Development of an Active Metastable Module for Adaptive Structures

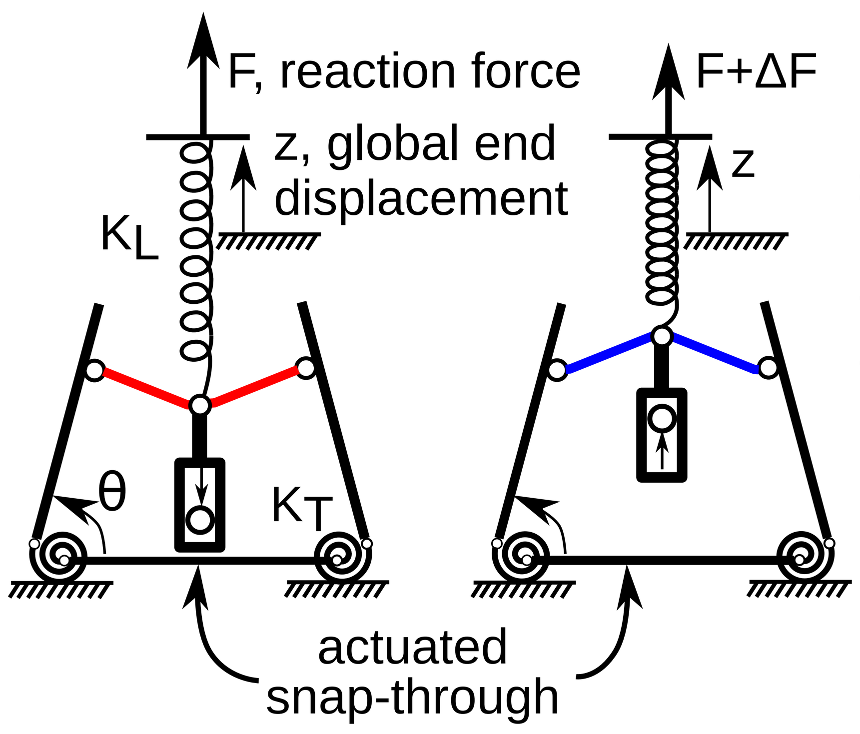
Xiaowen Zhang, Dr. R.L. Harne, and Prof. K.W. Wang

