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Nonlinear mechanics of hummingbird beak and its potential application in fast response soft robots

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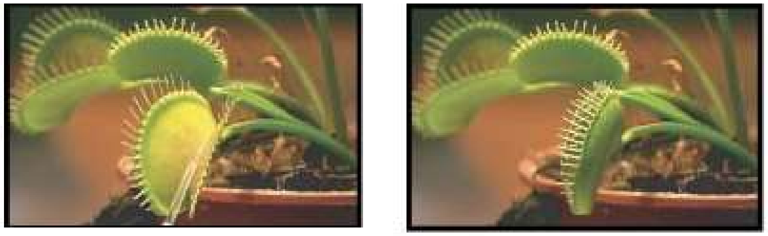
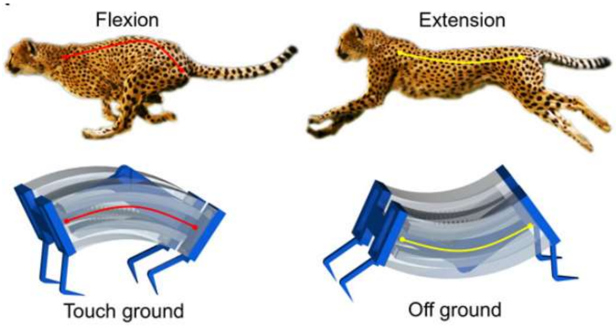
Advantages of soft robotics and their shortcomings

(from Soft Lab in Beihang University, China)

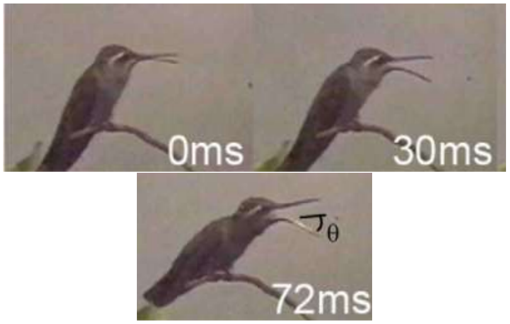
- Advantages
  - Flexibilities to execute unstructured tasks
  - **Safe** interaction with users at **affordable** prices.
- Shortcomings: slow actuation speed



(Cheetah et al. 2005)

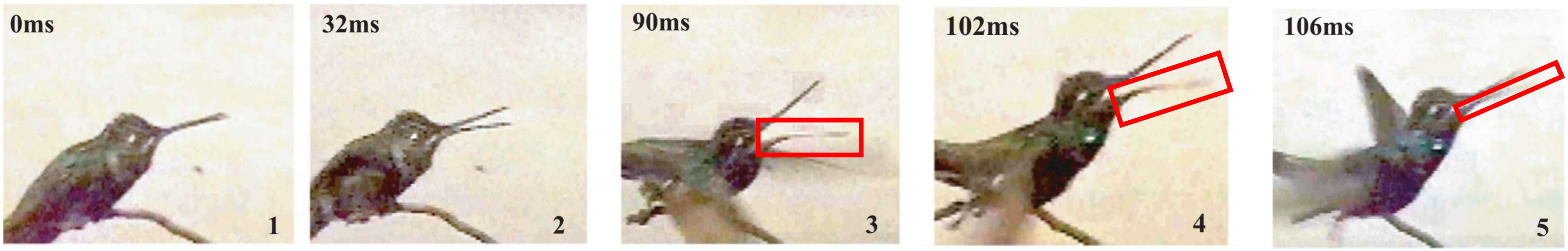


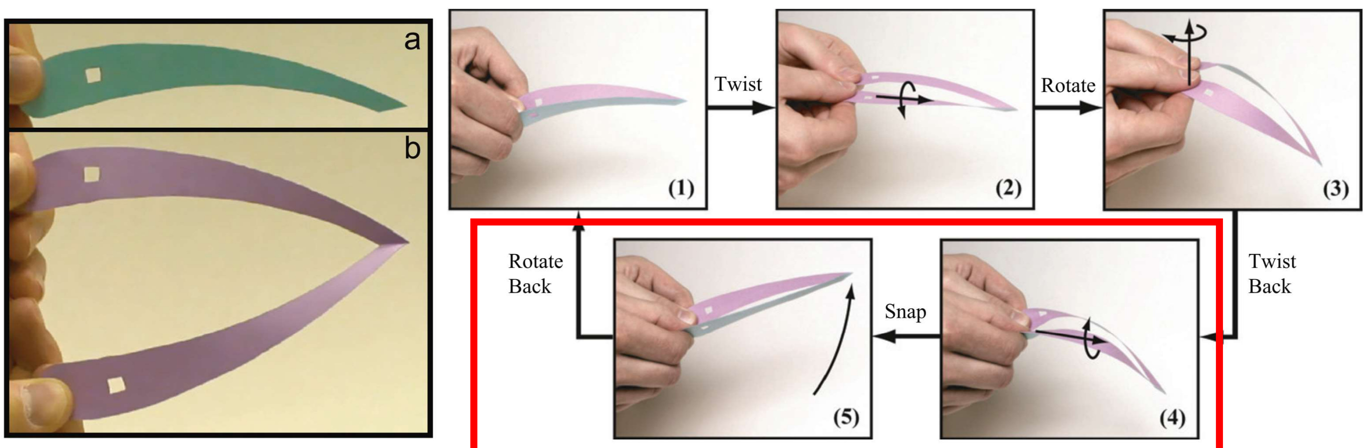
(Tang et al. 2022)



