

Motivation

Fixed wing UAS are being increasingly utilized in different scenarios. The problem is that fixed wings that are optimized for one condition are non optimal for other flight conditions. The SMSDL lab has a new concept for a morphing wing that has ligatures and preloaded by springs. These ligatures can be actuated in flight to change the load bearing and shape of the wing. This would enable the ability to change the fixed wing configuration given a flight mission.



Raven UAV in flight

Overview

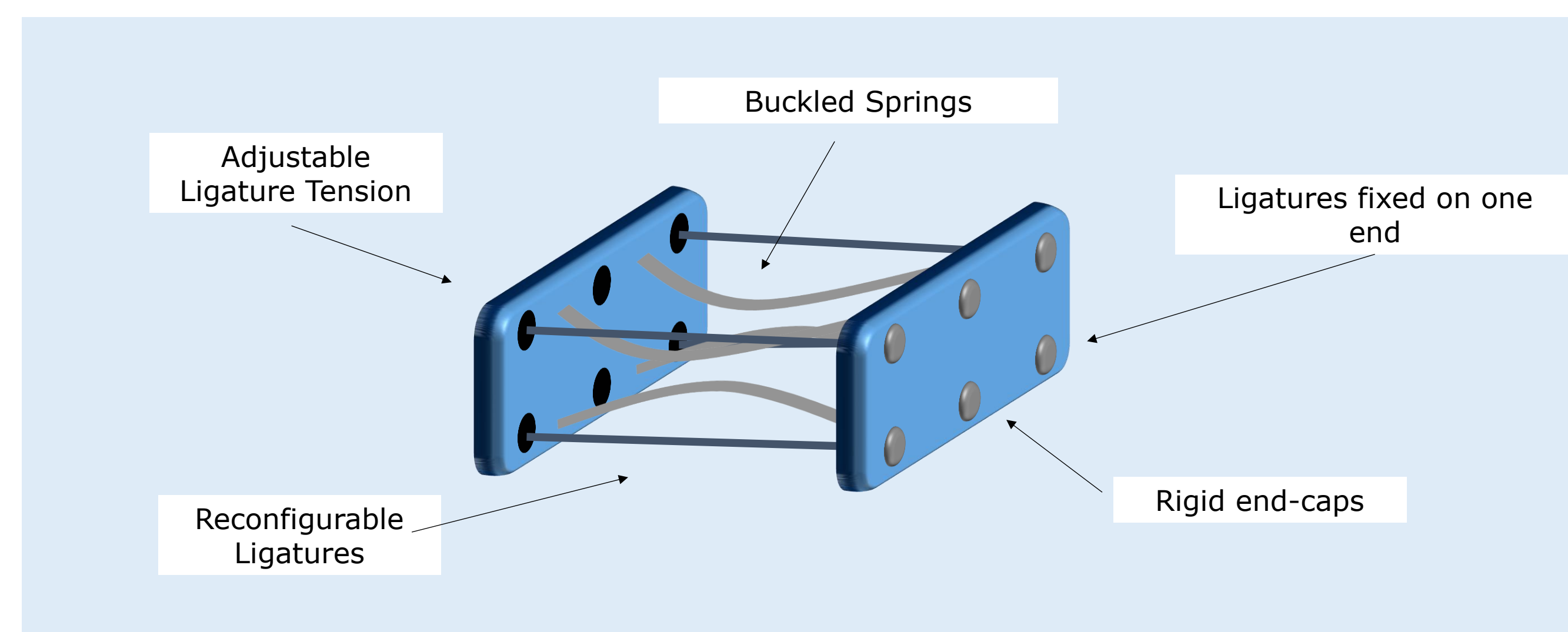
Goal: Study how different ligature configurations and preloads change the x-axis torsion, y-axis torsion, and z-axis translation load response.

