Seminar Title:

Topology optimization of self-actuating shape-memory polymer mechanisms

Seminar Abstract:

Shape-memory polymers are a class of memory materials capable of undergoing and recovering significant amounts of applied deformation. When used in the design of soft robotics, these multifunctional materials provide a source of actuation and allow for light-weight designs that can achieve complex motion with a high degree of dexterity. This talk presents a novel computational framework for design and synthesis of soft robotic mechanisms containing shape-memory polymers. We implement a transient finite element analysis model that incorporates the additive decomposition of small strains to simulate and predict the temperature-dependent displacement response of the material. The finite element model is combined with a topology optimization algorithm, which we use to optimally distribute multiple design materials within the volume domain of the mechanism. Each design material has its own unique activation temperature so that when the optimized design is subjected to a prescribed temperature cycle, it exhibits a desired motion that is encoded into its material distribution. We also derive and implement a path-dependent adjoint sensitivity formulation to compute the gradients required for the topology optimization algorithm. Lastly, we introduce a hierarchical design method in which we optimally combine a sequence of topologically optimized unit structures to achieve complex motions characterized by large displacements. The talk will conclude with several examples of computationally generated shape-memory polymer mechanisms, which we have 3D printed and validated experimentally.

Biographical Info:

Name: Kai A. James

Title: Assistant Professor

Affiliation: University of Illinois at Urbana-Champaign, Department of Aerospace Engineering

Biographical Sketch:

Kai James is an Assistant Professor in the Department of Aerospace Engineering at the University of Illinois at Urbana-Champaign, and the Principal Investigator of the Computational Design Innovation Lab at UIUC. From 2012 to 2015, he was a postdoc in the Computational Mechanics Group at Columbia University, and he earned his PhD in aerospace engineering from the University of Toronto in 2012. His research focuses on computational solid mechanics and computational design optimization with an emphasis on problems involving various sources of nonlinearity, such as viscoelastic creep, superelasticity, and large deformations. He is especially interested in developing novel algorithms that leverage high-fidelity computational models and topology optimization methods for conceptual design and synthesis of complex engineering structures. Some of his major research projects include aerostructural optimization of transonic aircraft wings, structural design optimization of a cardiovascular stent, optimal design of a bi-stable airfoil, and computational synthesis of multi-body systems. Dr. James is the recipient of the NSF CAREER award (2018), and in 2020 he received the Scott White Aerospace Engineering Faculty Fellow Award from the University of Illinois.