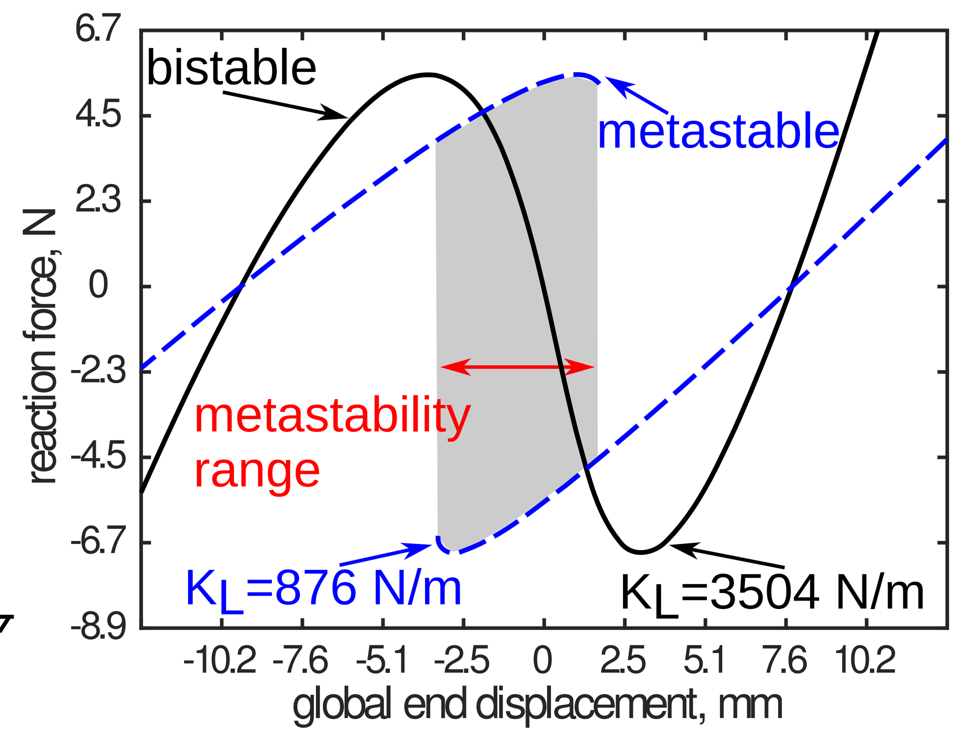
Motivation and Research


source: J. MacNeil, IEEE Spectrum, 2007, http://spectrum.ieee.org/aerospace/aviation/fly-like-a-bird

Passive-adaptable mechanical properties enabled via multi- and metastable architectures provide valuable versatility for many engineering applications. Such features include stiffness and damping tunability, or dramatic shape change. However, few efforts have explored the potential for embedded actuation of such architectures. This project develops a compact, controlled, multistable module that actively switches between metastable states for intelligent properties adaptation.

Design Specifications





1. Metastability: defined here as coexistence of metastable states
2. Modular and easy to assemble into greater architectures
3. Able to actively switch between internal stable states
4. Consistent state change ability and quick response time
5. Actuator disengagement when not required
6. System adjustability in terms of metastability range and system stiffness, defined by specifc tasks

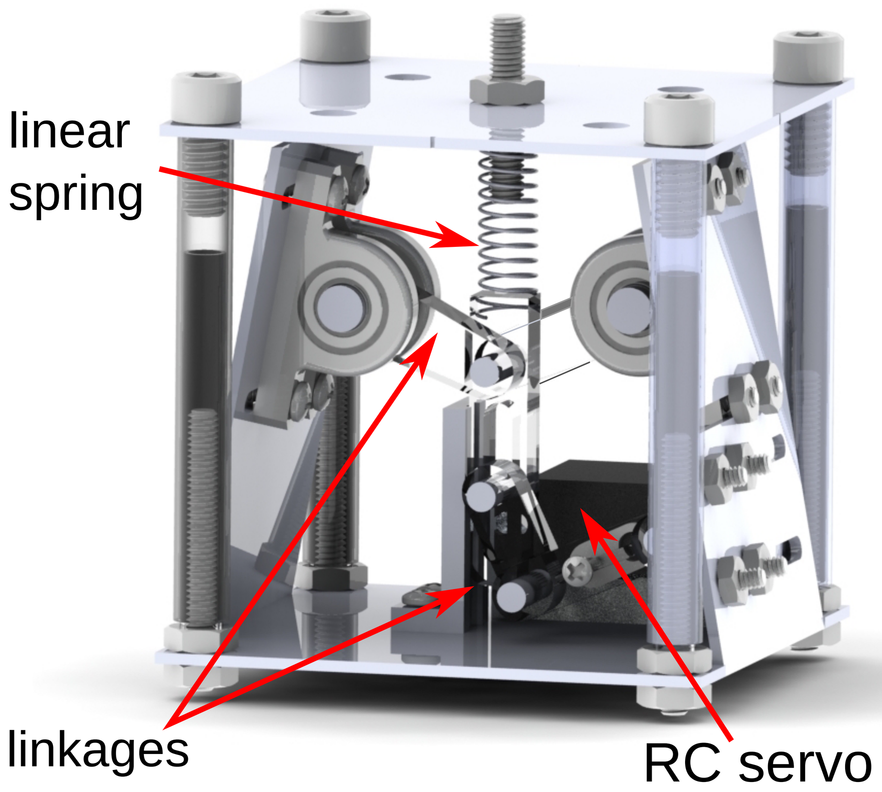
A bistable system exhibits two stable states of displacement for one force. A metastable system has this feature but also exhibits two forces for one displacement, providing useful adaptable mechanical properties. The energetic transition from one state to the other is called snap-through. The design focuses on the mechanism to generate metastability and actively control it. A model is formulated to predict the design parameters required to meet the target specifications.

