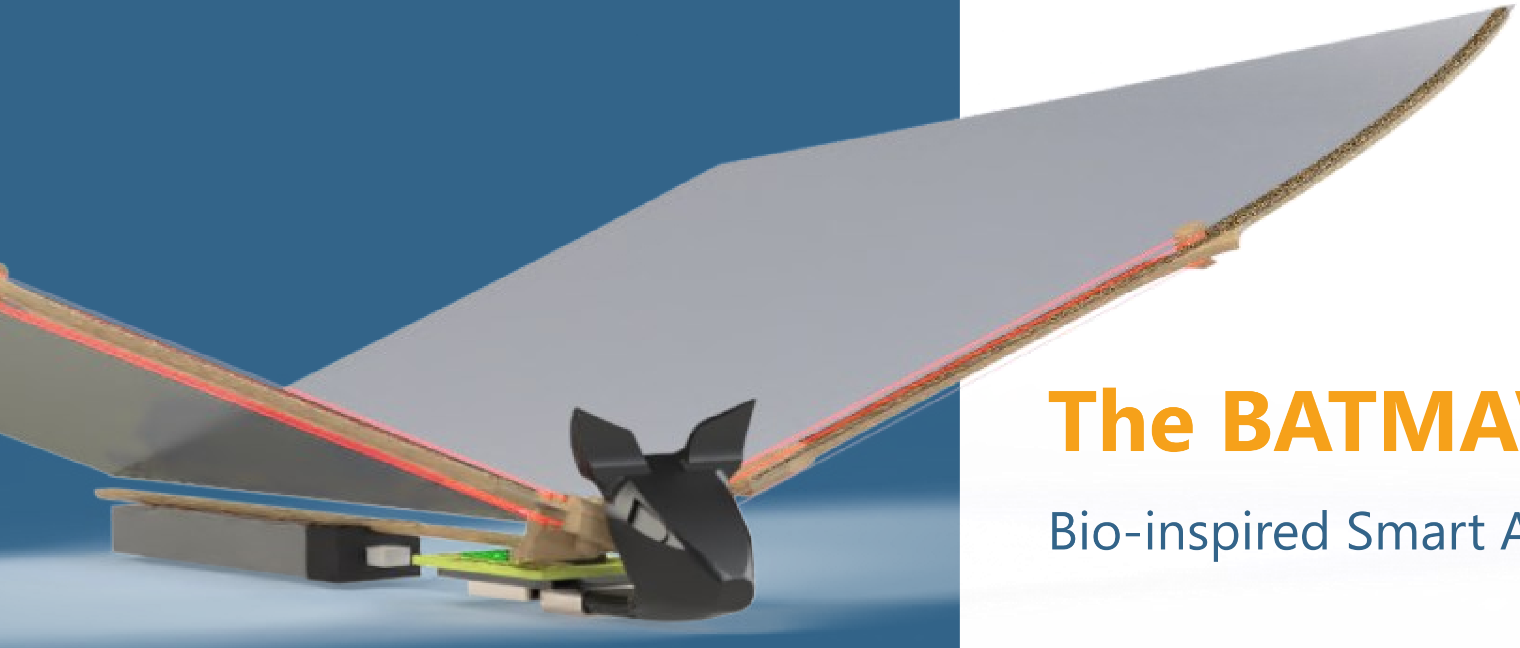


The BATMAV Project

Bio-inspired Smart Actuated Micro-size Air Vehicle

Wiss. Mitarb. ***Domenico Bevilacqua***

Prof. Dr.-Ing. ***Stefan Seelecke***

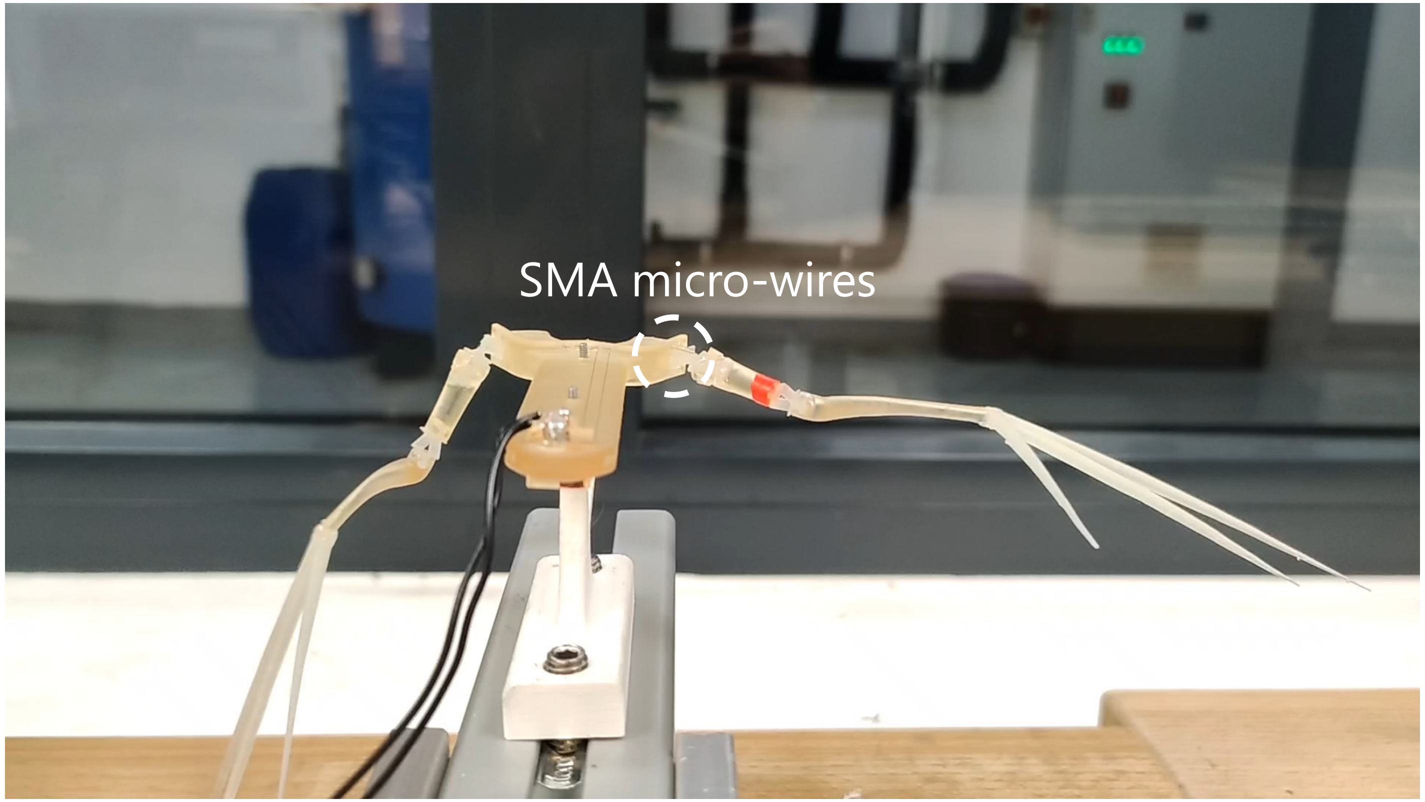
Intelligent Material Systems Lab (iMSL)
Saarland University, Saarbrücken, Germany

Flapping Mechanism – Motor Actuation

Limitations:

- Gearbox and Motor Weigth
- Reduced D.O.F. (wings are jointed)
- Easy Breakability

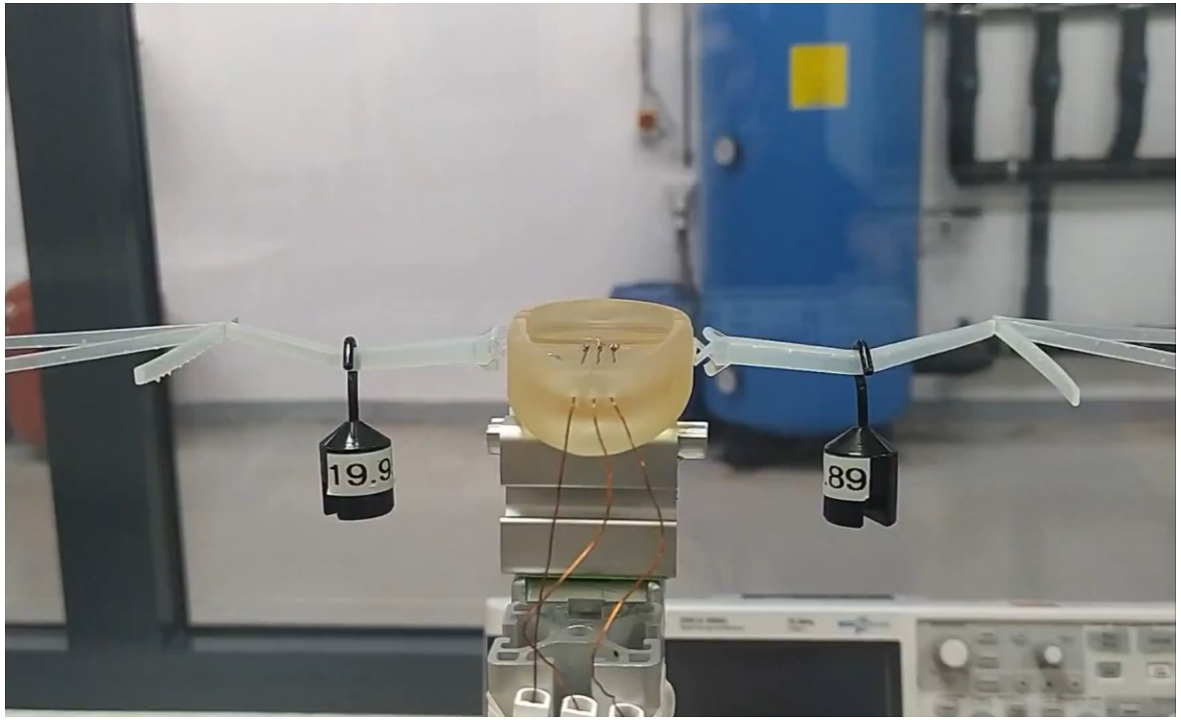
Flapping Mechanism – SMA Actuation



Advantages:

- **High Volume-Force Ratio**
- **Negligible Actuator Weight**
- Freedom Movement (wings are actuated independently)
- Resistant to Bending