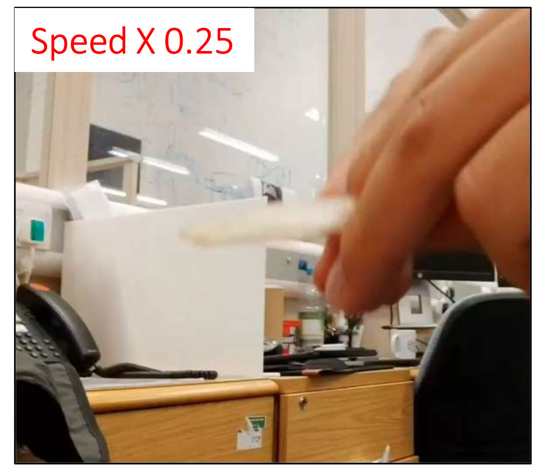
(Smith et al. 2011)

Snaps to open and close a hummingbird beak



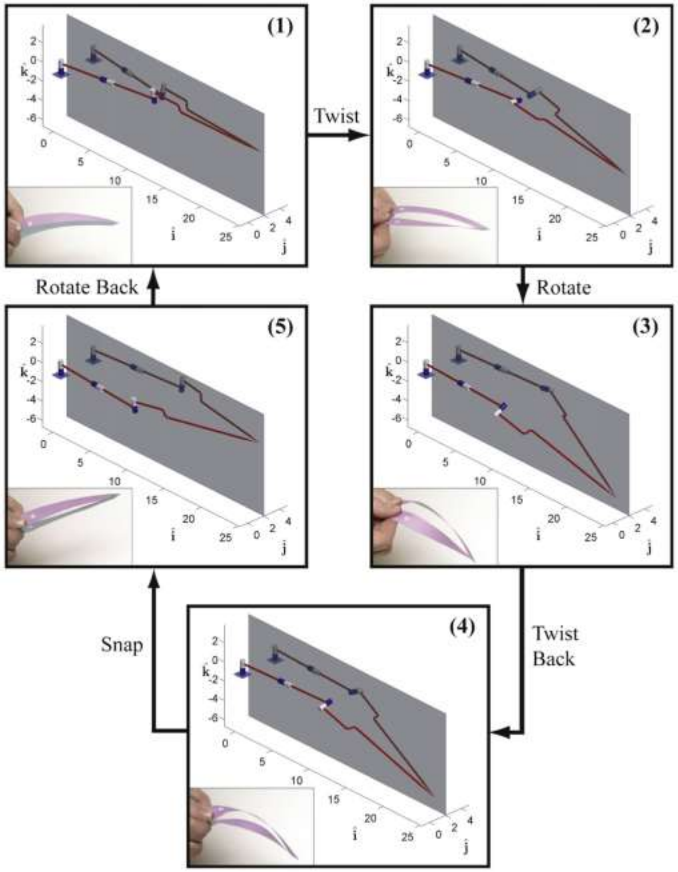


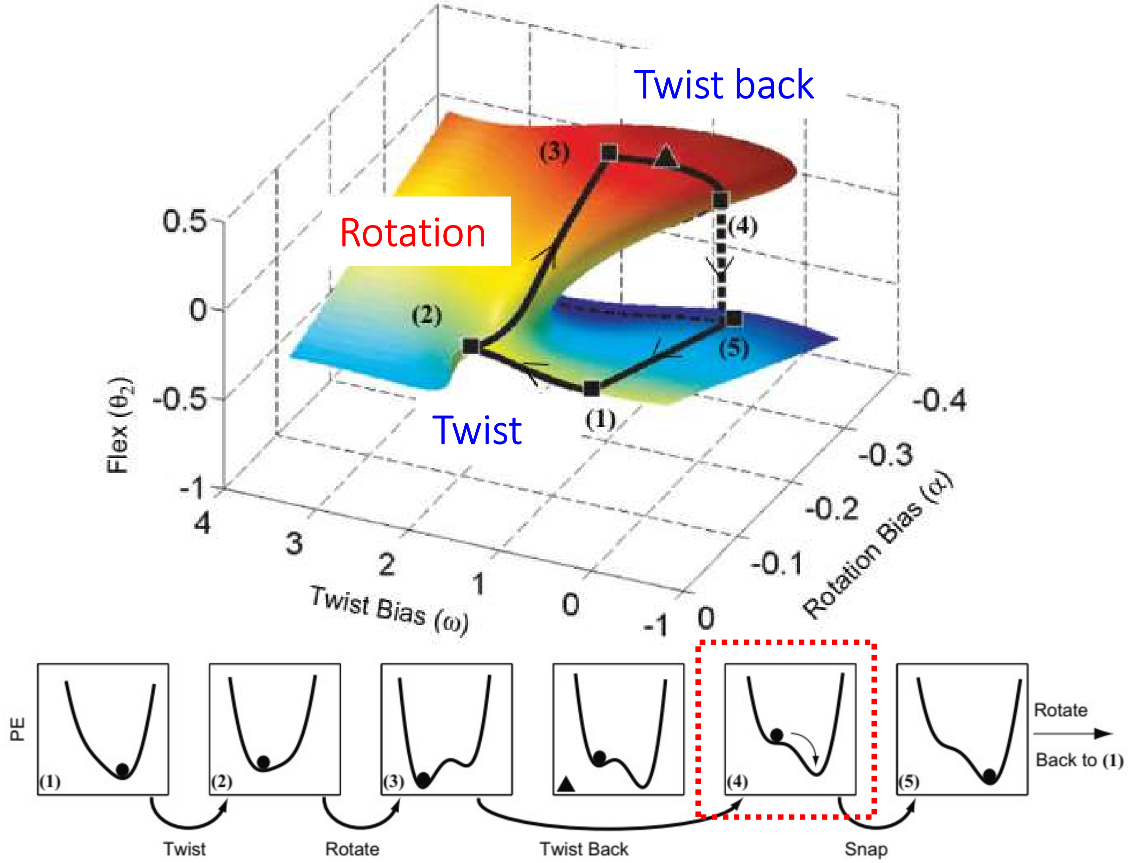
Paper model by Smith et al. (2011)