Objectives:

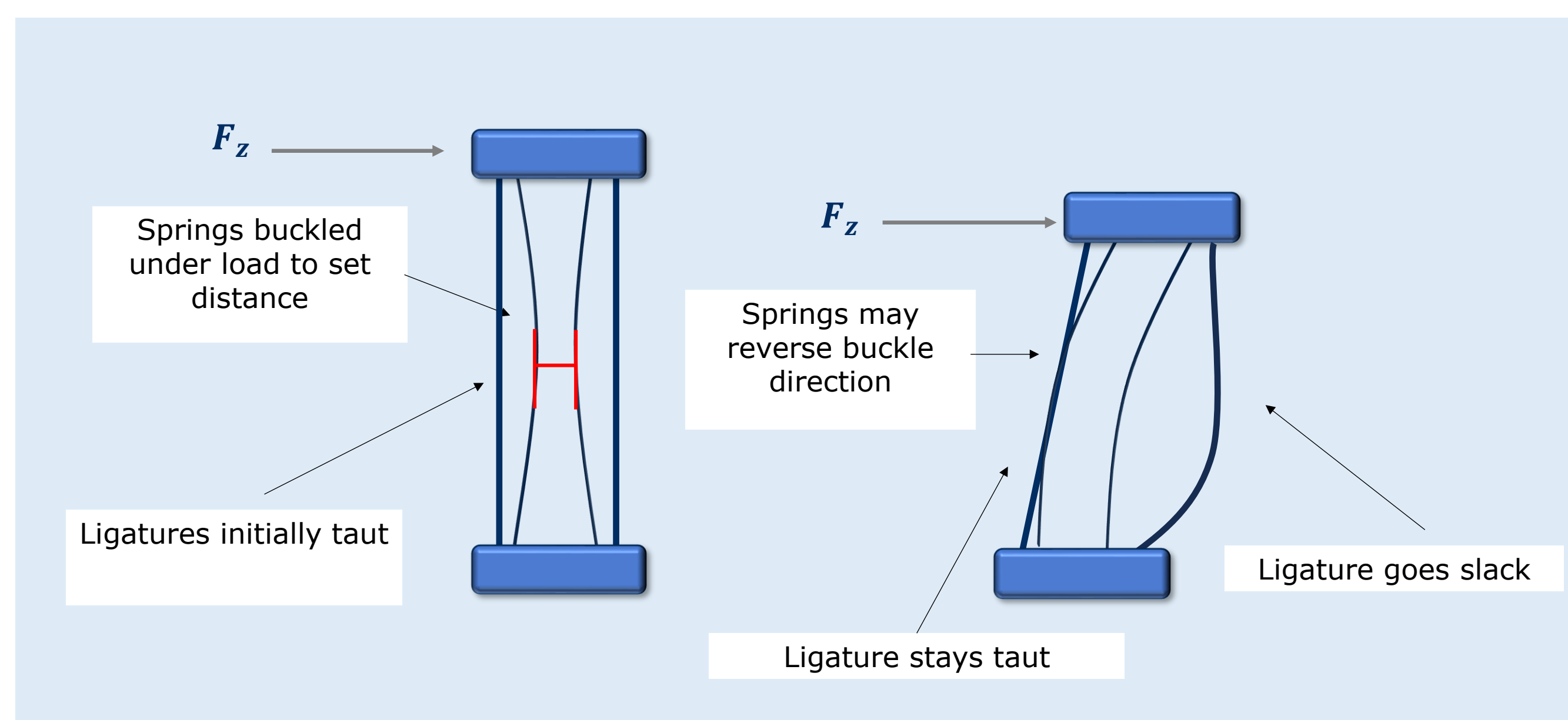
- Design a testable spanwise wing demonstration article
- Conduct an analytical model analysis of key configurations to understand constrained degrees of freedom
- Develop a reconfigurable test article and experimental lab setup and procedures
- Experimentally test and analyze x-axis torsion, y-axis torsion, and z-axis translation response
- Demonstrate ability of different configurations to allow ligature-driven twist morphing

Spanwise Ligature Concept

Architecture:



Operation:



Configuration Modeling

Kinematic Constraint Model

$$l_i^T(v + \omega \times r_i) = 0 \quad l_i^T(r_i \times l_i^T) \begin{bmatrix} v \\ \omega \end{bmatrix} = 0 \quad V = \begin{bmatrix} v_x \\ v_y \\ v_z \\ \omega_x \\ \omega_y \\ \omega_z \end{bmatrix} \quad CV = 0$$

No motion along tendon direction Each tendon contributes one row to constraint matrix

Example Configuration:

