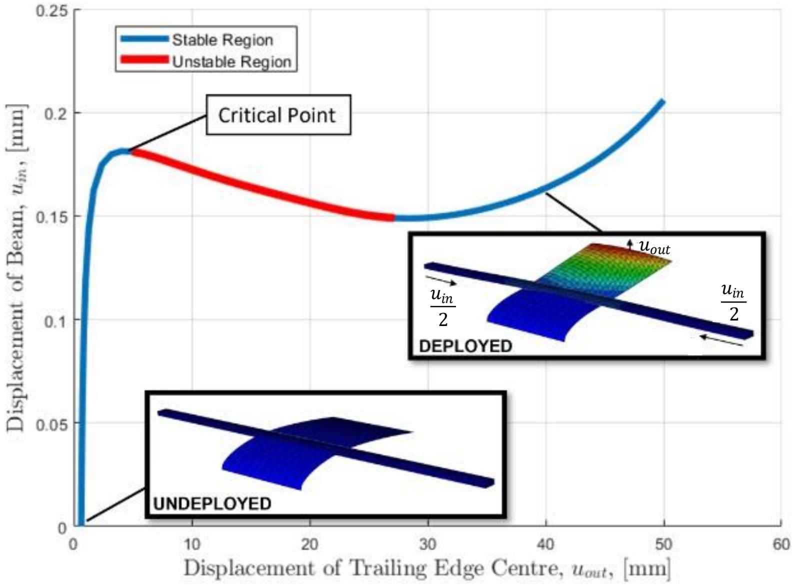

Figure 1 *Equilibrium manifold of proposed concept, modelled using ABAQUS. The undeployed and deployed configurations of the device are shown inset. The colourmap pertains to magnitude of deformation from the undeformed state..*

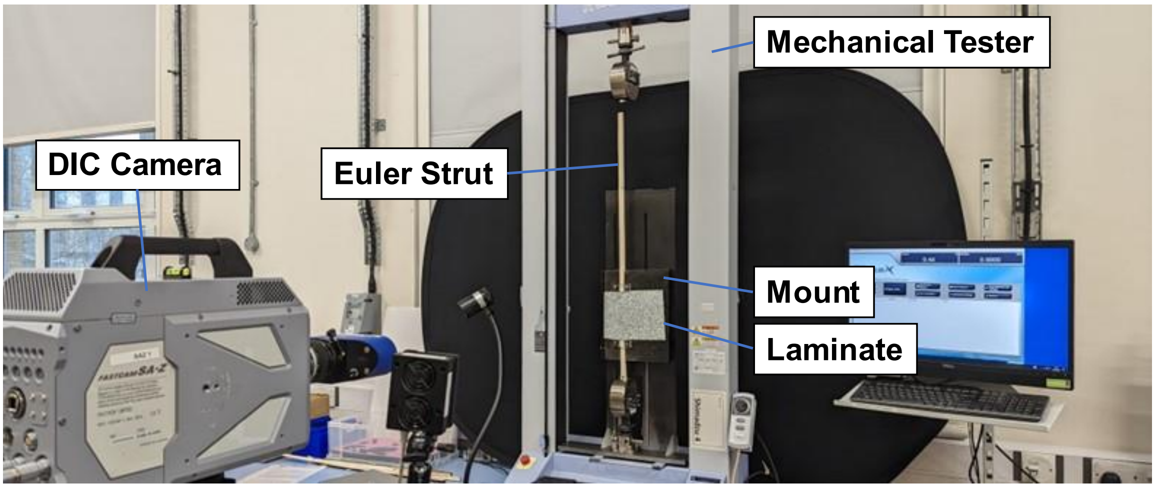

Figure 2 *Experimental setup in testing machine with DIC camera.*

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