Silicon beak model

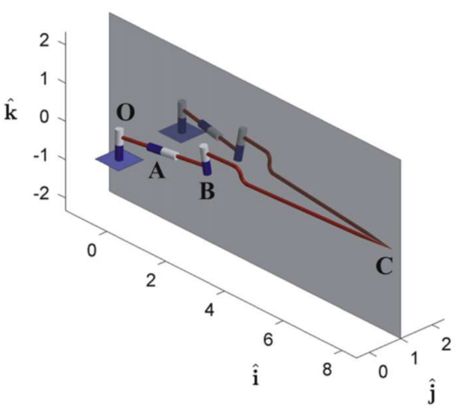
Results from the simplified spring—rigid bar model (Smith et al. 2011)

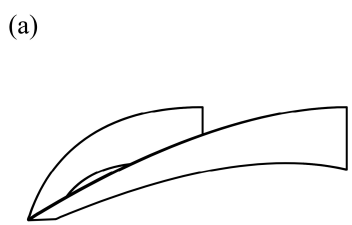


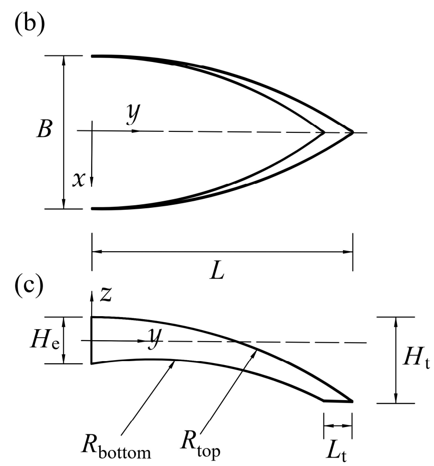


Comments about the simplified model

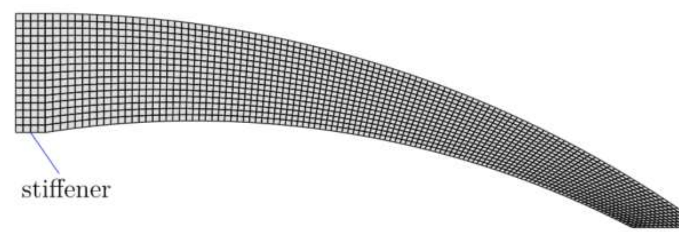
- Unveil the key mechanics governing the behaviour of hummingbird beak — limit point bifurcation
- Cannot provide direct guidance on the design of engineering systems.