Center Cross

$$C = \begin{bmatrix} 0 & 1 & 0 & -0.75 & 0 & 2.5 \\ 0 & 1 & 0 & 0.75 & 0 & 2.5 \\ 0 & 1 & 0 & -0.75 & 0 & -2.5 \\ 0 & 1 & 0 & 0.75 & 0 & -2.5 \\ 0 & 0.9744 & 0.2249 & 0.7308 & 0 & 0 \\ 0 & 0.9744 & -0.2249 & -0.7308 & 0 & 0 \end{bmatrix}$$

Constraints along tendon length and rotational contribution

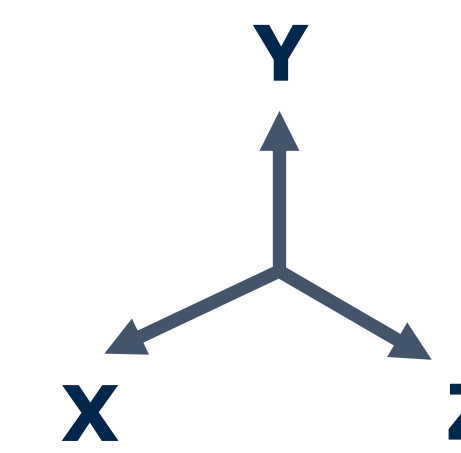
$$C_{red} = \begin{bmatrix} 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

Motion is constrained in y, z, rx, rz directions

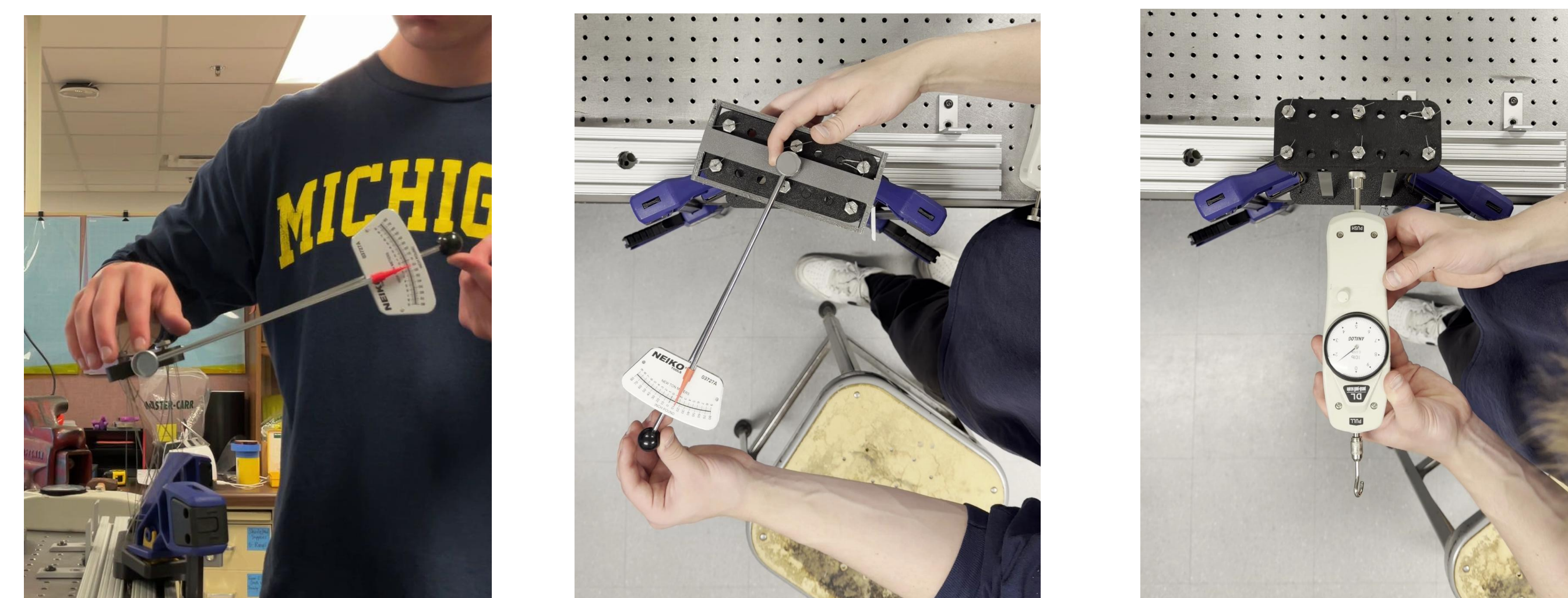
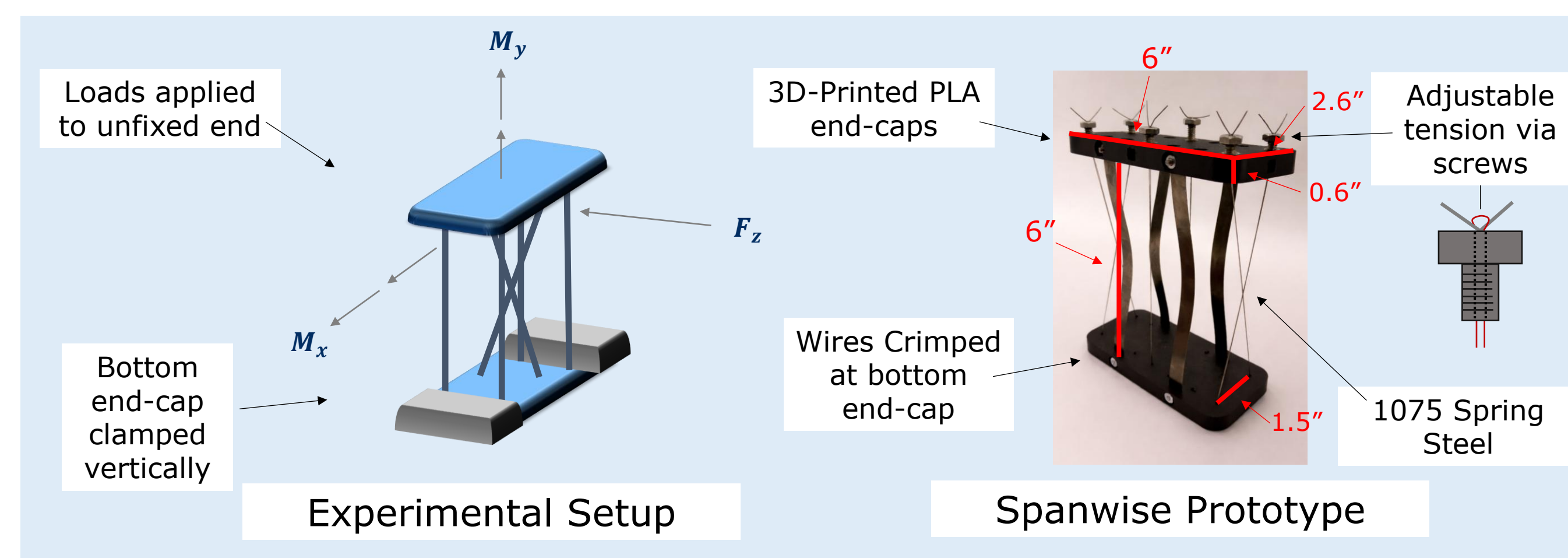
Configuration Comparison

