Key Problems to address:

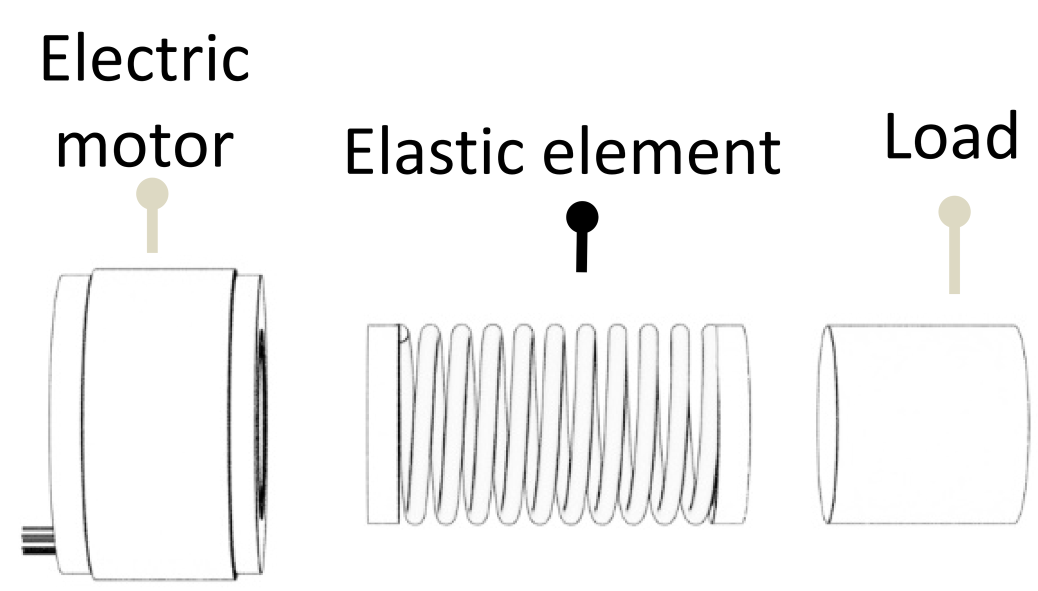
Framework for nonlinear springs acknowledging uncertainty

Achieve global solutions in polynomial-time

Solution independent of initial conditions

Avoid overdesign or underdesign resulting from safety factors

Challenge: Use series elasticity to minimize energy consumption and satisfy actuator constraints despite uncertainty



Series **E**lastic **A**ctuator (**SEA**)

Scientific Impact:

Formulate spring design of SEAs as a convex program

Framework to guarantee performance in uncertain environments

Bridge robust optimization and mechatronic design

Robust Semidefinite Optimization

Cost: Motor energy consumption

α: Spring compliance vector

$$\begin{aligned} \underset{\alpha}{\text{minimize}} \quad & \frac{1}{2}\alpha^T \boldsymbol{G}\alpha + \boldsymbol{h}^T\alpha + w \\ \text{subject to} \quad & \alpha^T \boldsymbol{Q}_i \alpha + \boldsymbol{q}_i^T \alpha \le r_i, \; i = 1, \dots, l \\ & \boldsymbol{M}\alpha \le \boldsymbol{p}, \; \forall \{\boldsymbol{M}, \boldsymbol{p}, \boldsymbol{Q}_i, \boldsymbol{q}_i, r_i\} \in \mathcal{U} \end{aligned}$$