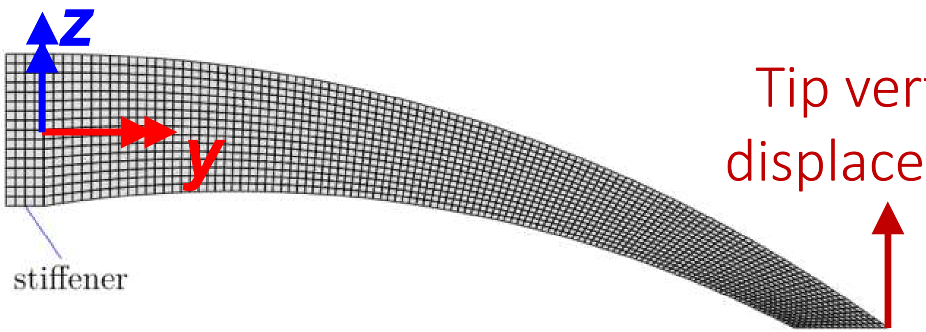


Parametric FE model discretised using shell elements



FE model using shell elements and advanced solver

(a) *y-z* view



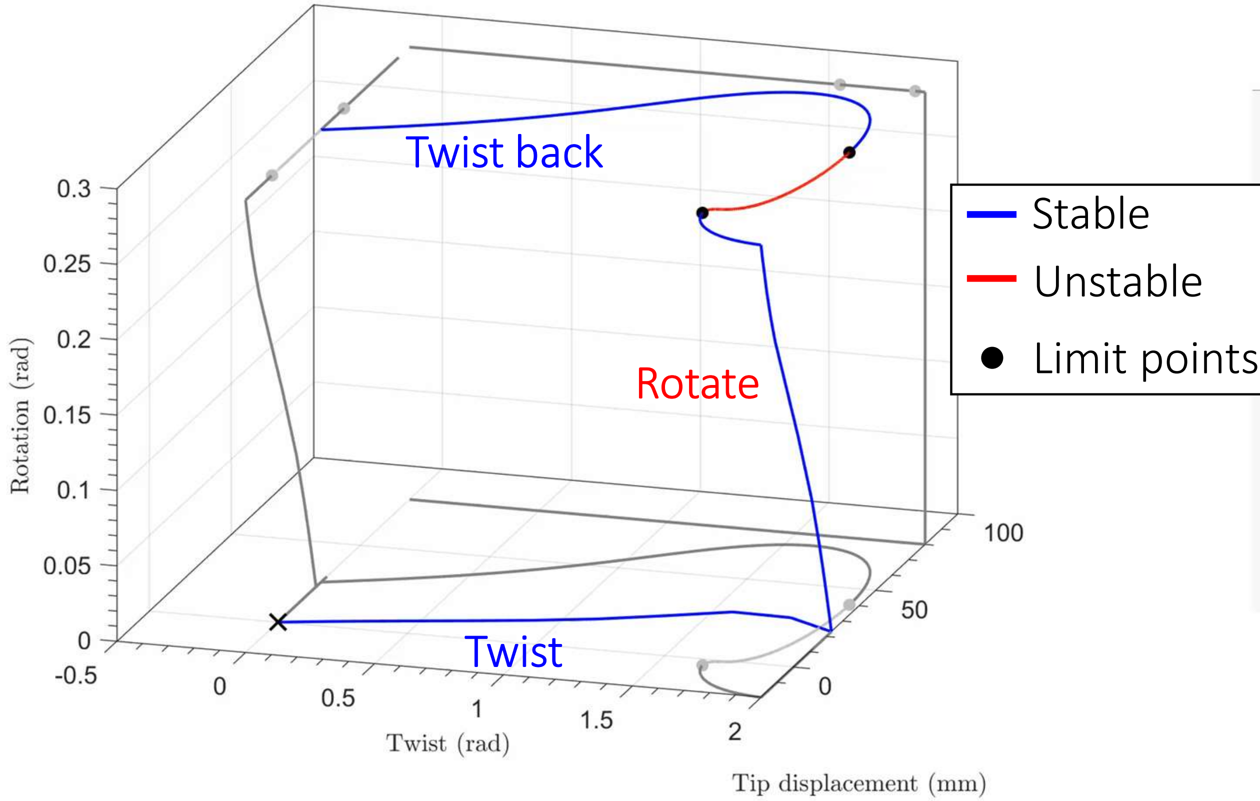
Tip vertical displacement

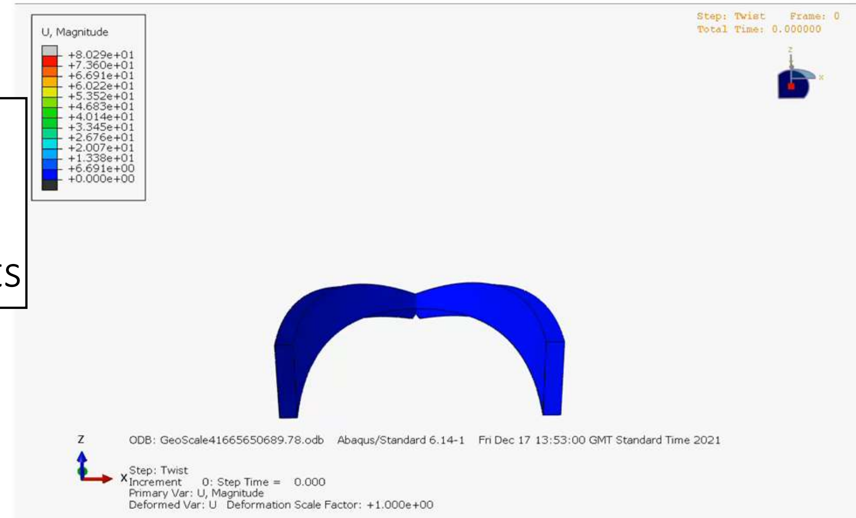
(b) *x-y* view

- Apply actuations at the *end-section*
  - Twist/twist back about the *y* axis
  - Rotation about the *z* axis.

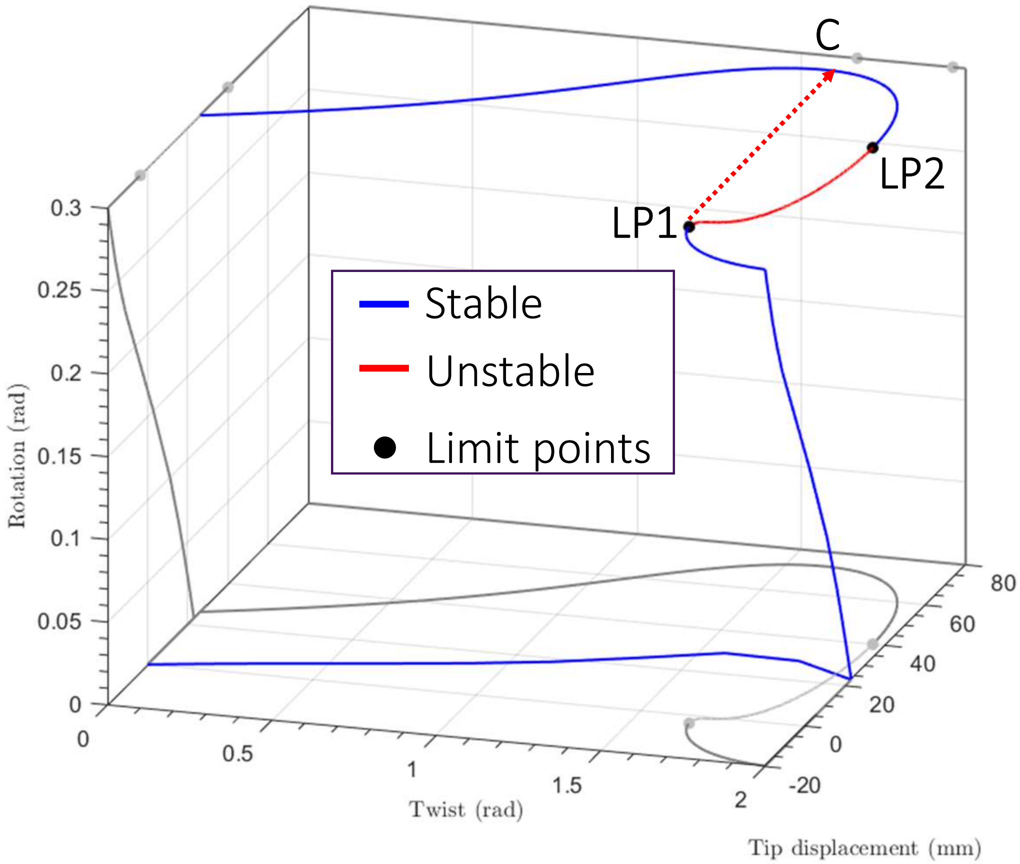
- FE model discretized with shell elements
- Half beak is modelled based on *symmetry* condition
- Generalized path-following solver: Riks solver + *critical points pin-pointing* + tracing critical points w.r.t. the *rotation inputs* efficiently