Constrains	Straight	Center Cross	Side Cross
(x)	x	x	x
y	x	x	x
z		x	x
rx	x	x	x
ry			x
rz	x	x	x

Due to geometry of the springs, all configurations constrain x implicitly



Experimental Characterization



Rotation About x-axis (Bending)

Rotation About y-axis (Twist)

Translation in z-axis

Procedure:

- Airfoil facing upward, springs buckled to one of two preset deflections
- Apply load using force gauge for push/pull or torque gauge for top/depth torsion
- Increase load gradually until a tendon becomes slack
- Record response and repeat for all four experiment types and both spring deflections

Experimental Results

Effect of Axial buckling force

- Wide and short spring deflections demonstrate similar shaped responses.
- Reached failure at the same force but the more buckled springs had more translation to get there



Axial test measured similar loads for the different buckling presets

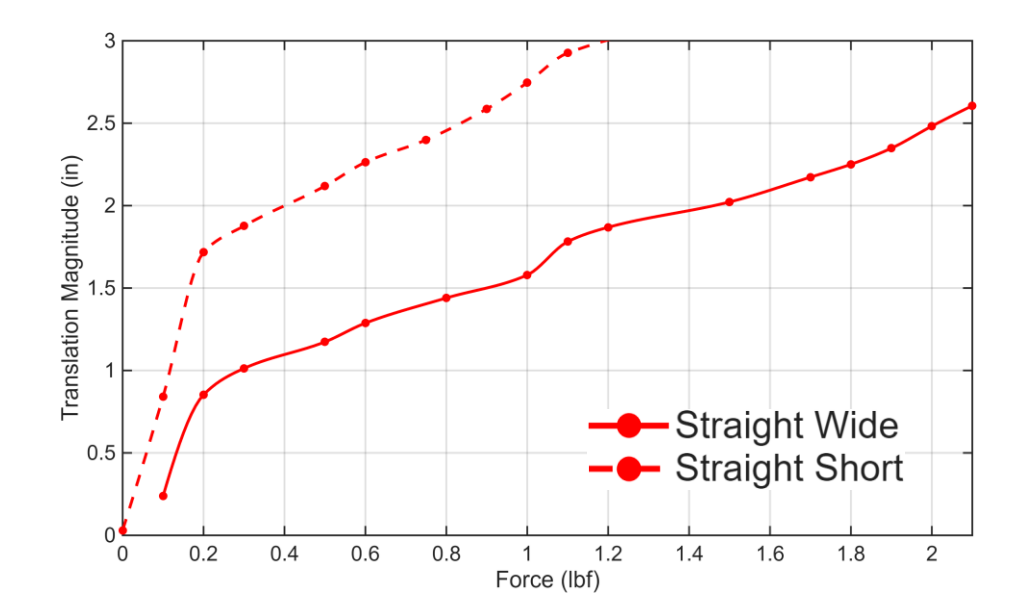


Figure 1: z-axis Response Straight Comparison

Configuration Comparison Load-Bearing Results:

Configuration	F_z^{max} (lbf)	M_x^{max} (lbf-in)	M_y^{max} (lbf-in)
Straight	0	8.25000	0
Center Cross	1.26945	8.25000	0
Side Cross	1.26945	8.25000	6.34555