Module Development

Investigation undertaken to determine component selection and fabrication processes required to generate metastability in the mechanical properties. Challenges come from the fabrication, where prototyping speed was balanced against module adjustibility. Designs were iterated to explore the effects of materials, dimensions, and spring stiffnesses on module behaviors. Acrylic-based and steel-based modules are fabricated as testbeds.

Module Components

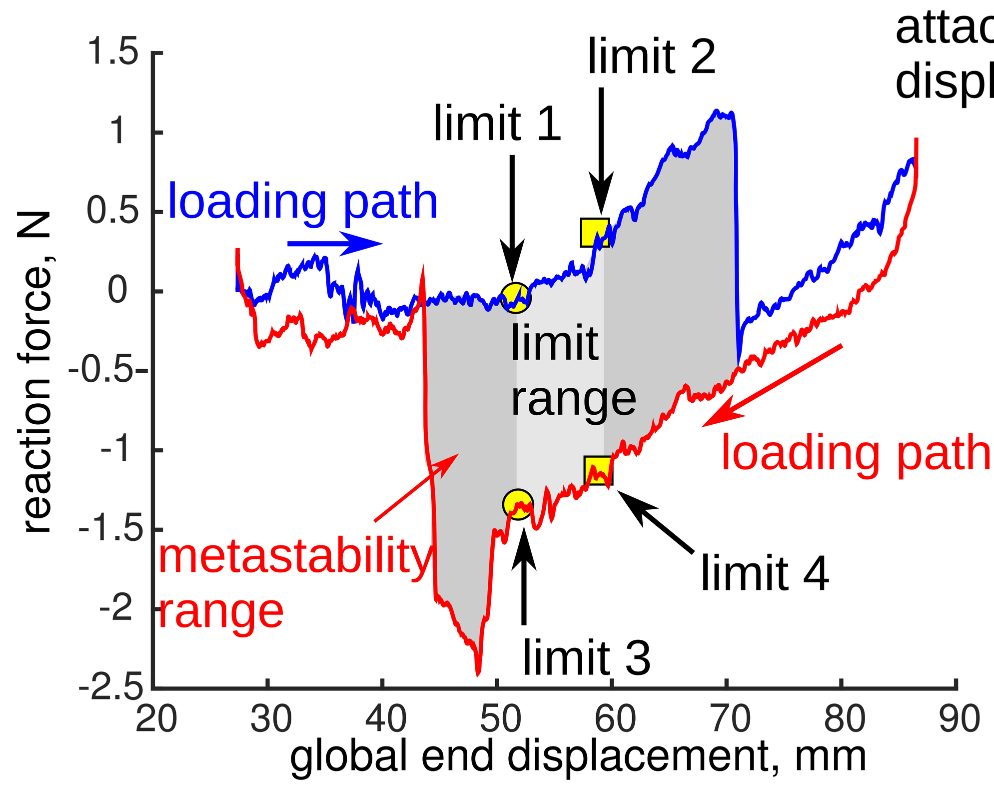
• RC servo (actuator) • Steel/Acrylic plates • Linear spring • Bearings
• Axles • Acrylic transmission linkages • Hinges • Torsional springs

