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Abstract

Learning from the Earwig Wing: A Bioinspired Approach towards Fast Morphing Structures using Multistability

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In natural examples of shape change, such as the Venus flytrap (Forterre, Skotheim et al. 2005) or the fern seed catapult (Noblin, Rojas et al. 2012), the driving force, or underlying actuation, is diffusion and thus swelling of tissue or cells. This swelling process is generally very slow, in the order on minutes, hours or days. Yet, these plants are able to perform explosive movements and rapid shape changes (Forterre 2013). Their underlying principle for converting slow-paced actuation into high-speed shape change is pre-stress that leads to bistability: The structure shows two stable deformation states, which can be described as local energy minima. Upon reaching a certain critical deflection, the structure undergoes a snap-through process and rapidly takes on a second stable configuration.

For technical applications, actuation principles for shape morphing are also often limited in terms of speed, achievable stroke or force. Transferring the bioinspired principle of restrained actuation combined with structural bistability to synthetic systems is therefore highly promising to overcome these limitations. In this study, we analyze a core principle from another biological example of a large reconfiguration, airborne structure – the earwig wing (Fig. 1) – for implementation in possible bioinspired, composite shape-adaptation applications. Literature suggests that the earwig wing incorporates a bistable joint in its center, which locks the wing in an open position during flight (Haas, Gorb et al. 2000). In contrast to the well-researched bistable composite plates made from certain unsymmetric layups, this mechanism represents a different class of bistable element. While bilayer composites are inherently bistable due to internal stresses and incompatible curvature, the earwig's central mechanism purely relies on its topology, resembling a pyramid-shaped sheet in the open wing state. This pyramid can, as easily imaginable through a simple paper model, be inverted to a second stable state. In comparison to the plant examples, where the bistable regions equal the morphed area, this bistable mechanism is very localized – it covers only a tiny fraction of the wing area. Yet, it is able to influence the curvature of the entire wing. Due to the very low-energy and localized snapping event of the center joint, the wing as a whole is being altered into a different configuration. We performed elaborate numerical studies of the central joint and its snapping process (Fig. 2). The herein presented results show that the assumed or visually observed principles driving the shape morphing of the earwig wing can be reproduced, and can be transferred to other types of shape adaptable structures. Furthermore, we show that a large shape reconfiguration is possible by a very localized snap-through event. We present parameter studies, in which the main geometric and material properties of such bistable elements are systematically varied and analyzed with regard to bistability, energy minima, actuation requirements. These results show a distinct border between bistable parameter sets, where two energy minima exist and monostable configurations.

We further assessed 3D printing and composite technologies to create accordant snapping mechanisms that are rapidly shape changing upon external stimuli. While bilayer composites have already shown their potential as bistable structures, the current modelling and fast prototyping tools such as 3D printing allow for a close combination of design optimization and manufacturing to produce structures with unique morphing capabilities. We conclude the study by presenting bistable, fast morphing demonstrators pointing at possible applications in deployable structures or morphing wings.