Flapping Mechanism – SMA Actuation

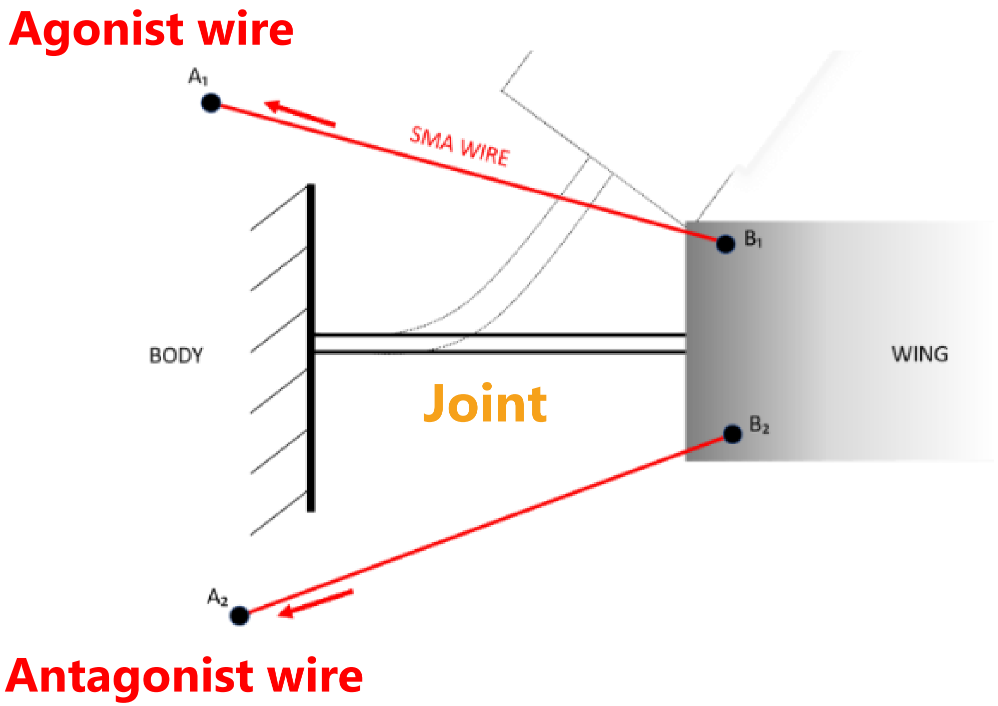


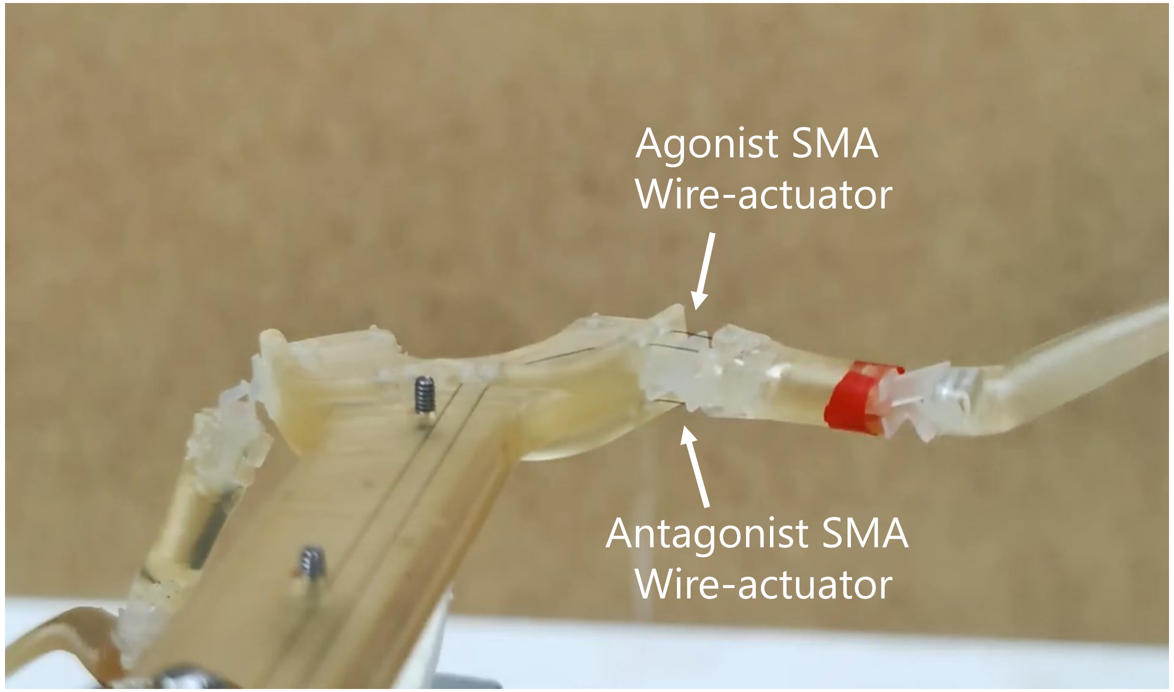
Challeges:

- Low Strain Ratio
- Low Actuation Frequency
- Low Energy Efficiency

Can we overcome these with some **smart design ideas**?