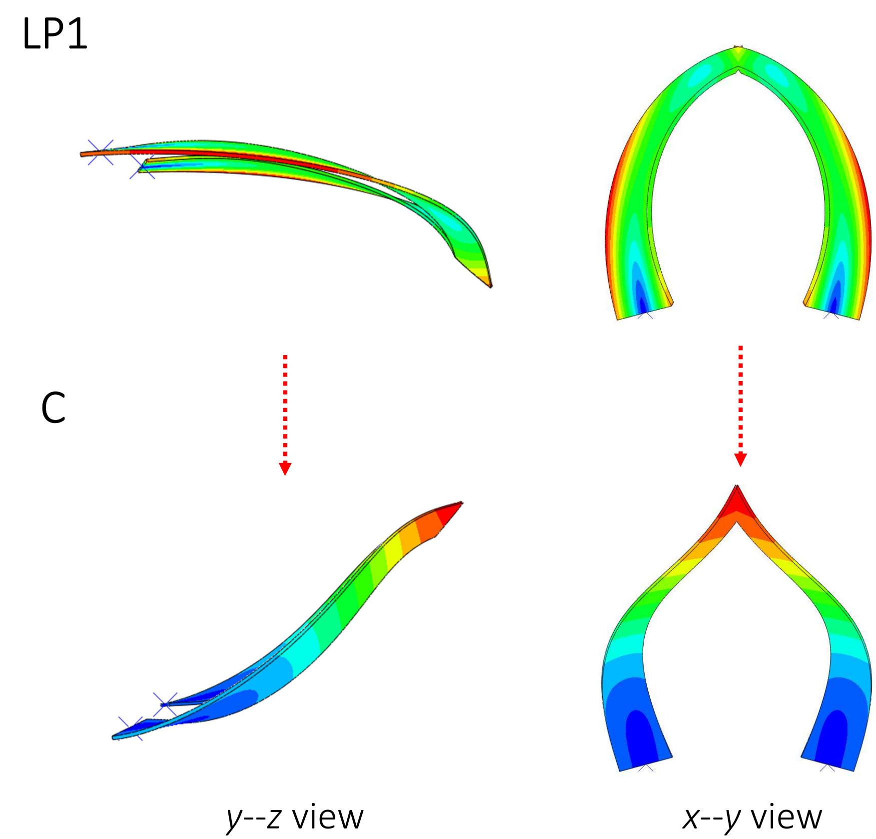
Response of baseline structure—snap-through instability reproduced





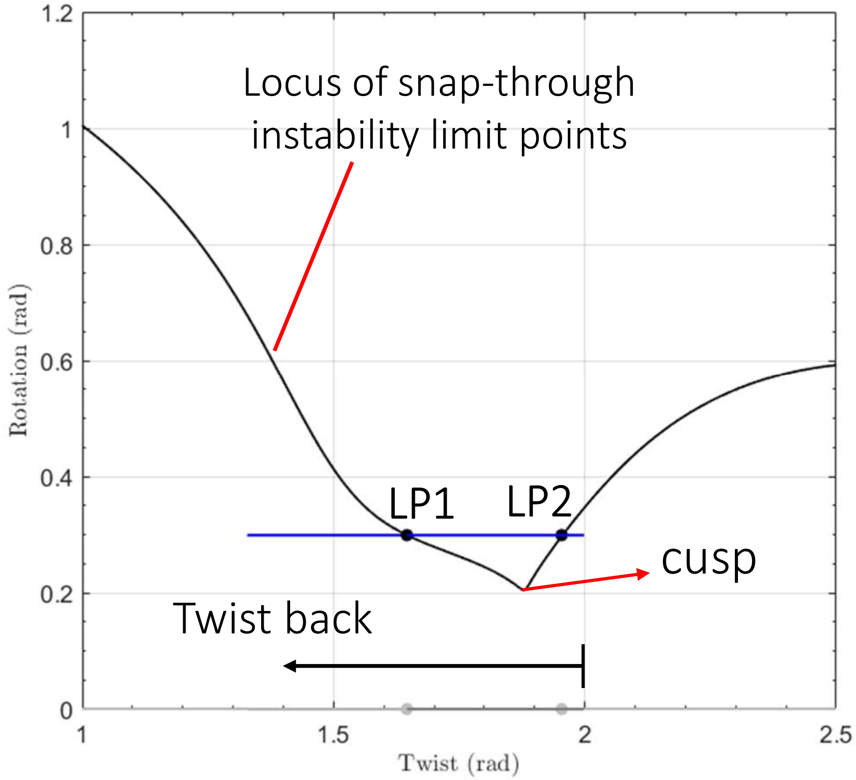
Shape shifting due to snap-through instability





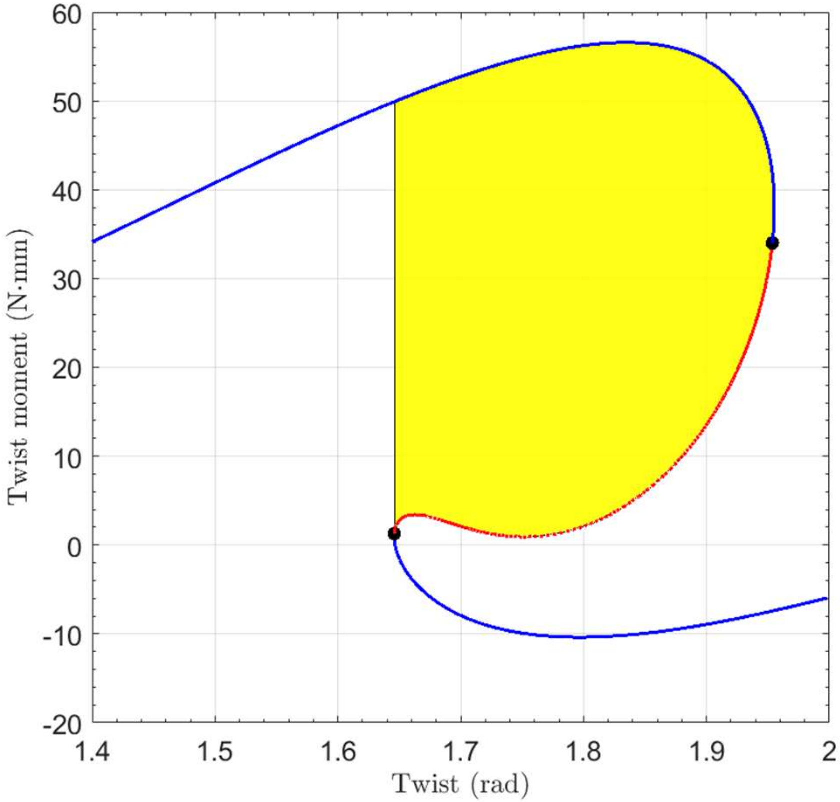
Effects of rotation inputs on the snap-through behaviour