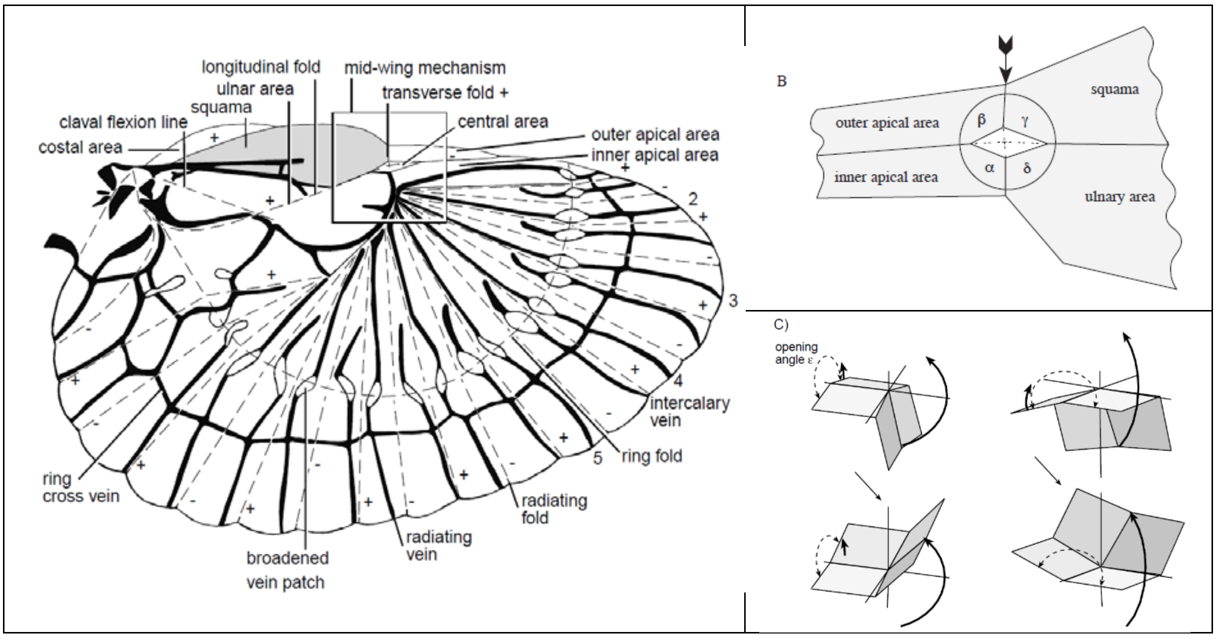

Fig. 1: Earwig wing and bistable mechanism. A) Overview of the wing. B) Central joint with the four depicted angles adding up to only 350°. The mechanism does not fold flat and is thus bistable. C) Two perspectives of folding beyond the bifurcation point. Adapted from (Haas, Gorb et al. 2000).

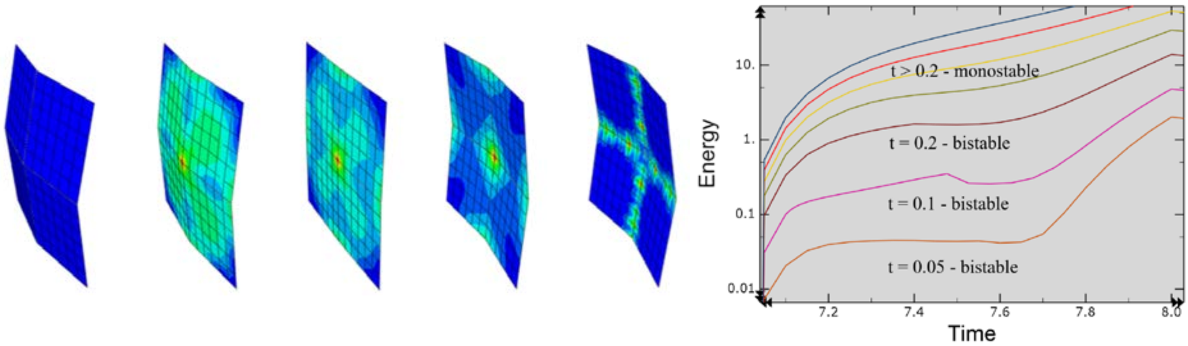

Fig. 2: FEA Studies of bistability mechanism. A) Shape and stresses during snap-through of a simplified, generic geometry. B) Strain energy over displacement for varying sheet thicknesses (preliminary results), two minima indicating bistability.

Key References

Forterre, Y. (2013). "Slow, fast and furious: understanding the physics of plant movements." J Exp Bot **64**(15): 4745-4760.

Forterre, Y., J. M. Skotheim, J. Dumais and L. Mahadevan (2005). "How the Venus flytrap snaps." Nature **433**(7024): 421-425.

Haas, F., S. Gorb and R. J. Wootton (2000). "Elastic joints in dermapteran hind wings: materials and wing folding." Arthropod Structure & Development **29**(2): 137-146.

Noblin, X., N. O. Rojas, J. Westbrook, C. Llorens, M. Argentina and J. Dumais (2012). "The Fern Sporangium: A Unique Catapult." Science **335**(6074): 1322-1322.