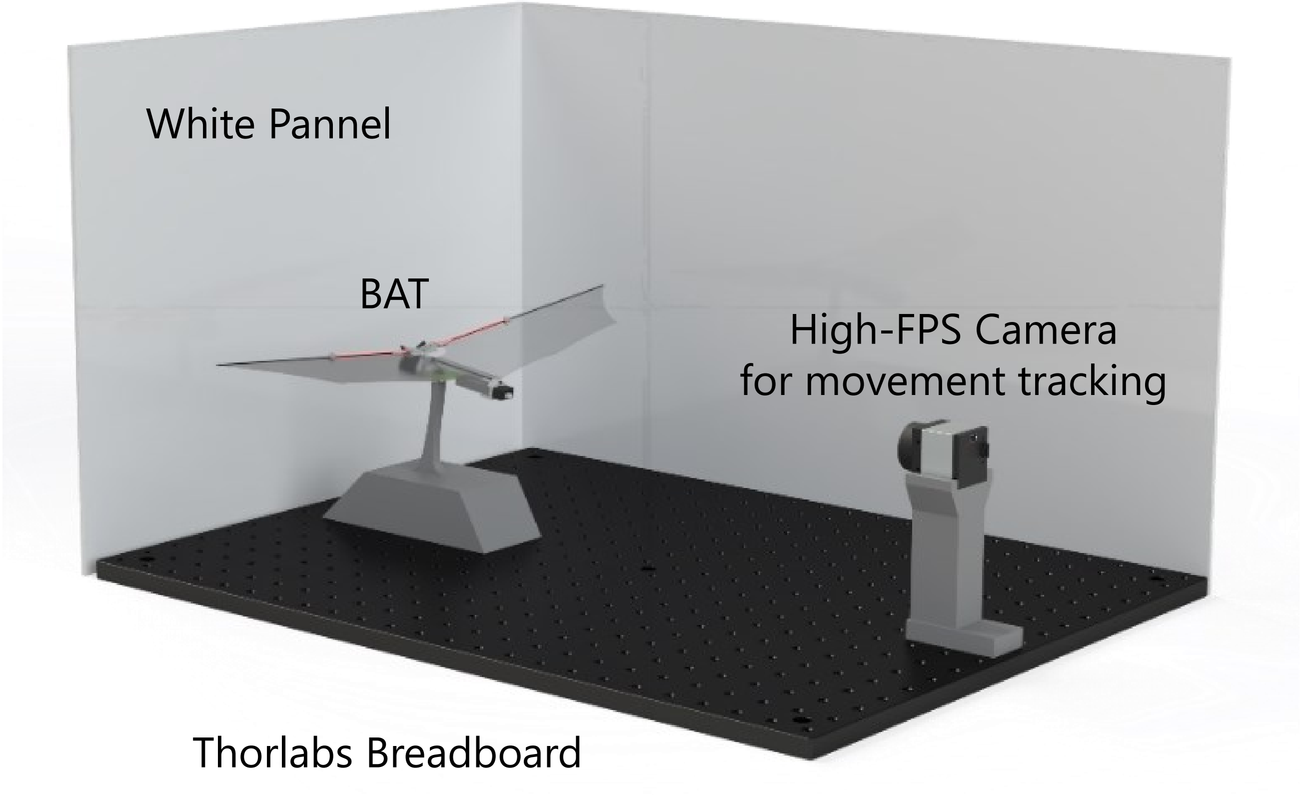
1. Agonist-Antagonist SMA
Design





1. Agonist-Antagonist SMA

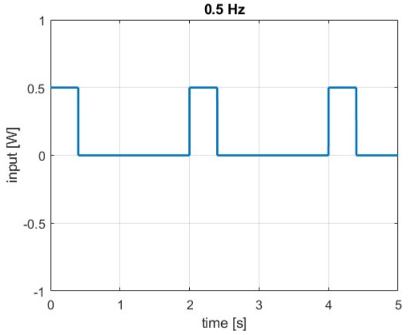
Experimental Setup

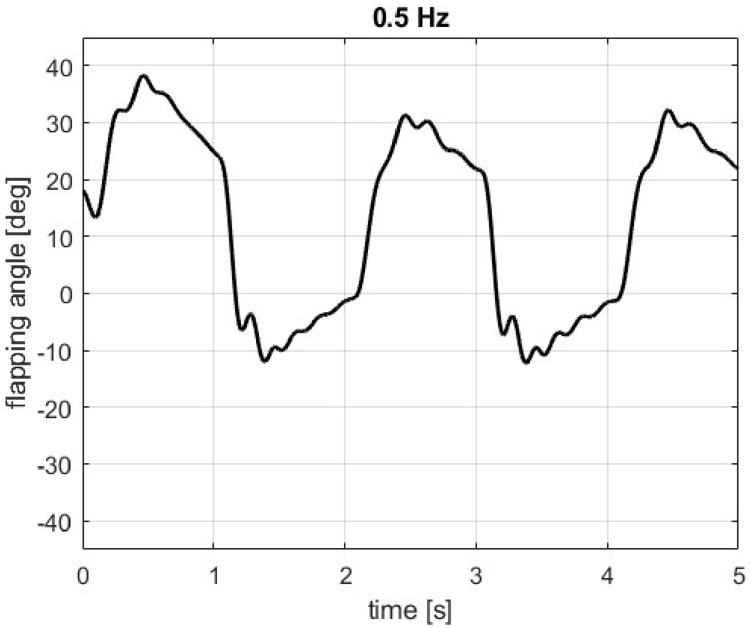


1. Agonist-Antagonist SMA

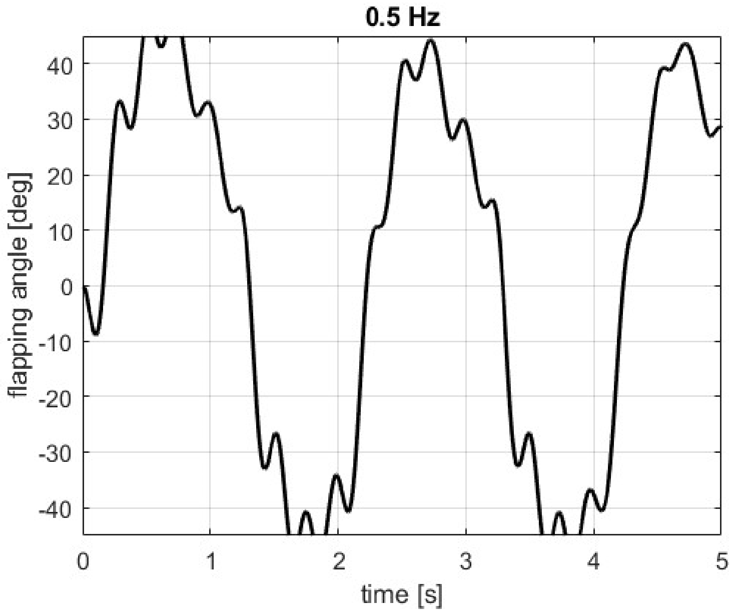
Performances

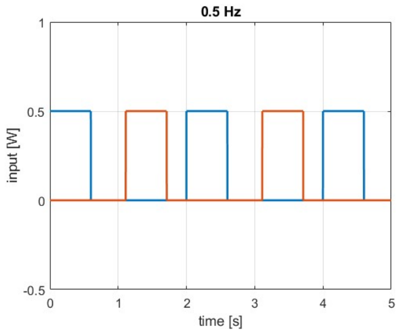
Single-wire





Agonist-Antagonist





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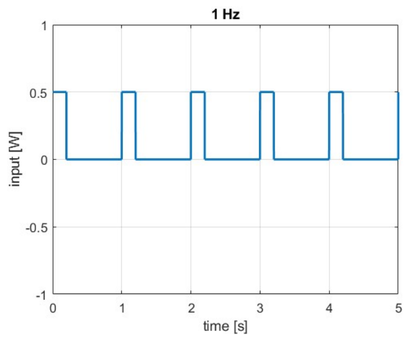
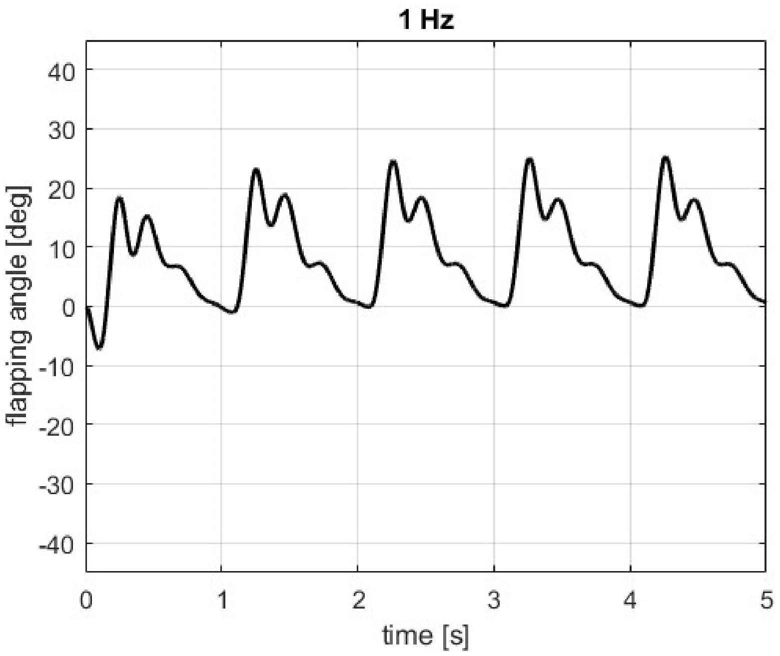
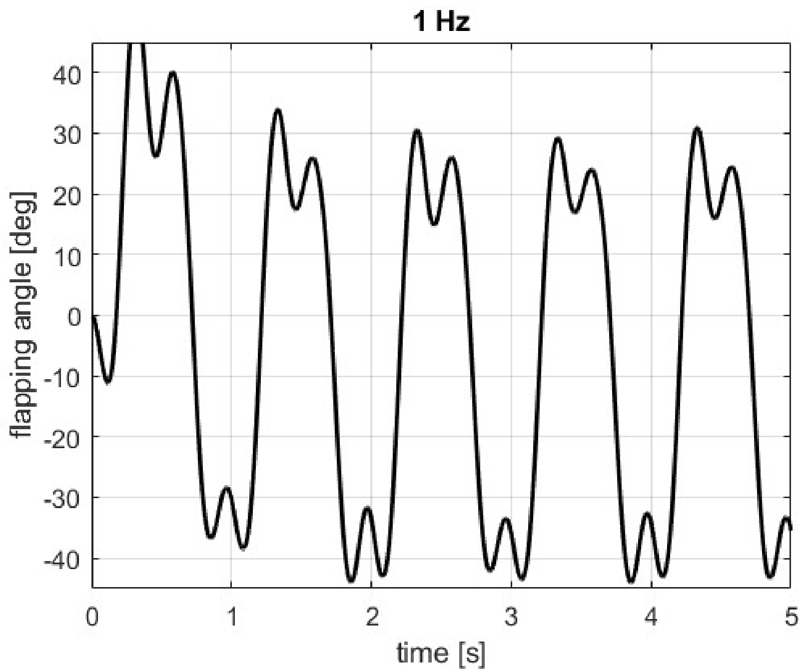
Performances