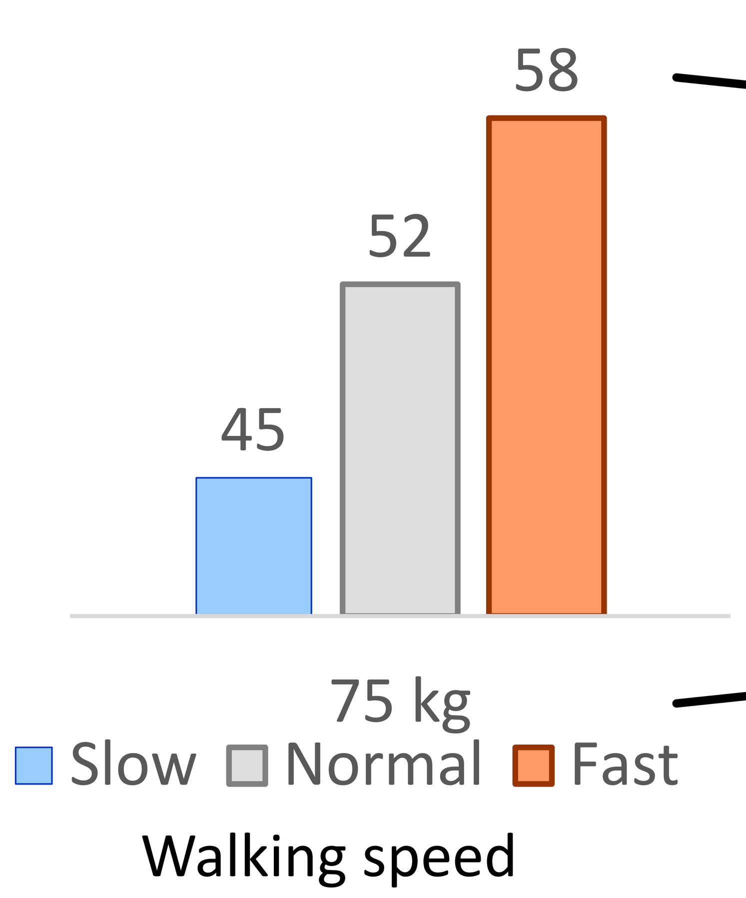
Uncertain Quadratic Constraints

Current, voltage, and mechanical deflection limits across multiple walking behaviors with imperfect modelling

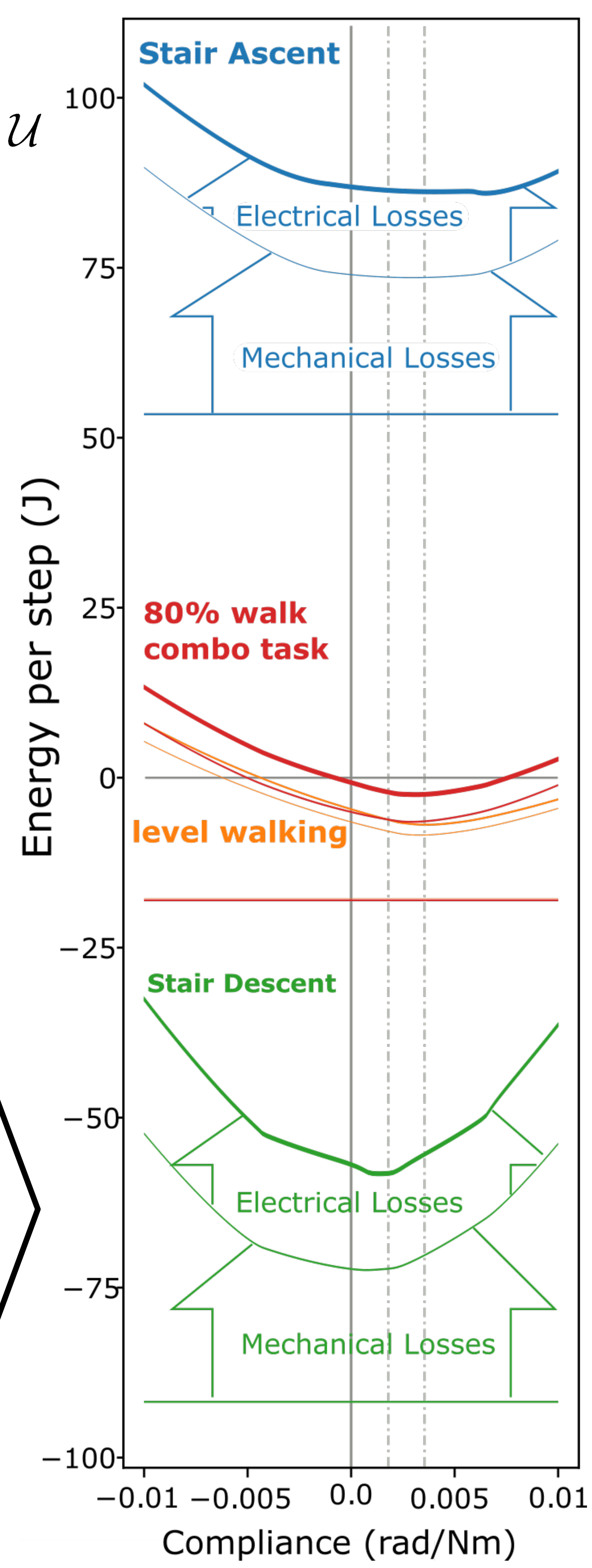
SEA Energy Reduction Lower for Low Gear-Ratio Actuators

