The Evolution of Mechanical Instabilities for Functional Applications

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Abstract

Mechanical instability is widespread in both daily life and engineering. They were traditionally viewed as failure mechanisms, such as collapse of liquid storage tanks, coating delamination, etc. These instabilities have been studied extensively since Euler's investigation of column buckling in 1744 to enhance safety in engineering and industrial design. More recently, mechanical instability has been harnessed as effective and robust strategies for functional applications, including soft robotics, metamaterials, flexible electronics, shape-morphing structures, and biomedical devices. In this talk, I will present two examples from our recent work demonstrating how mechanical instability can be leveraged to design functional systems. The first example draws inspiration from cylinder shell buckling to develop millimeter-scale origami systems for robotic surgery. The diagonal-shaped buckling pattern of cylindrical shells under torsion is adapted to create origami structures with tunable monostability and bistability. These designs enable multifunctional robotic systems capable of omnidirectional bending and twisting, as well as amphibious millirobots with multimodal locomotion, drug delivery, and cargo transport capabilities. The second example utilizes the buckling of elastic rods with large natural curvature to create a novel type of origami with multiple stable states and programmable strain energy. This origami serves as a fundamental building block for assembling larger structures with adjustable stiffness and 'spring constant', enabling vibration control by switching between functions such as rigid vibration, wave isolation, amplification, and mode tuning.

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