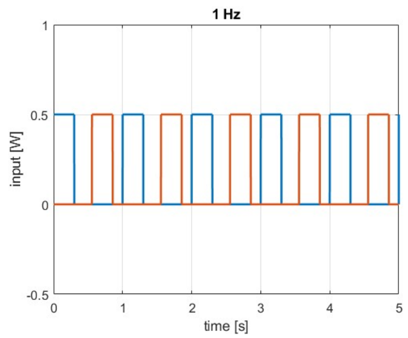
Single-wire





Agonist-Antagonist

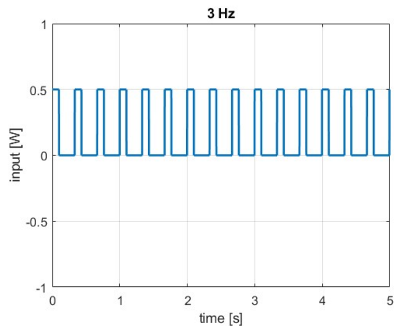


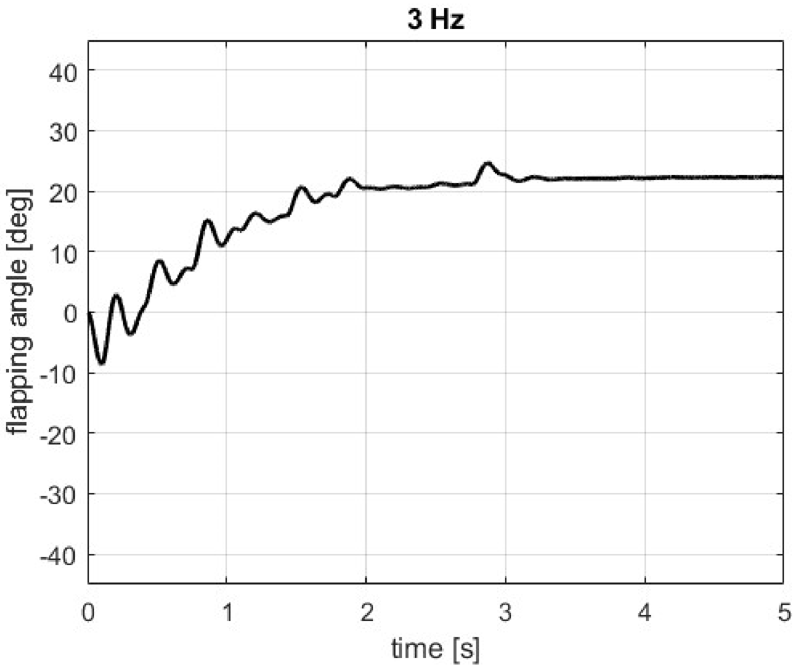


1. Agonist-Antagonist SMA

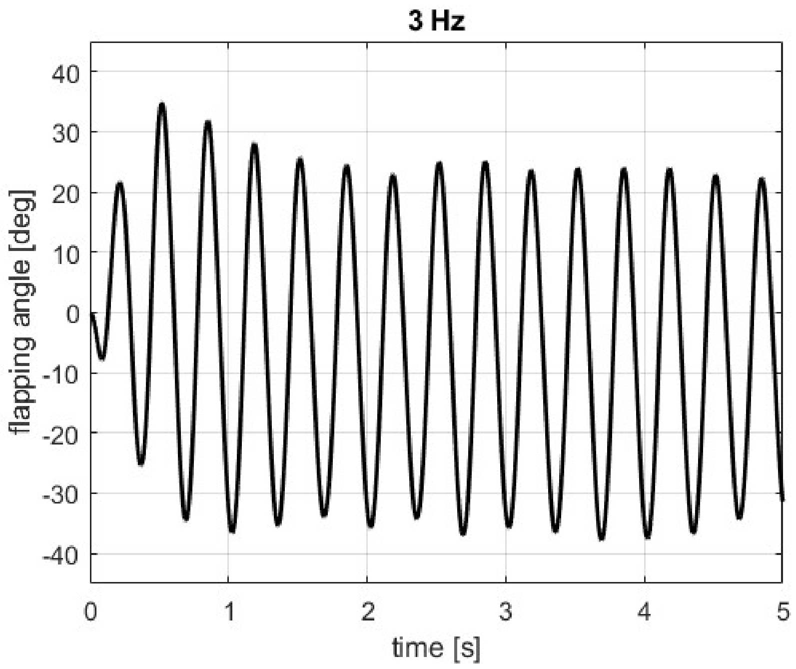
Performances

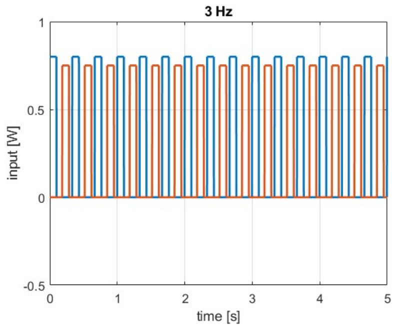
Single-wire





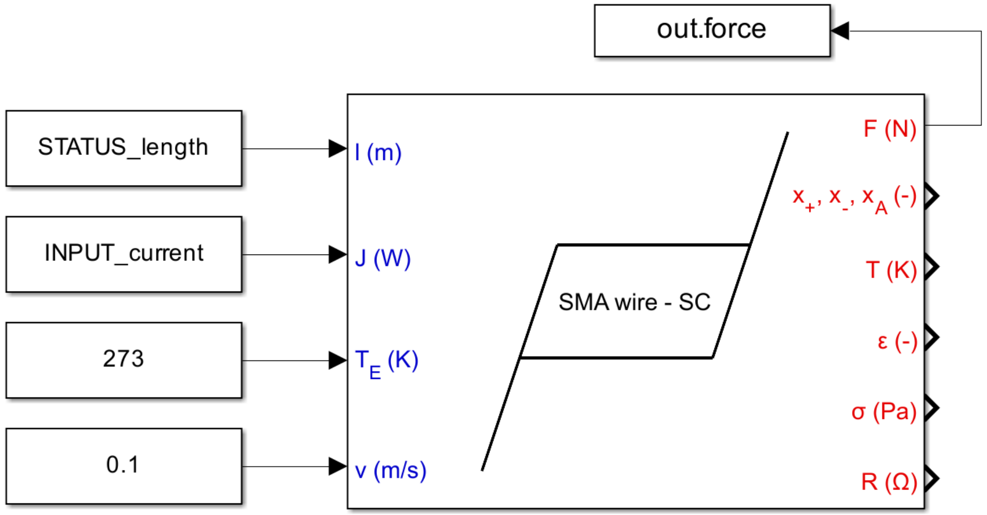
Agonist-Antagonist

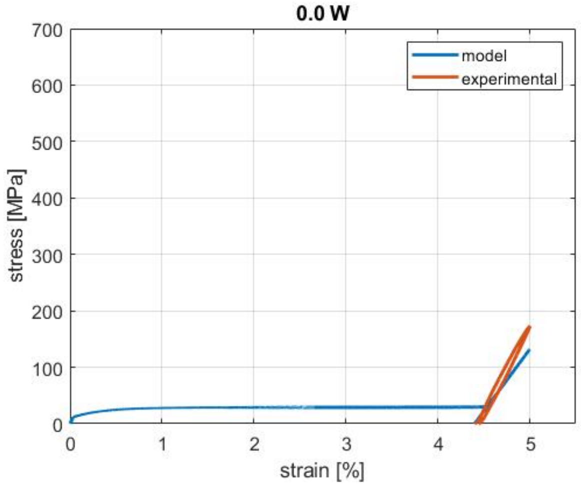


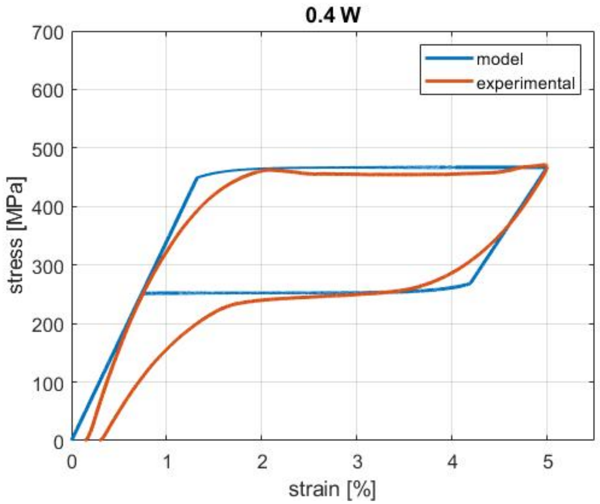


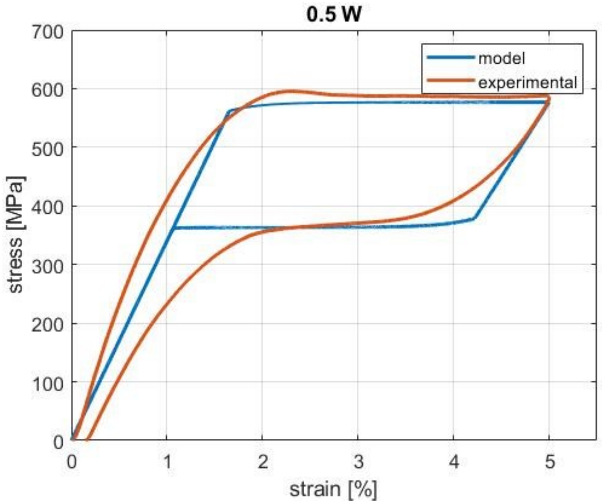
1. Agonist-Antagonist SMA

Model









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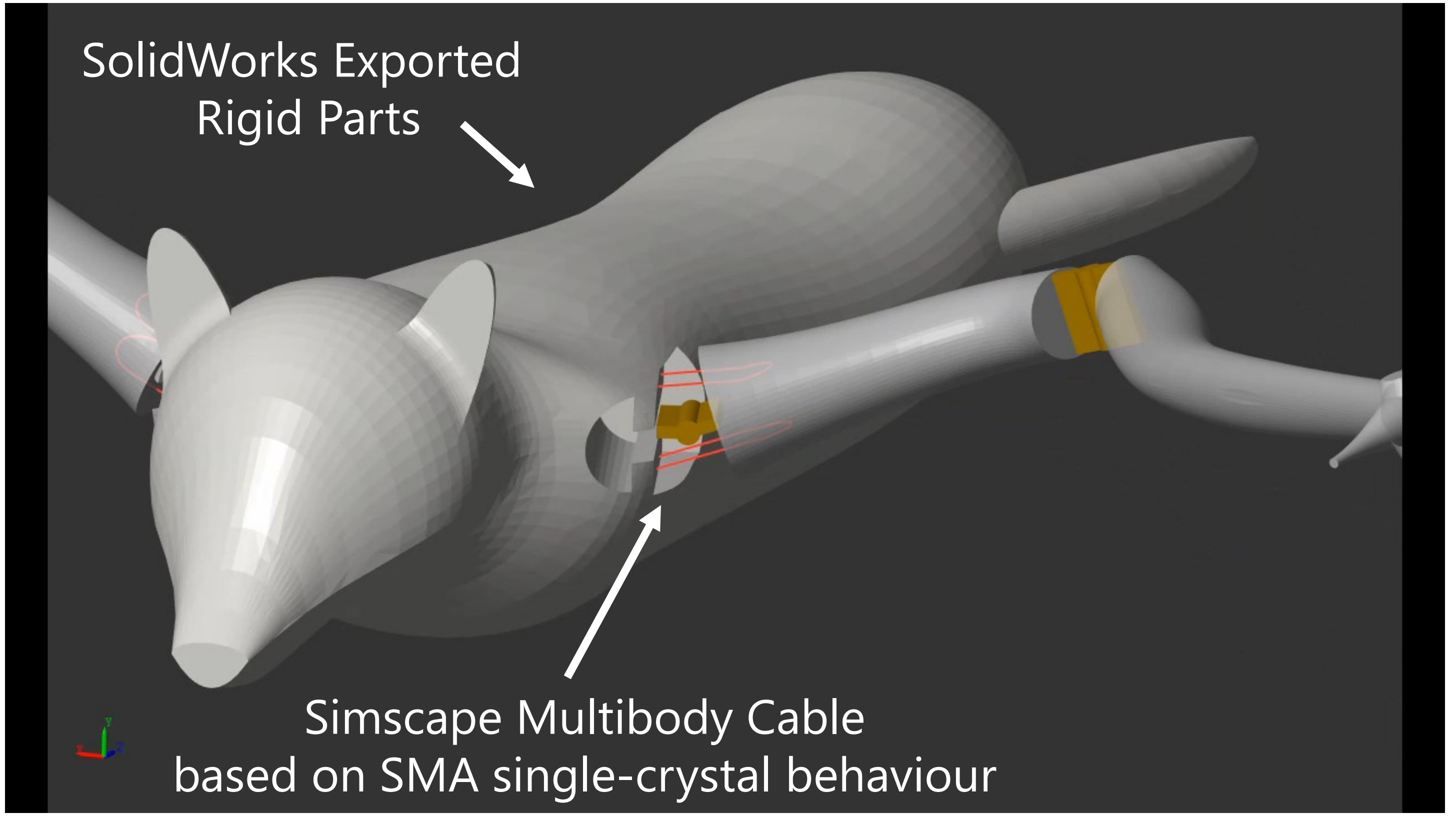
Model



2. Resonant Compliant Joint
Design

Inertia Model

$$I_{wing}\ddot{\theta} + b\dot{\theta} + K\theta = M$$

Natural frequency

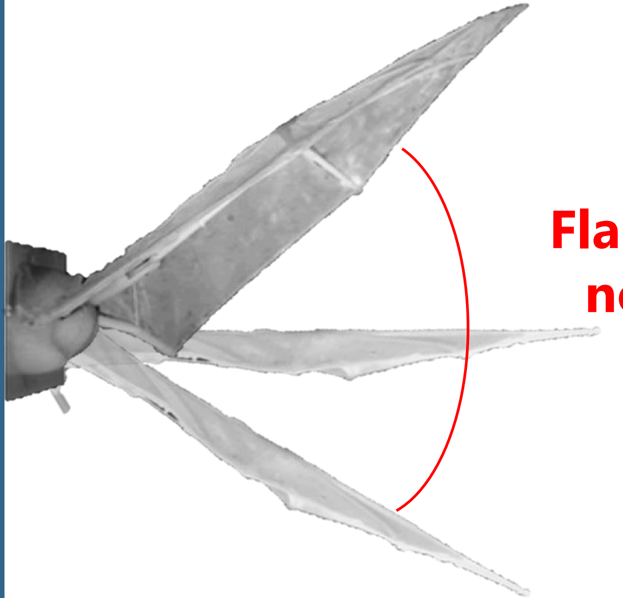
$$w_n = \sqrt{\frac{K}{I_{wing}}} = 2\pi f$$

Joint stiffness

$$K = \frac{3EI}{L^3}$$

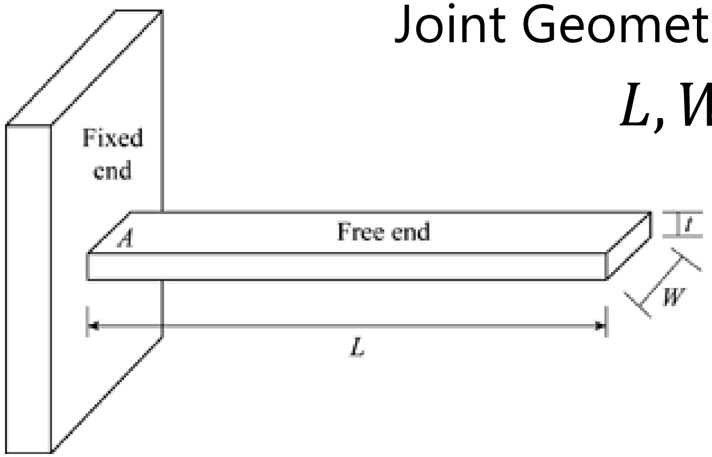
Joint Geometric Measures

$$L, W, t$$



Target:

