Eggstreme Mechanics: Shell We Buckle?

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Abstract

From birds' eggs to architectural domes and from viral capsids to aerospace vessels, shell structures are ubiquitous across scales in both nature and engineering, primarily due to their exceptional capacities for load-bearing and enclosure. Since the golden era of shell buckling in the 1960s, pioneered by Zoelly, von Kármán, Tsien, Koiter, Budiansky, Hutchinson, and many others, this field has been marked by the fundamental challenge of reconciling theoretical predictions of buckling strength with experimental observations, particularly regarding the dramatic sensitivity to geometric imperfections. The past decade has witnessed a renaissance in shell buckling research, driven by advances in computational methods and fabrication techniques, thereby renewing efforts to move beyond empirical knockdown factors toward more predictive frameworks and rational designs.

In this talk, I will present recent advances in the predictive understanding of the buckling of thin shell structures, with a primary focus on spherical shells, but also presenting some more recent work on cylindrical and negatively curved shells. Empowered by our development of precise fabrication techniques for thin elastic shells of nearly uniform thickness, and combining precision experiments, finite-element simulations, and shell-theory analyses, we have thoroughly investigated how single localized defects and distributed imperfections influence buckling strength. For the probabilistic problem of shells containing multiple defects, we have uncovered that a distribution of defects whose amplitudes are distributed log-normally yields knockdown factor statistics that are well-described by a three-parameter Weibull distribution. This finding reveals shell buckling as an extreme-event statistics problem governed by a finite-size weakest link mechanism, where the most severe imperfection ultimately dictates the buckling strength. Practical applications of this research will also be discussed, including a refreshable braille dot utilizing bistable buckling of magneto-active shells and the design of stiffened shells for aerospace applications.

Even after more than a century of active research, the mechanics of shell buckling continues to raise fundamental questions, reveal surprising phenomena, and remain as practically relevant as ever at the confluence of applied mathematics, mechanics, and engineering. After all, quoting Budiansky and Hutchinson, "Everyone loves a buckling problem"!

*Speaker

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