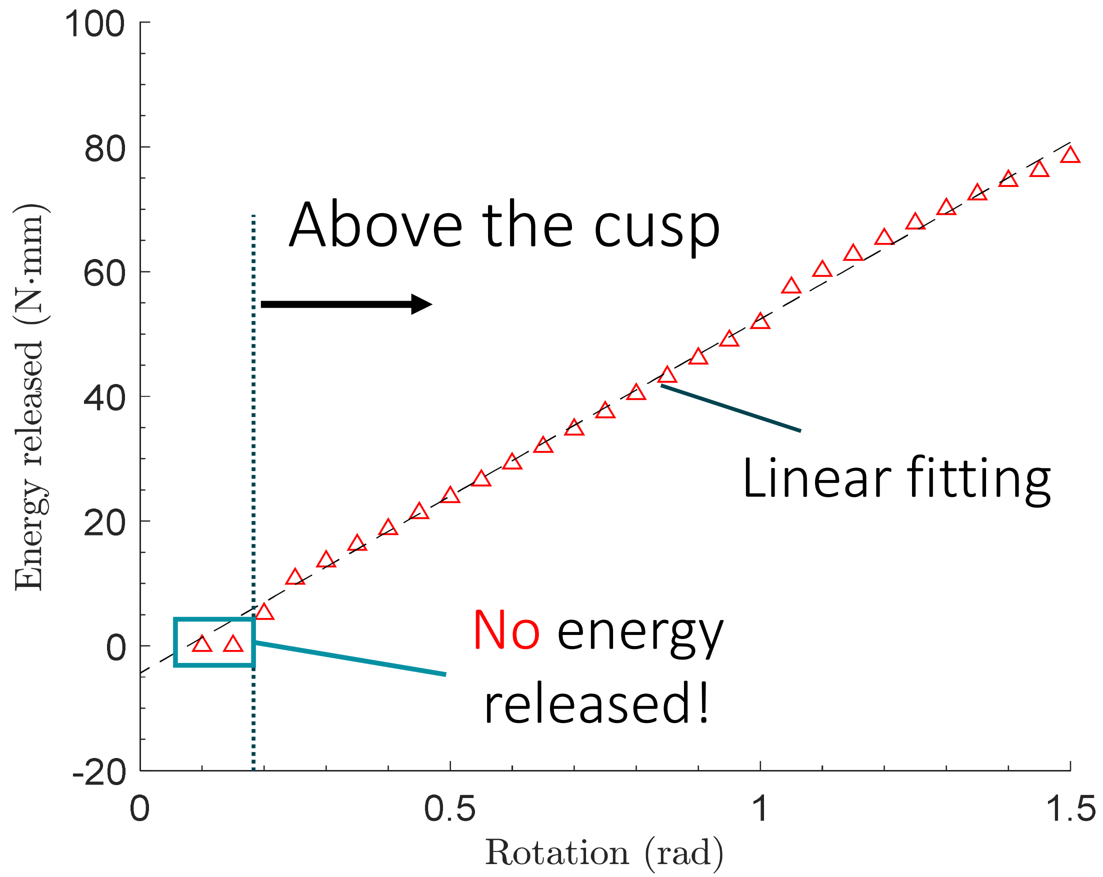
➢ Evolution of the snap-through limit points with varying *rotation* inputs



- When rotation input is below the cusp, there is no snap-through instability.
- Larger twist back is required to trigger the snap-through instability with increasing rotation.

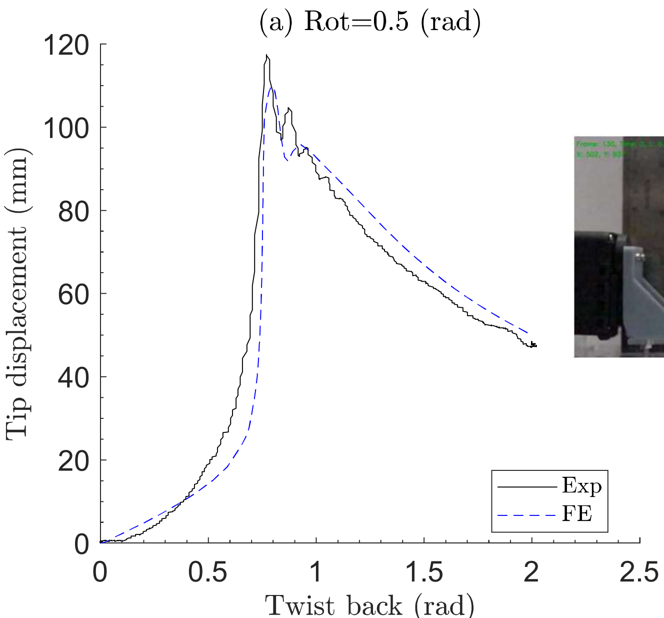
Energy released due to snap-through instability