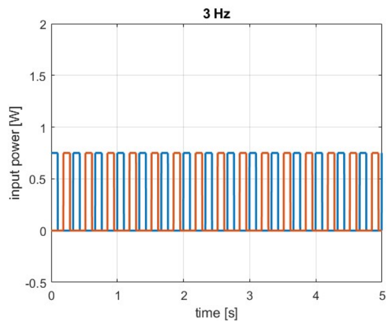
Flapping ~60° at 7 Hz
no external cooling

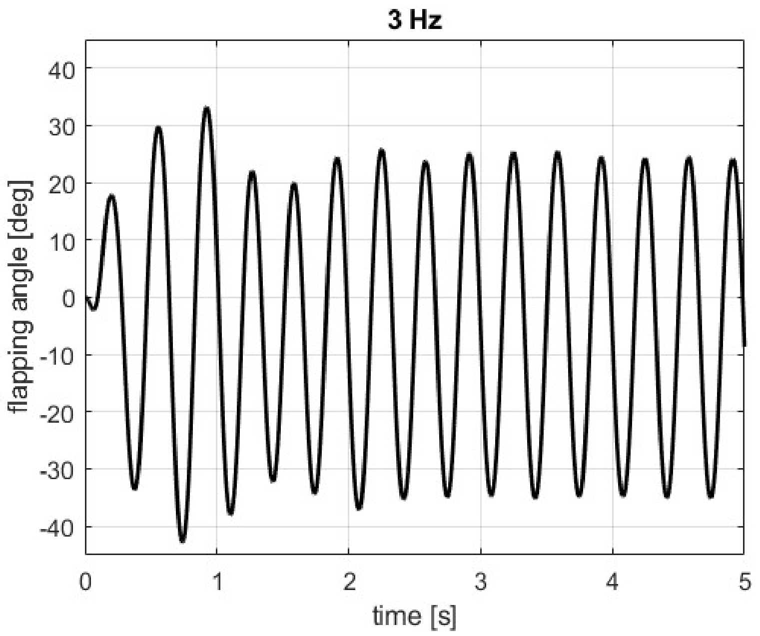


2. Resonant Compliant Joint

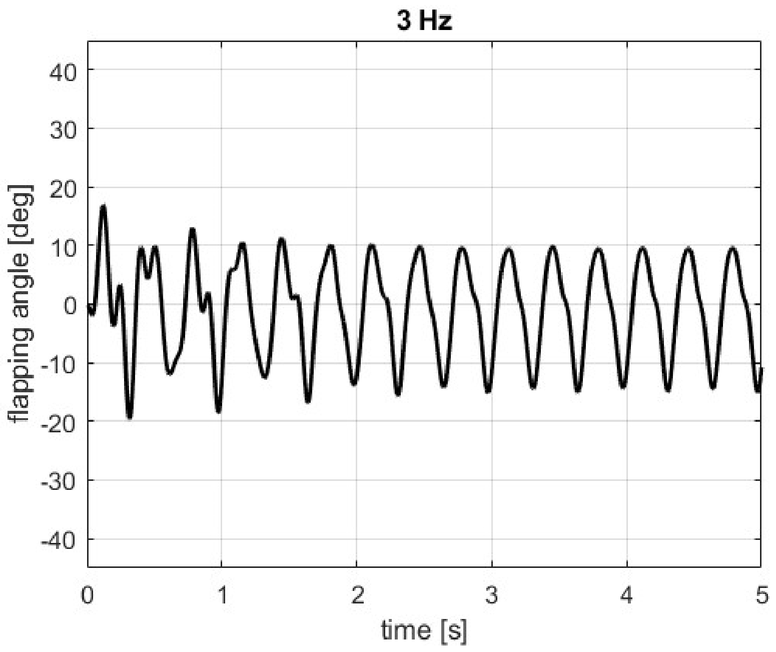
Performances

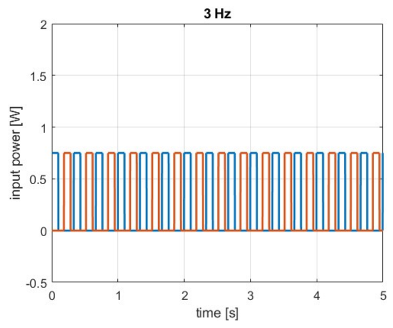
No-Resonant





Resonant (7 Hz)





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Performances

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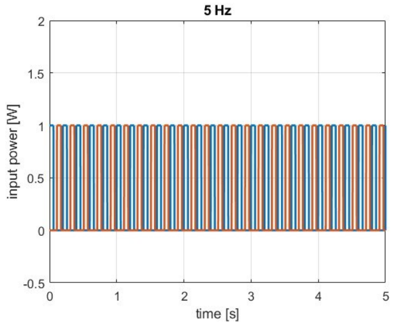

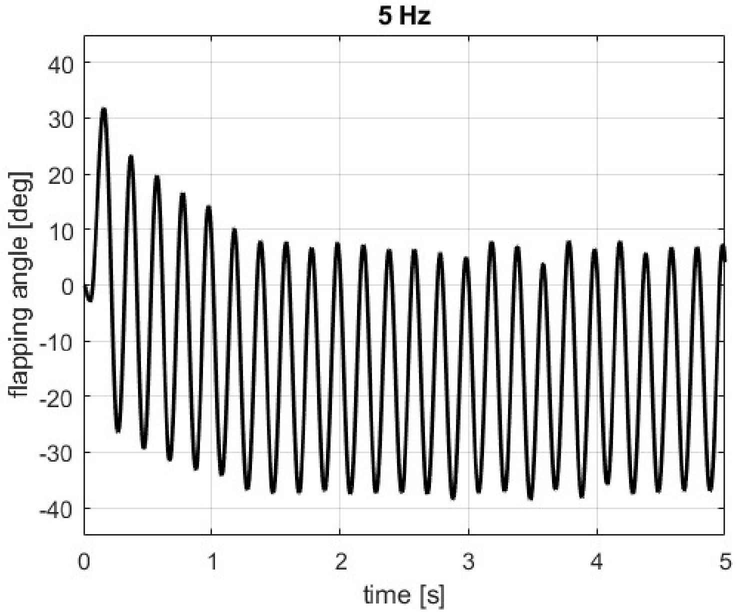

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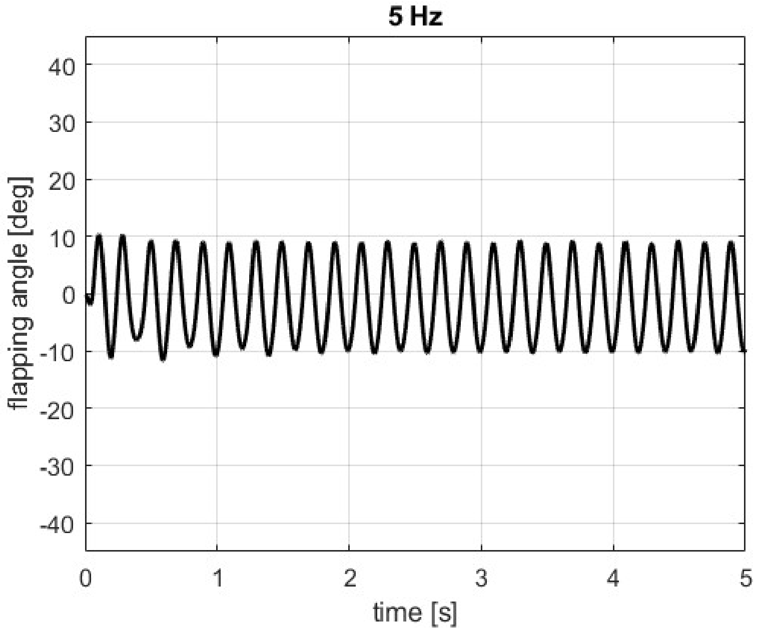

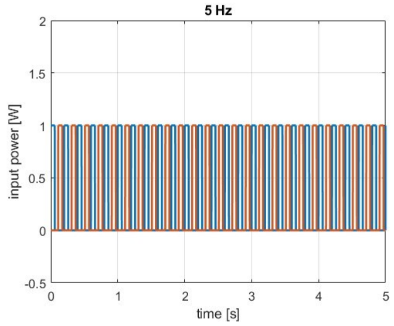

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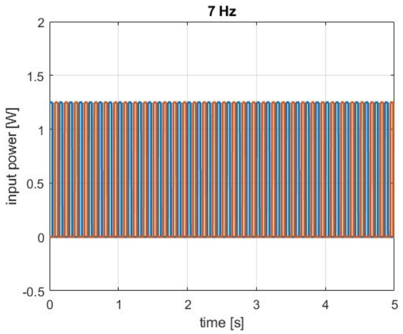

