LMS Seminar series 2024 – 25

Imperfection Sensitivity in Shell Buckling: Longstanding Questions and New Answers

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Venue: Amphi 104 (Pole Meca)

Abstract

In this duet talk, we will present recent advances in the predictive understanding of the buckling of thin shell structures. We will focus on our collaborative work over the past decade, including very recent preliminary results from an ongoing project.

From viral capsids to fuel tanks and from birds' eggs to architectural domes, shell structures are ubiquitous across scales in both natural and engineered systems, primarily due to their exceptional load-bearing and enclosure capacities. Since the golden era of shell buckling in the 1960s, pioneered by Zoelly, von Kármán, Tsien, Koiter, Budiansky, and many others, this field has been marked by the fundamental challenge of reconciling theoretical predictions of the buckling strength with experimental observations, particularly regarding the dramatic sensitivity to geometric imperfections. The past decade has witnessed a revival in shell buckling research, driven by the need to move beyond empirical knockdown factors toward more predictive frameworks and rational designs.

First, focusing on spherical shells, we will demonstrate through precision experiments, finite-element simulations, and shell-theory analysis how both individual 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, revealing shell buckling as a problem of extreme-event statistics governed by a finite-size weakest link mechanism.

Then, we will present our latest results on iso-grid stiffened cylindrical shells under axial compression, a problem relevant to modern space structures, especially space rockets. By way of example, we demonstrate how shells with 30% of their weight in stiffeners can achieve buckling loads 1.5 times higher than unstiffened shells of equivalent weight. The concept of effective thickness provides new insights into imperfection sensitivity, with stiffening effectively reducing the impact of geometric imperfections by more than a factor of two. This work establishes a comprehensive framework for predicting and optimizing the stability of shell structures by bridging fundamental research on imperfection sensitivity with practical design considerations.

Even after more than a century, the mechanics of shell buckling continues to raise fundamental questions, reveal surprising phenomena, and remain as practically relevant as ever at the confluence of mathematics, mechanics, and engineering.

About the speaker: Pedro Reis

Pedro M. Reis is a Professor of Mechanical Engineering at EPFL in Switzerland. After a Ph.D. at the University of Manchester (2004), he was a postdoc at the City College of New York (2004-05), CNRS/ESPCI Paris (2005-07) and MIT (2007-10). In 2010, he joined the MIT faculty, with dual appointments in Mechanical Engineering and Civil & Environmental Engineering, first as the Esther and Harold E. Edgerton Assistant Professor and later as Gilbert W. Winslow Associate Professor (2014). Some of his honors include selection to Popular Science's "Brilliant 10" list (2013), the NSF CAREER Award (2014), the ASME Thomas J.R. Hughes Young Investigator Award (2016), and the APS GSOFT Early Career Award (2016). He served as President of the Society of Engineering Science (2021) and is an APS Fellow. His research focuses on the geometrically nonlinear mechanics of slender structures and soft materials. Further information can be found at: https://www.epfl.ch/labs/flexlab/

About the speaker: John Hutchinson

John Hutchinson received his undergraduate education in engineering mechanics at Lehigh University and his graduate education in mechanical engineering at Harvard University. He joined the Harvard faculty in the School of Engineering and Applied Sciences in 1964 and is currently the Abbott and James Lawrence Professor of Engineering Emeritus. Hutchinson and his collaborators work on problems in solid mechanics concerned with engineering materials and structures. Buckling, structural stability, elasticity, plasticity, fracture, and micro-mechanics are all central in their research. Ongoing research activities are: (1) development of a mechanics framework for assessing the durability of thermal barrier coatings for gas turbine engines, (2) fracture mechanics of tough ductile alloys, (3) micron scale plasticity, and (4) stability phenomena in plates, shells and soft materials. Further information and publications can be downloaded at http://www.seas.harvard.edu/hutchinson .