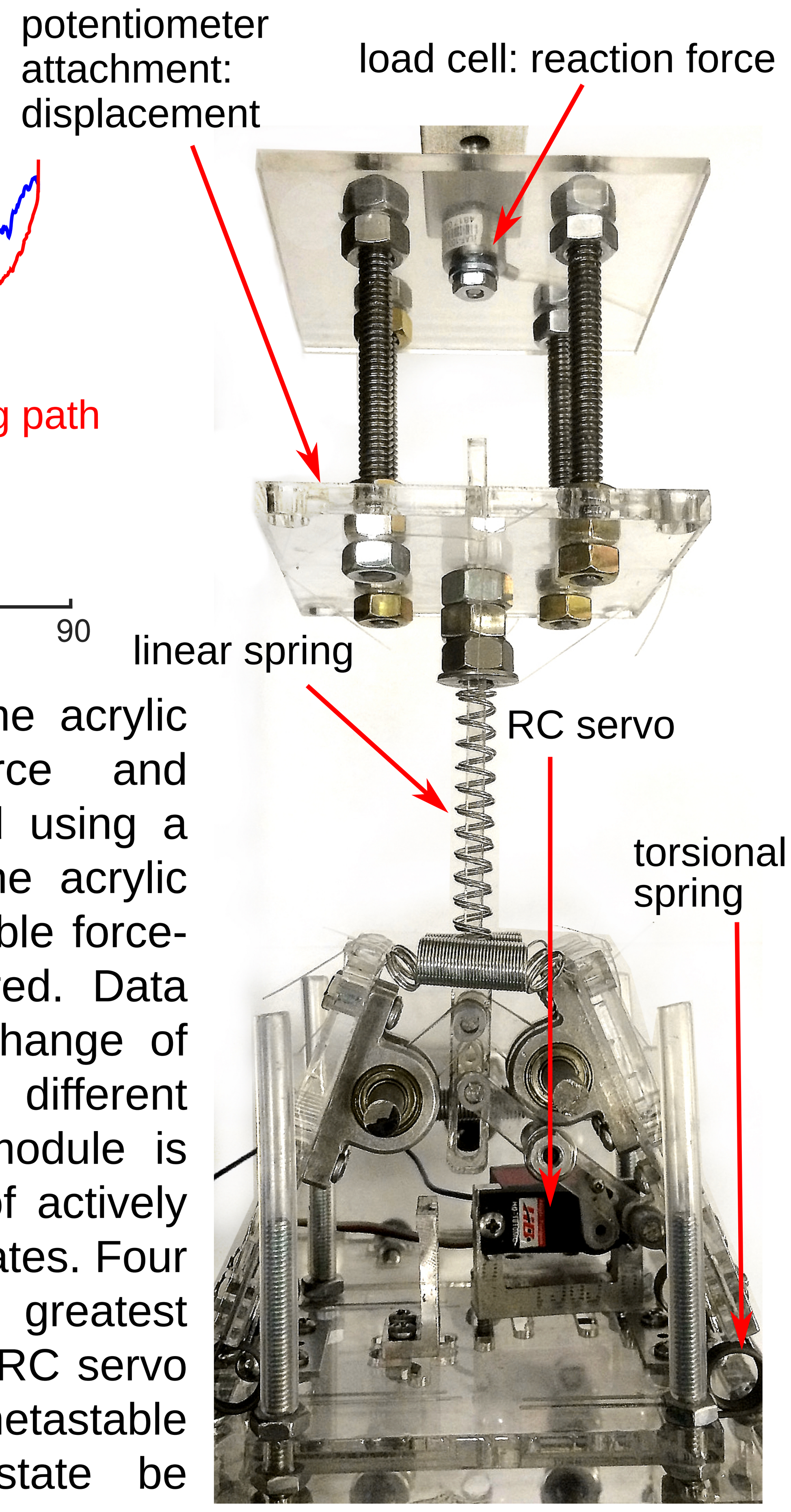


Module Features

- Actuator able to selectively engage based on linkage design
- Metastable states generated by torsional springs and middle linkages
- Guided, uniaxial motion
- Torsional spring stiffness adjusted by bending steel plates or binding the lateral acrylic plates