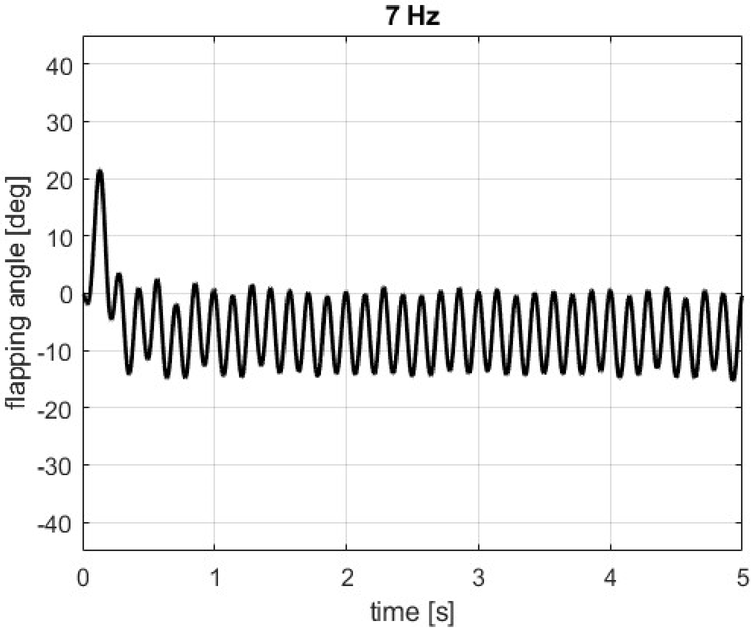

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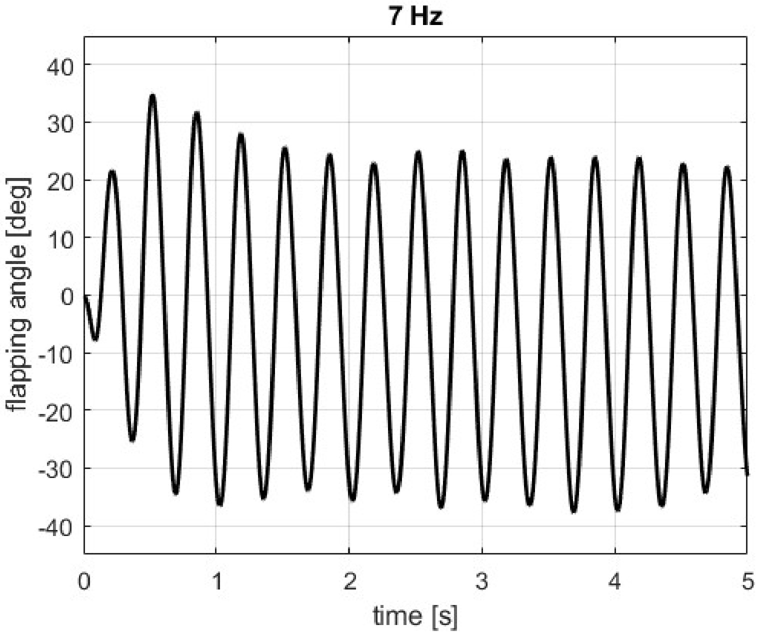
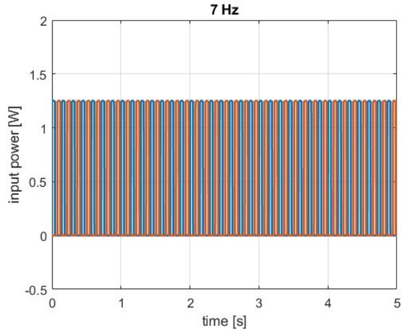
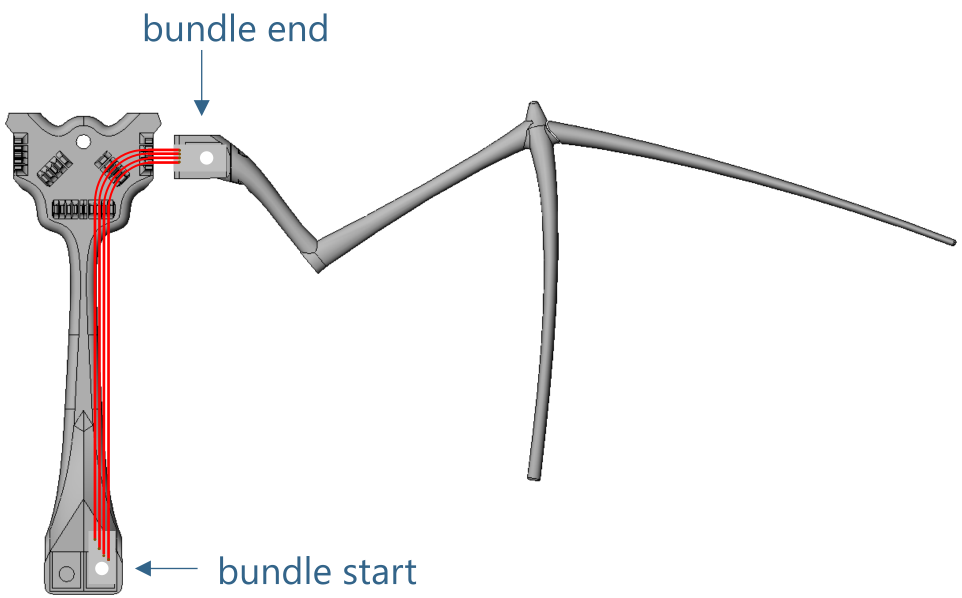