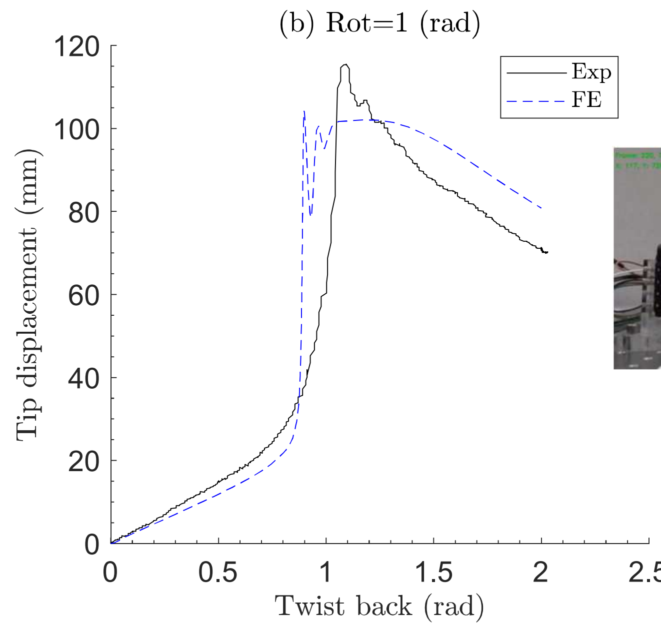


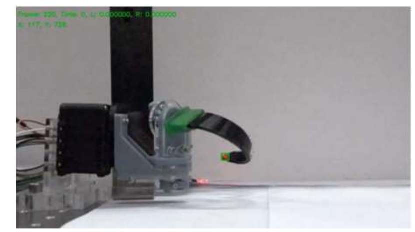
Experimental result and validation of the FE model

- ➢ Rotation: 0.5 rad



- ➢ Rotation: 1.0 rad





- Less than 20 ms to achieve mode shifting for both cases.

  *Camera speed: 1000 fps

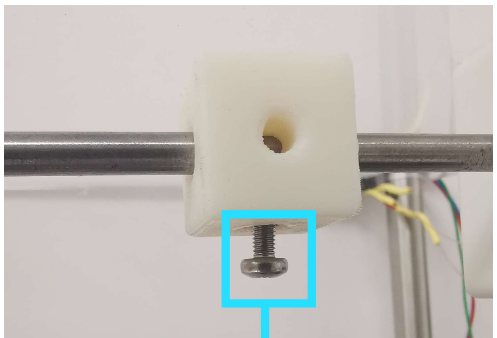
  *Samples are 3D printed using TPU.

Brief summary

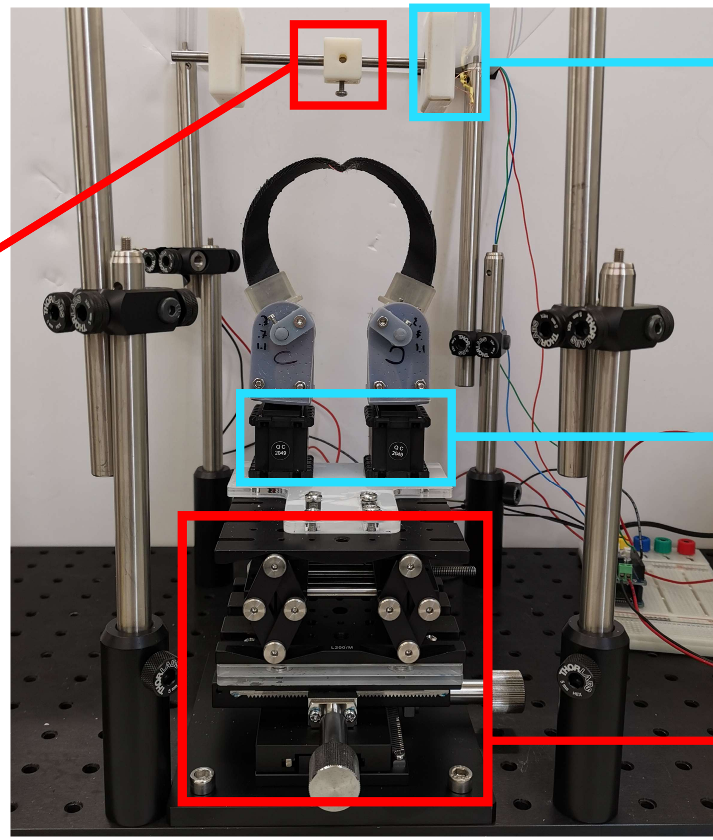
- FE model can capture and unveil the underlying mechanics.
- FE model verified by experiments.
- Compared with simplified model, FE model provides richer information about the beak and can be directly used for the design of soft robot.