% Reduction, 700:1 Actuator

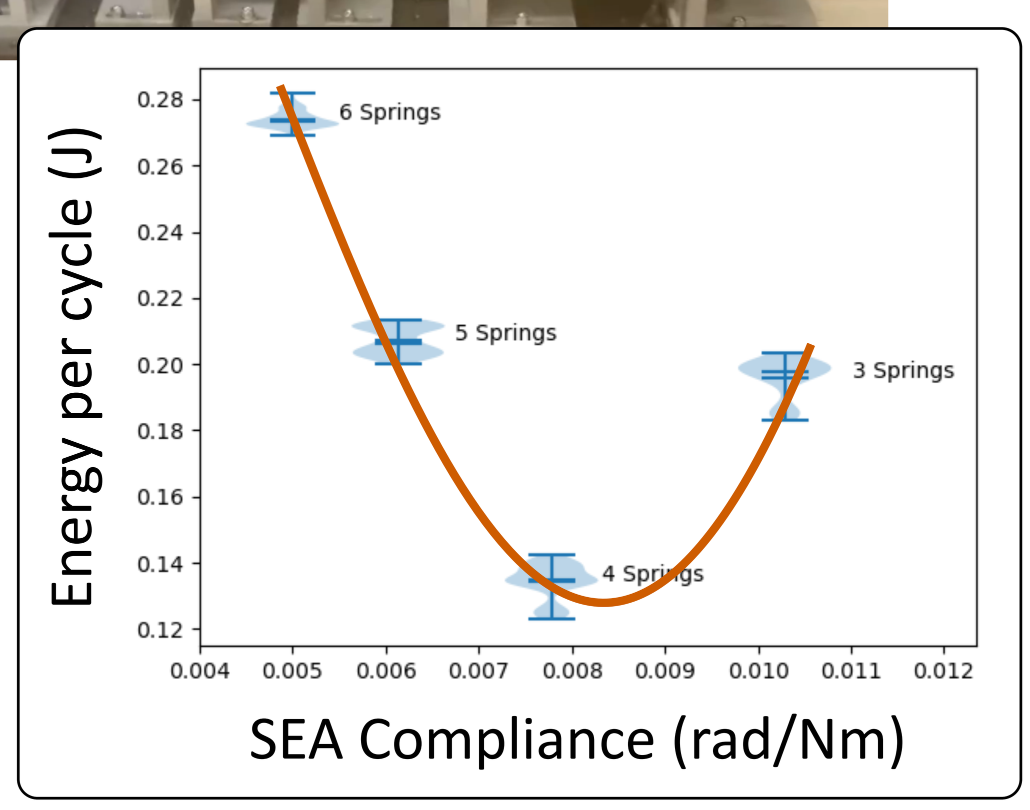
Move to 50:1 Actuator

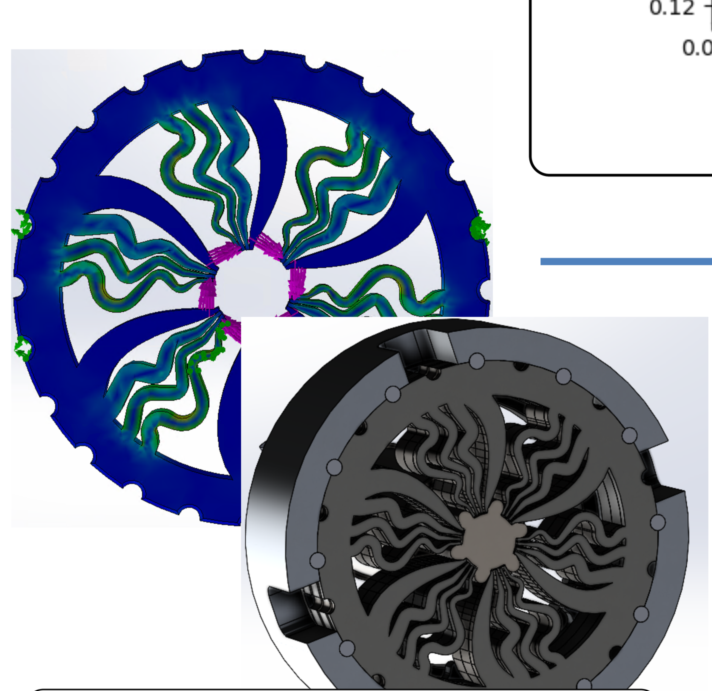


Anticipated Curves for the NSF-Funded Open-Source Leg Prosthesis



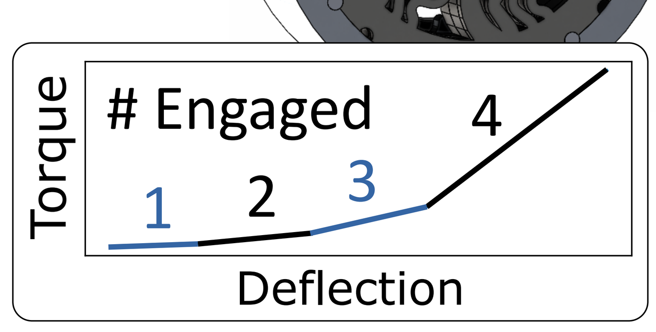
Experimental Validation of Convexity





Stiffening Springs

Flexure-flexure collisions enable stiffness increases. Optimization over non-linear spring profiles



Outreach

Award ID#:
1953908, 1830338

UNIVERSITY of DENVER