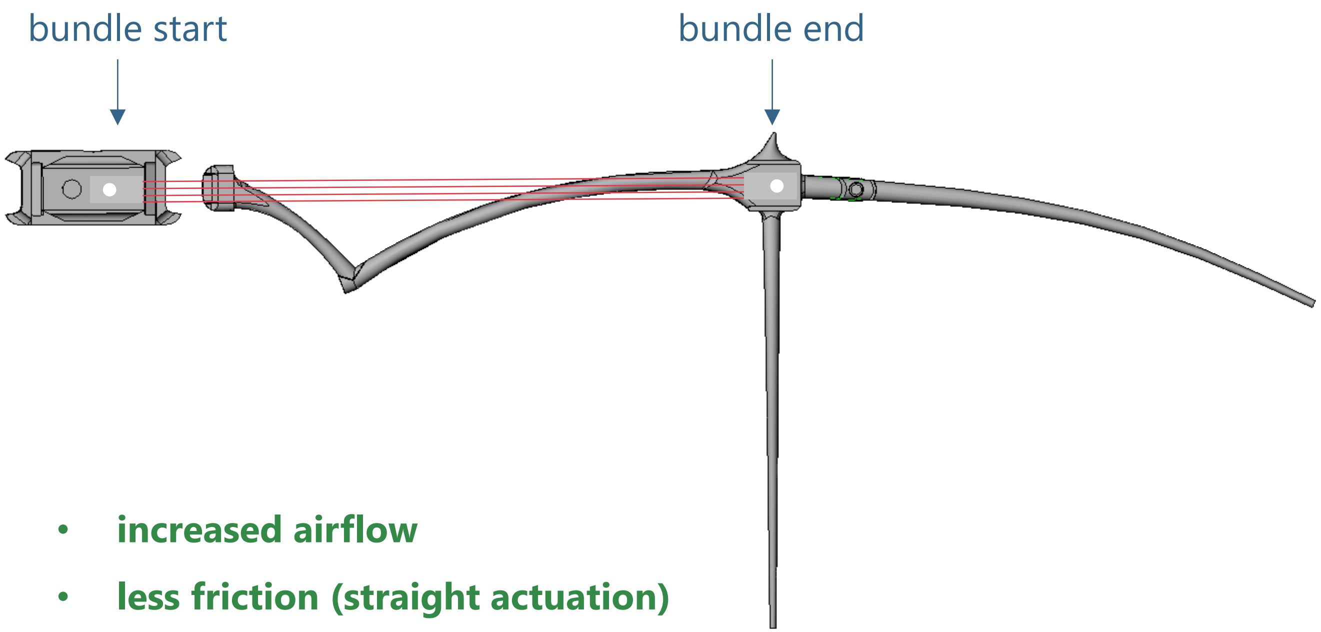
3. SMA Wing Integrated Design

Design

previous design



the bundle flaps with the wing

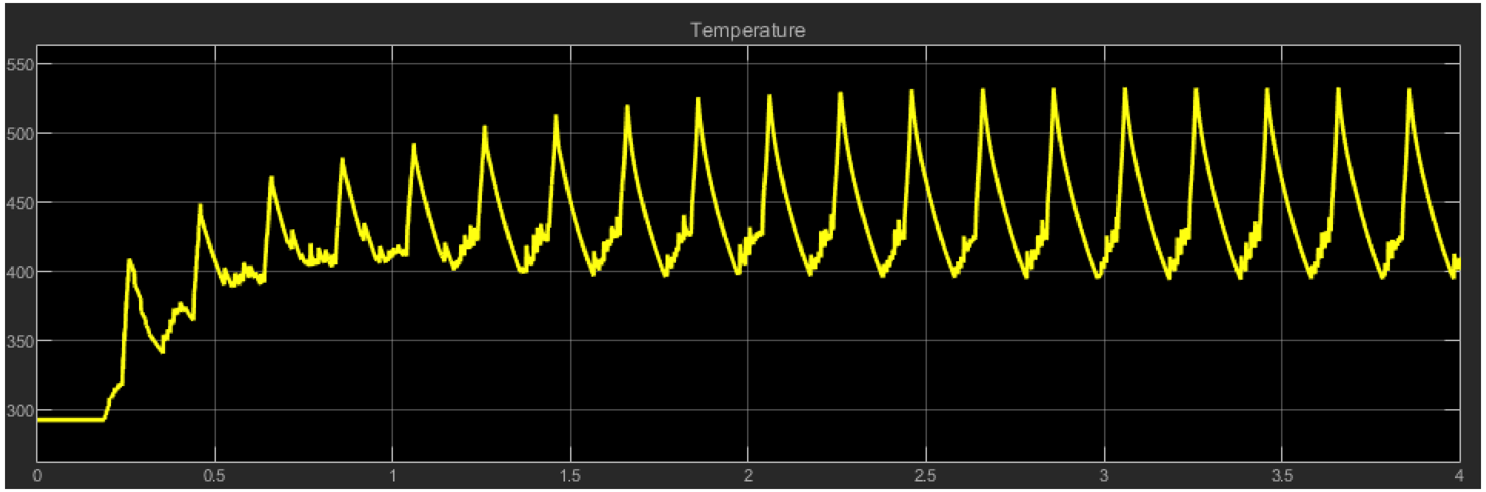


- **increased airflow**
- **less friction (straight actuation)**

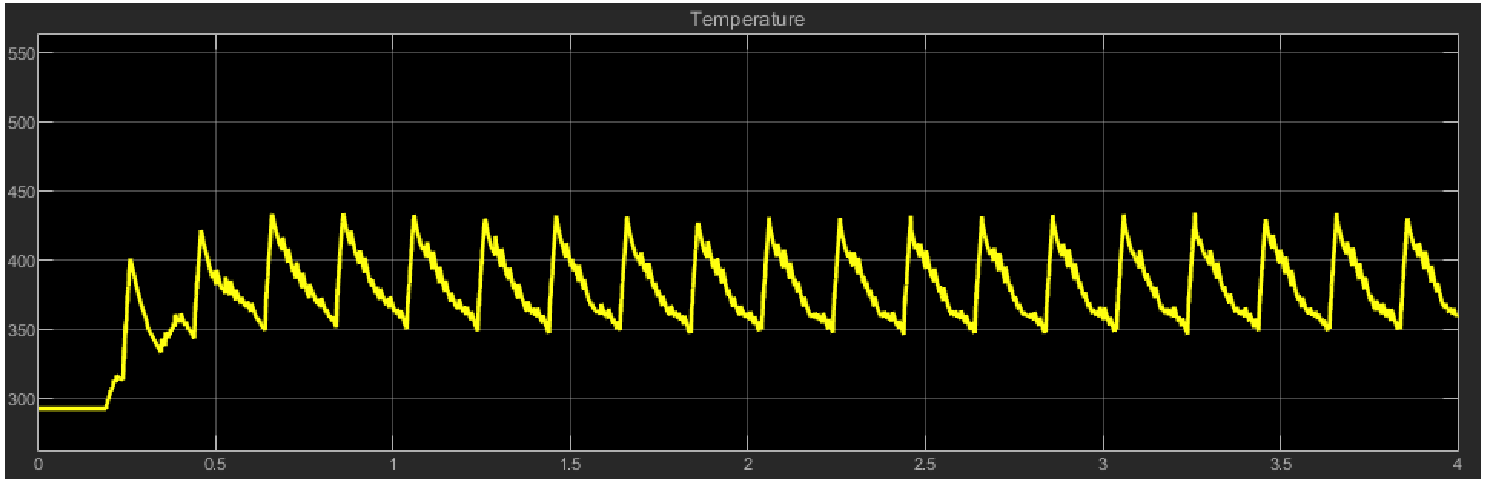
3. SMA Wing Integrated Design

Performances

Heat Transfer at static-air

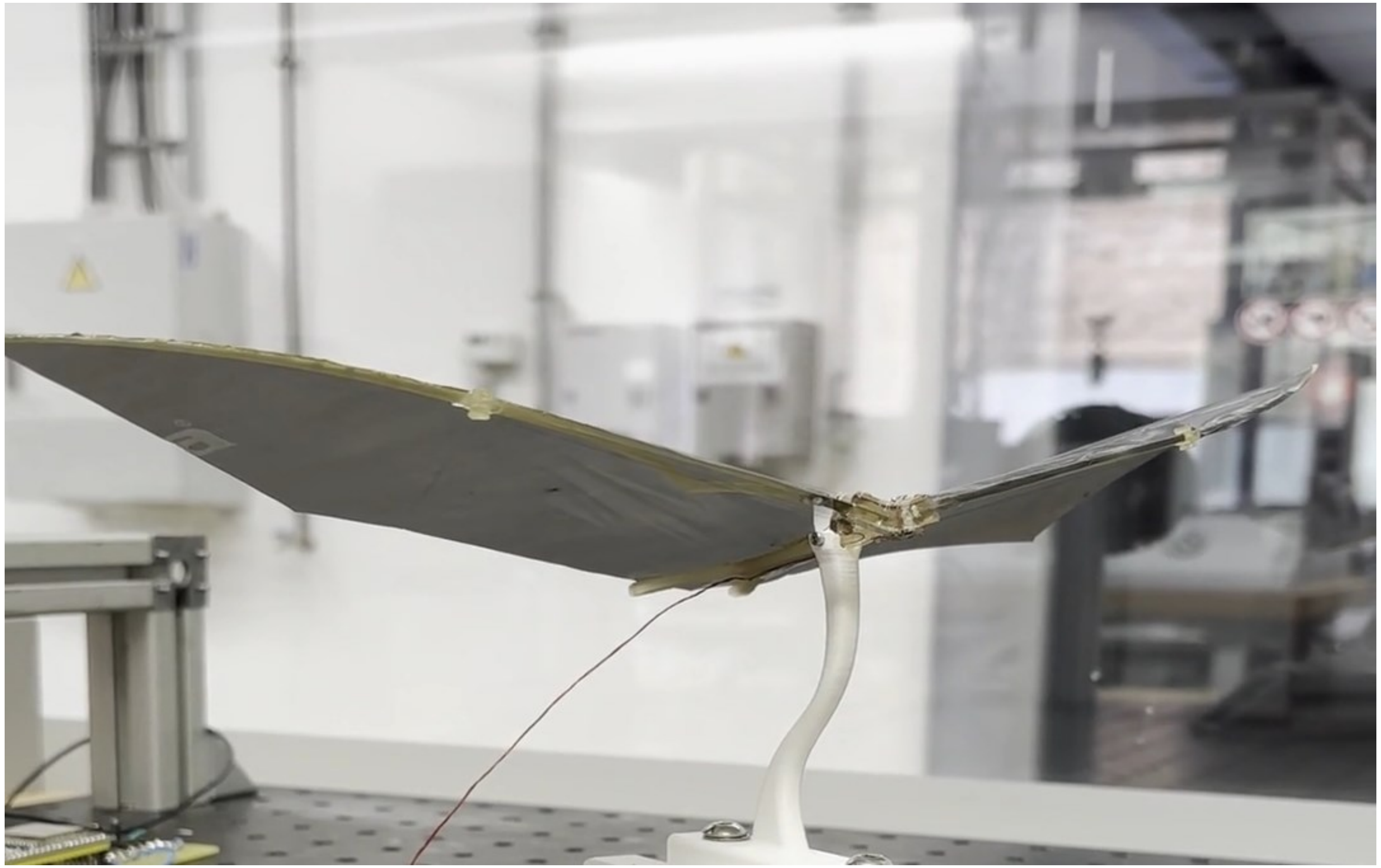


Heat Transfer with increased airflow



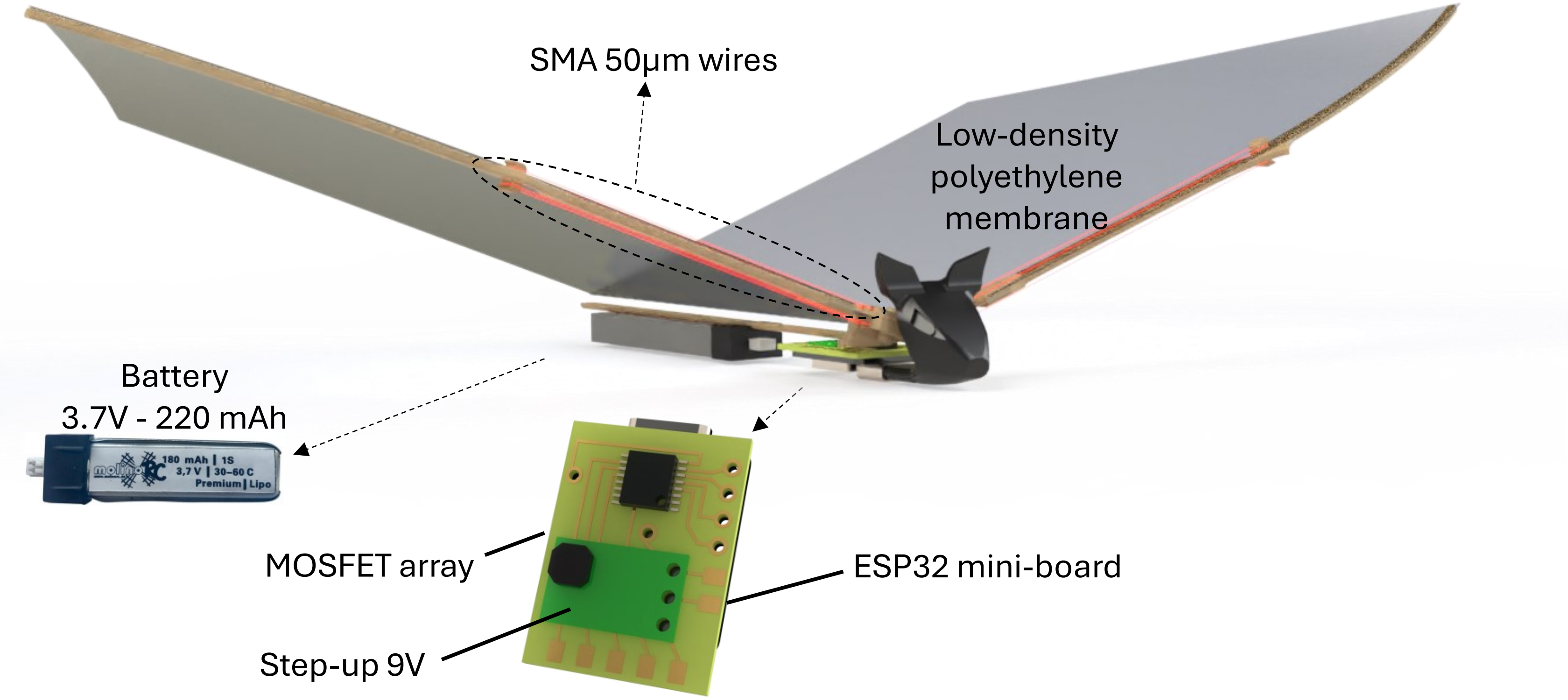
4. Wing Aereodynamics

Final Design



4. Wing Aereodynamics

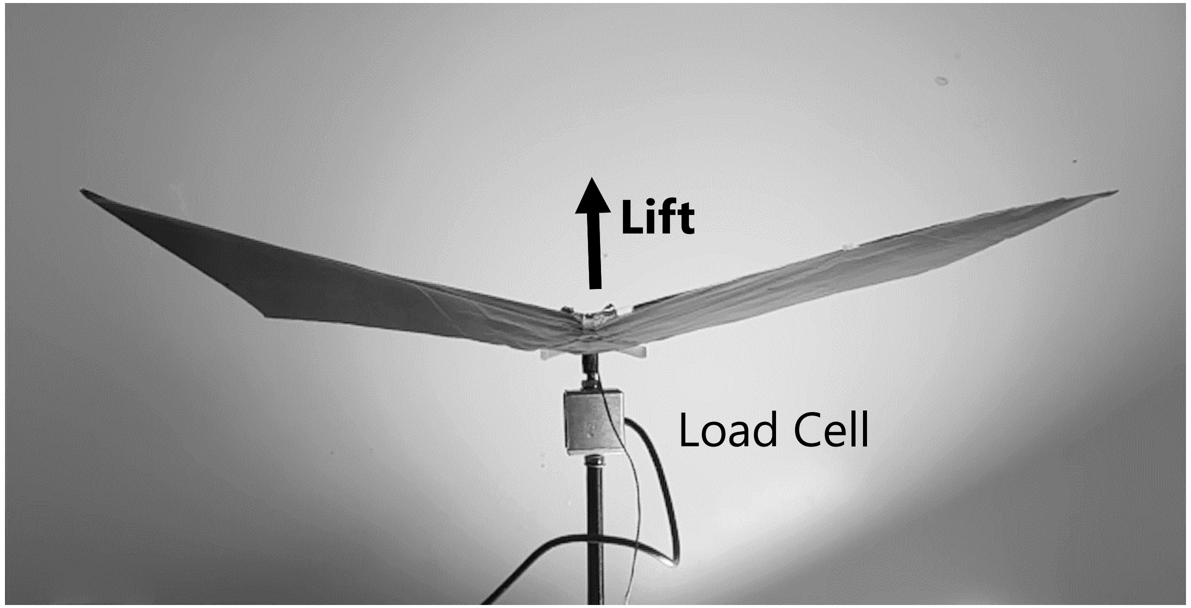
Final Design

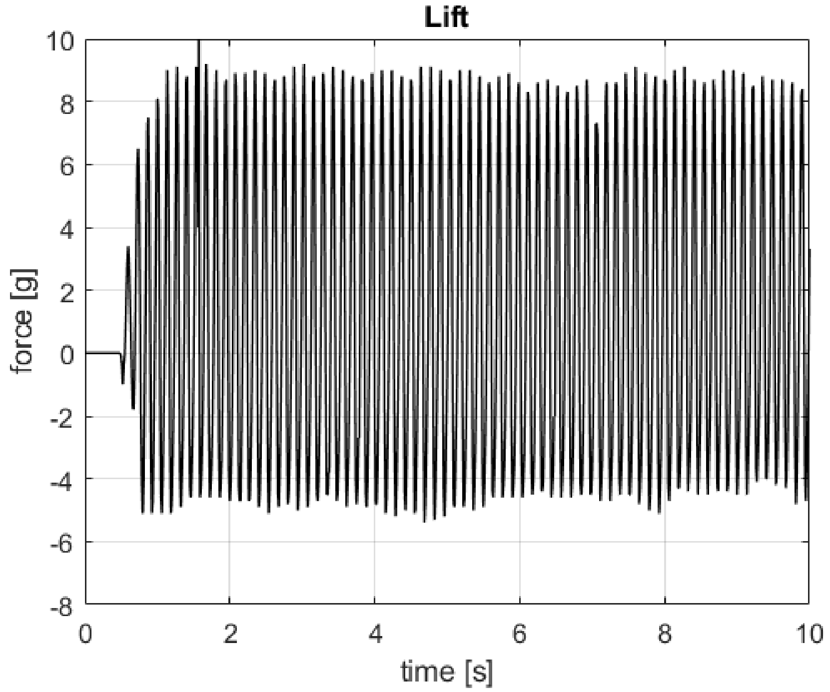


Wingspan: **380 mm**
Weight: **14 grams**