Pendulum test to assess the beak performance

Pendulum



Bolt for impact purposes



Rotation sensor

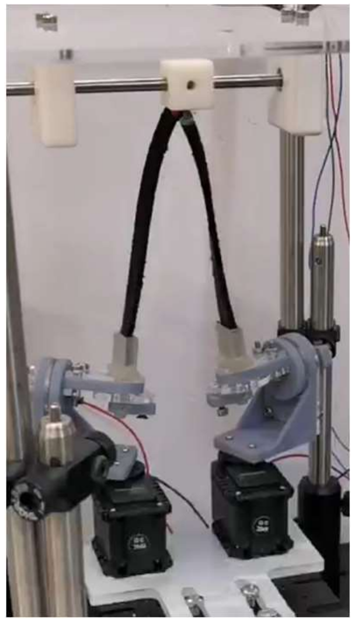
'Twist back' motor

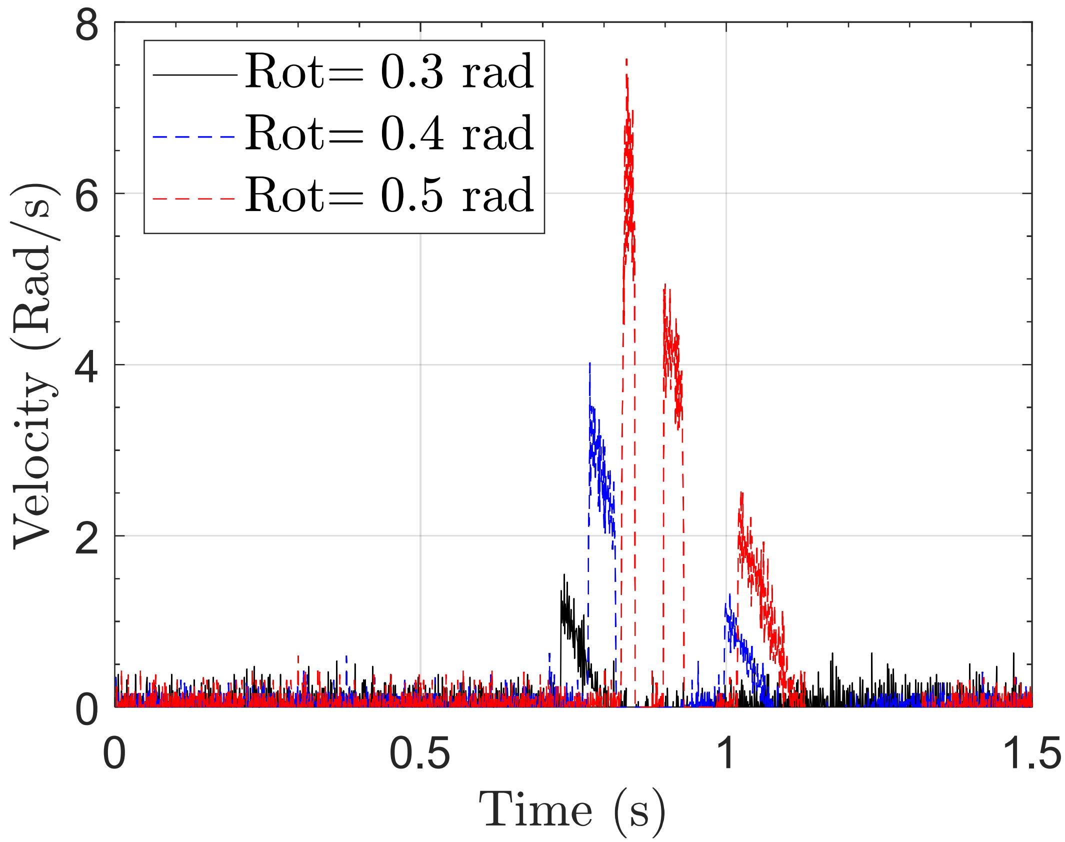
Adjustment base

Pendulum test results

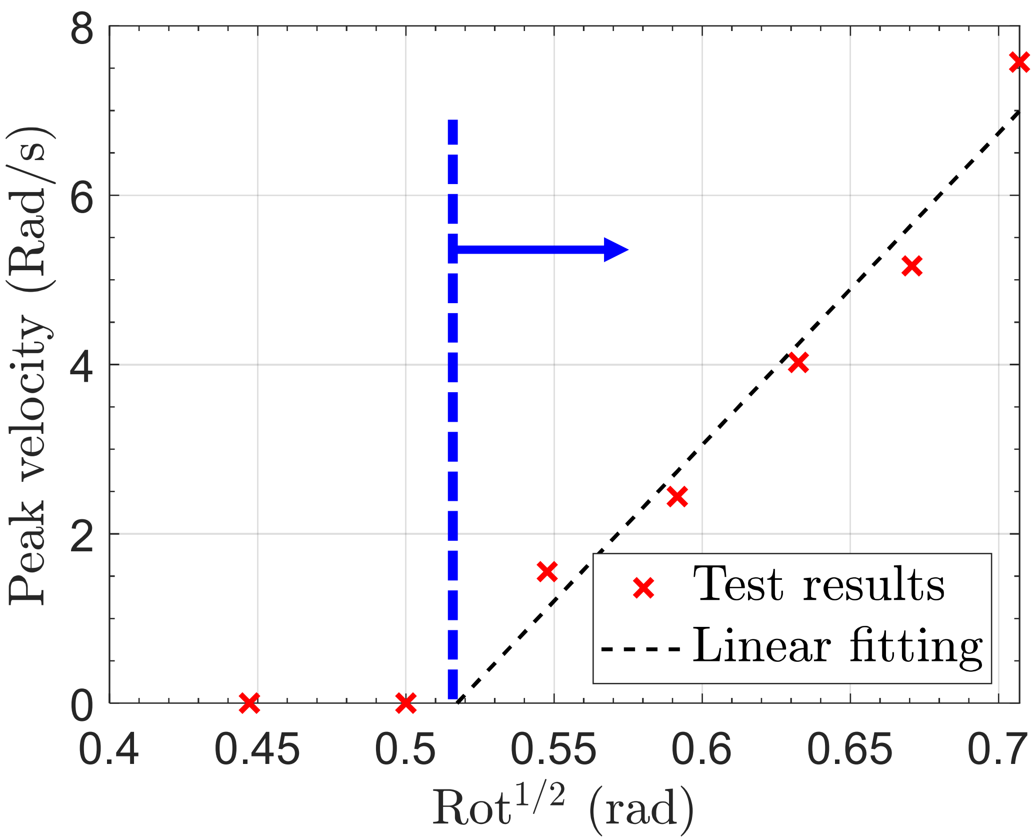
Rotation=0.3 rad

Rotation=0.4 rad





Pendulum test results—peak velocity



- Peak velocity ∝ (Rot)$^{1/2}$ above the threshold
- The response of the beak system can be programmed by adjusting the rotation input.

Concluding remarks

- FE model developed to unveil the effects of actuation inputs on beak mechanics
  - Rotation input is essential to achieve fast response
  - A threshold rotation is required to trigger the snap through
- Demo actuator with its actuation system manufactured and tested.
  - Validate the developed FE model.
  - Fast response speed (less than 20 ms) is observed.
  - Pendulum test to quantify the energy released.

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Thanks for your attention.

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