Module Behavior

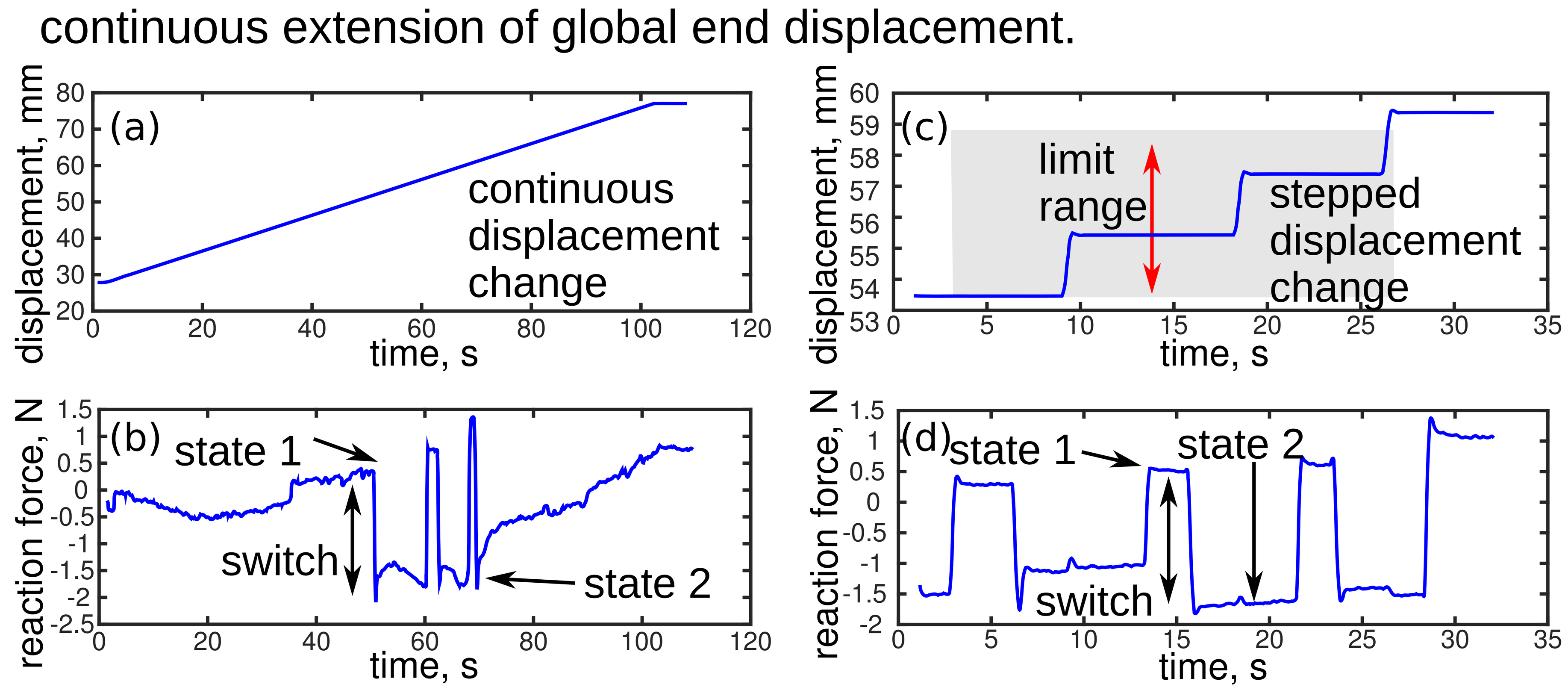




The mechanical properties of the acrylic module are measured. Force and displacement data are gathered using a potentiometer and load cell. The acrylic module demonstrated a metastable force-displacement behavior as desired. Data above indicate the significant change of reaction force due to the different metastable states. Then, the module is evaluated to identify the limits of actively switching between metastable states. Four limits are found that define the greatest end displacements at which the RC servo is able to switch between the metastable states and have the final state be thereafter maintained.

Active Metastability Evaluation

The module is evaluated for its ability to switch states repeatedly as the displacement is dynamically varied. Fig. (a,b) show the module can successfully change states even under circumstances of dynamic, continuous extension of global end displacement.



Tests are carried out using stepped displacement change to verify that state change may be achieved consistently and repeatably across the displacement range bound by the performance limits. As one example, Fig. (c,d) show that the module effectively achieves controlled transition between the metastable states in the limit range to tailor reaction force. Outside of the limit range, controlled switching ceases as anticipated.

Conclusions

This research developed a compact, active metastable module for controlled adaptation of mechanical properties. An RC servo selectively engages to enable the switching, but disengages when control is not needed to leverage the underlying passive module characteristics. Future efforts will explore assembly of the active metastable modules for large, programmable adaptation of assembly-level mechanical properties.

This research is supported by the Air Force Office of Scientific Research (FA9550-13-1-0122) and managed by Dr. David Stargel.