Aerospace Seminar

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Instability-driven nonlinear dynamics in (meta)materials: from structural domino to phase transitions

Thursday, March 21, 2019 | Onizuka | 12:00 P.M.

Abstract: Instabilities in solids and structures are ubiquitous across length and time scales, and engineering design principles commonly aim to prevent those. We aim for the opposite: exploiting instabilities to create mechanical systems with beneficial properties. At the core of all instabilities lies a non-convex energy landscape that is responsible, e.g., for structural buckling and localization but also, at much smaller scales, for phase transitions in materials or pulse propagation in cardio- and neurophysiology. The existence of multiple stable configurations can lead to nonlinear dynamic or kinetic effects, including strongly nonlinear transition waves that switch between stable configurations (e.g., propagating domain walls in materials or the snapping of structures between buckled shapes). Understanding the underlying physics enables us to create new mechanical systems that utilize effects of instability, and to mimic material-level mechanisms at the structural level. We will discuss theory and opportunities for structural systems whose nonlinear response shows intriguing analogies with phenomena found in materials at small scales. We show how periodic snapping structures can be exploited for propagating signals in lossy media and for soft mechanical logic, nonlinear diodes and shape-morphing structures. We further demonstrate how these soft architectures may be interpreted as structural-level analogs of solid-solid phase transitions like those found in ferroelectric ceramics undergoing domain switching. To show the analogy is not only qualitative, we compare the underlying governing equations and, by passing from a discrete structure to the continuum limit, reveal quantitative analogies that help us learn from one system about the other. Besides theory and simulations, we demonstrate through experiments the instability-driven nonlinear dynamic effects in a variety of mechanical systems.

Bio: Dennis Kochmann received his diploma and doctorate in Mechanical Engineering from Ruhr-University Bochum as well as a Master's in Eng. Mechanics from the University of Wisconsin-Madison. He was a postdoc and Fulbright fellow at Wisconsin and a Humboldt fellow at Caltech before joining the Caltech Aerospace faculty in 2011. In 2017, he became Professor of Mechanics and Materials at ETH Zurich, where he is Head of the Institute of Mechanical Systems and Deputy Head of the Dept. of Mechanical and Process Engineering. His research focuses on the link between structure and properties of a variety of materials and develops and applies methods of theoretical, computational and experimental mechanics (including continuum and atomistic modeling, scale-bridging multiscale models, phase field techniques, and experimental characterization). He has earned the IUTAM Bureau Prize in Solid Mechanics, the Richard von Mises Prize by GAMM, an NSF CAREER Award, the ASME T.J.R. Hughes Young Investigator Award, and an ERC Consolidator Grant.