Equilibrium equation with non-negative constraint on ligature tension

Model Predictions for Load-Bearing Capacities

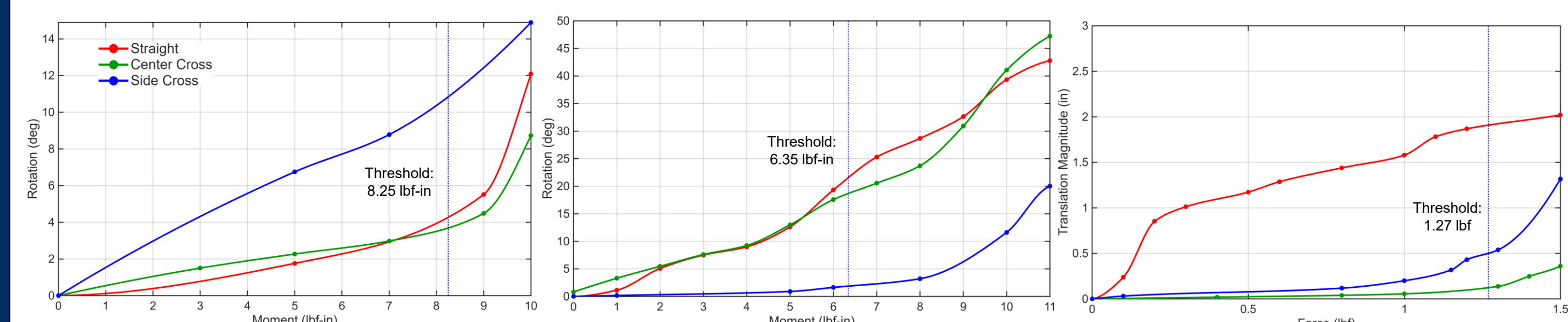


Figure 2: x-axis Rotation Comparisons

Figure 3: y-axis Rotation Comparisons

Figure 4: z-axis Response Comparisons

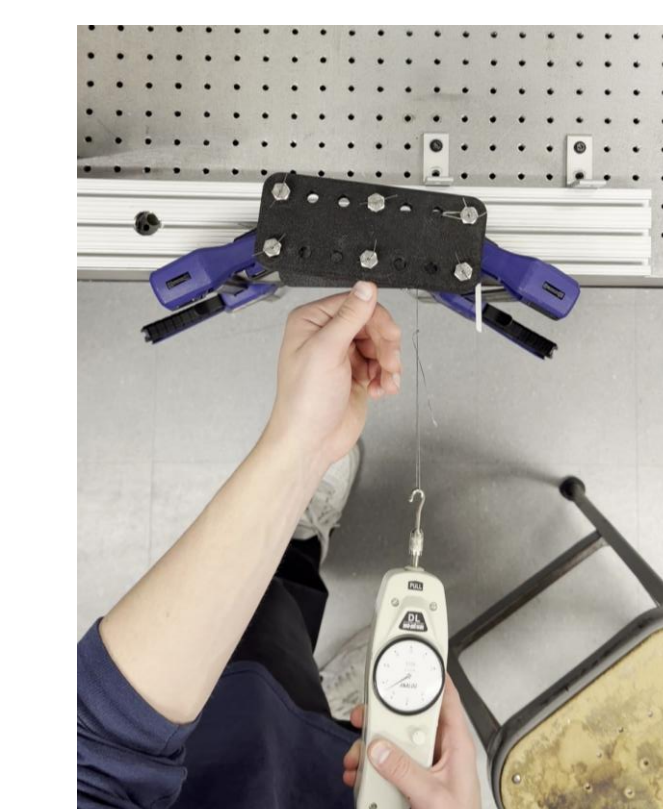
All restrict rx matching threshold, but Side Cross had experimental error

Only Side Cross restricted y-axis torsion: matched predicted threshold

Straight configuration allowed free motion, others matched predicted threshold

Ligature-Driven Twist Morphing Test

- Twist morphing enables aircraft control
- Ability to twist using driving ligature depends on configuration constraints
- Tests confirm free morphing motion for unconstrained configurations



Pull force actuating y-axis rotation

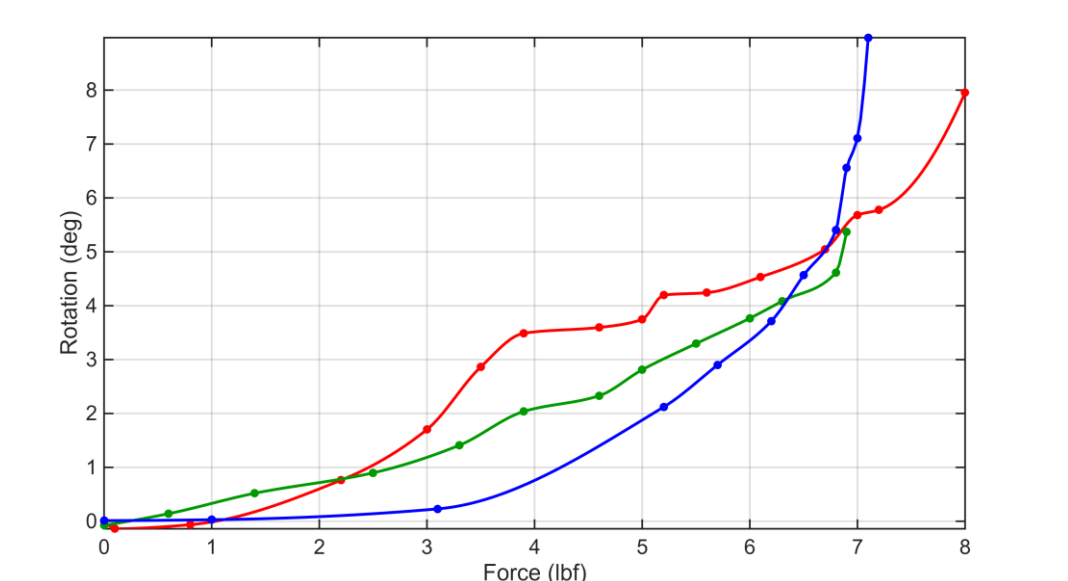


Figure 5: Force actuated y-axis rotation

Conclusion

- Spanwise ligature concept enables tailorable constraints for structural support while allowing morphing motions
- Kinematic model enables analysis of constraints
- Adjustable prototype allows testing of multiple configurations of load bearing
- Load bearing of 3 configurations in matches model predictions
- Driving ligatures effectively induce twist for unconstrained rotation

Acknowledgements

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