4. Wing Aereodynamics

Performances

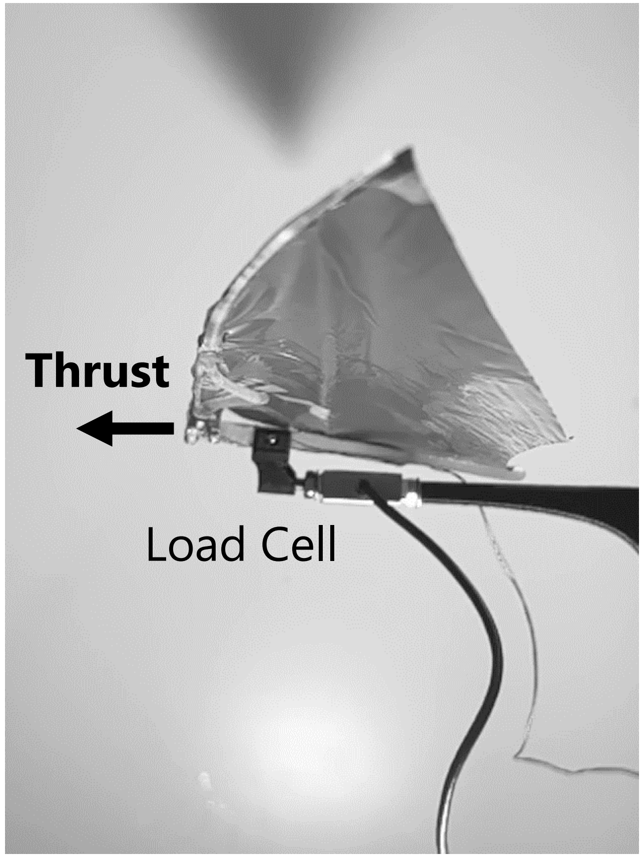


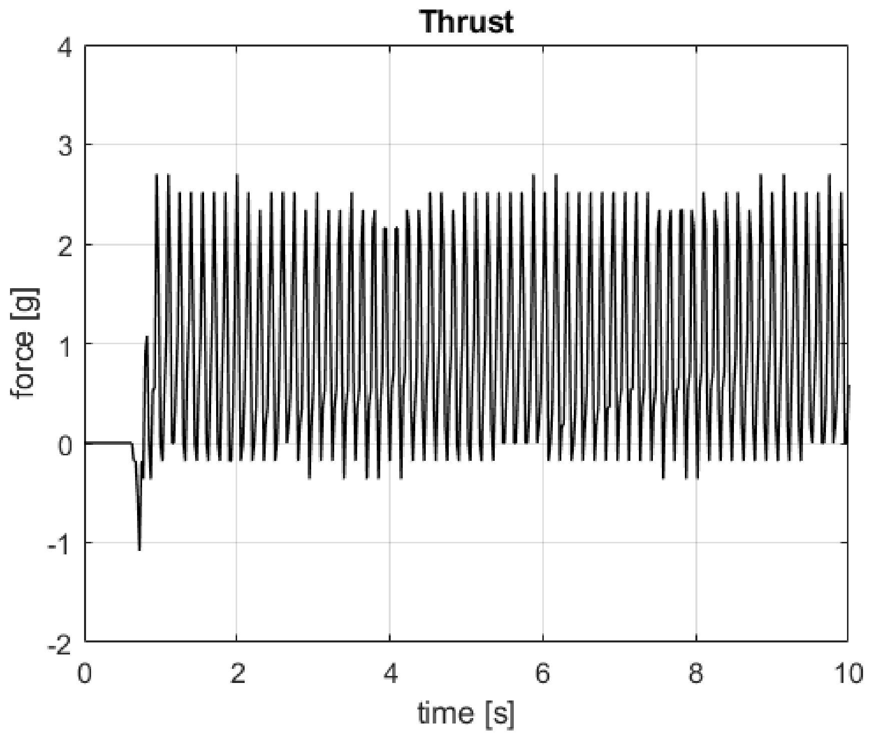


INTELLIGENT MATERIAL SYSTEMS LAB

4. Wing Aereodynamics

Performances

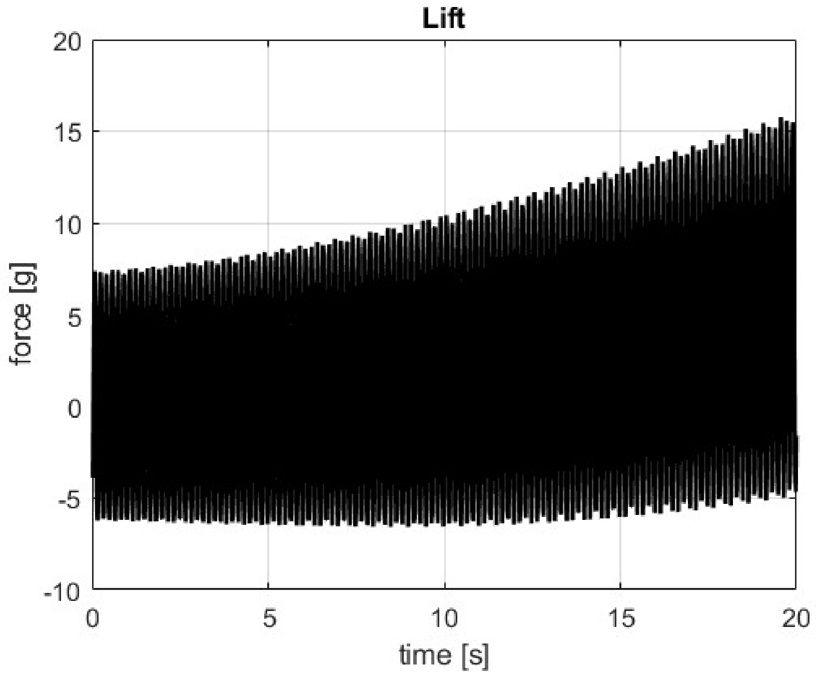




INTELLIGENT MATERIAL SYSTEMS LAB

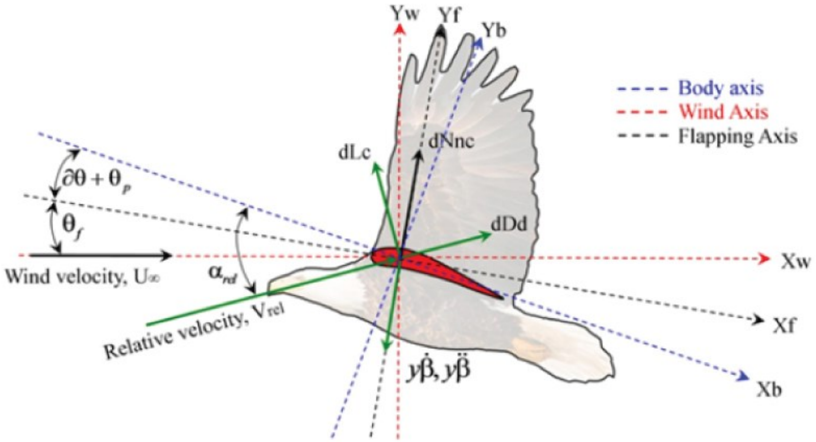
4. Wing Aereodynamics

Performances – Rotating Flight Demonstration

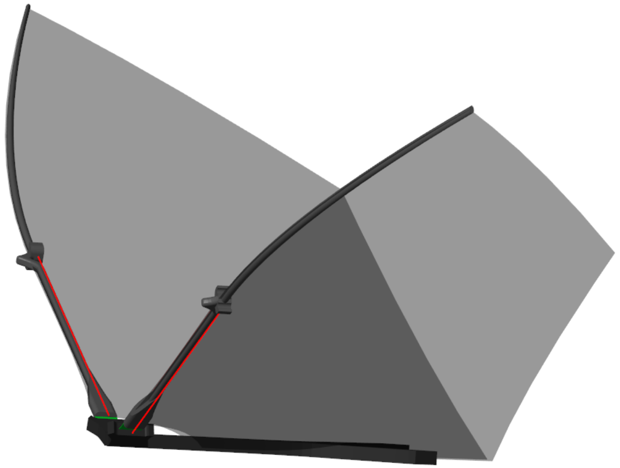


4. Wing Aereodynamics

Wing Flapping Model



BatMAV Model



$$dL_c = \frac{1}{2}\rho\, V_{rel}^2\, C_{l-c}\,.\,c.\,dr$$

Lift Component

$$dN_{nc} = -\frac{\rho\pi c^2}{4}\left(\dot{\theta}U + r\ddot{\beta}\cos\theta - 0.5\,\ddot{\theta}\right).\,dr$$

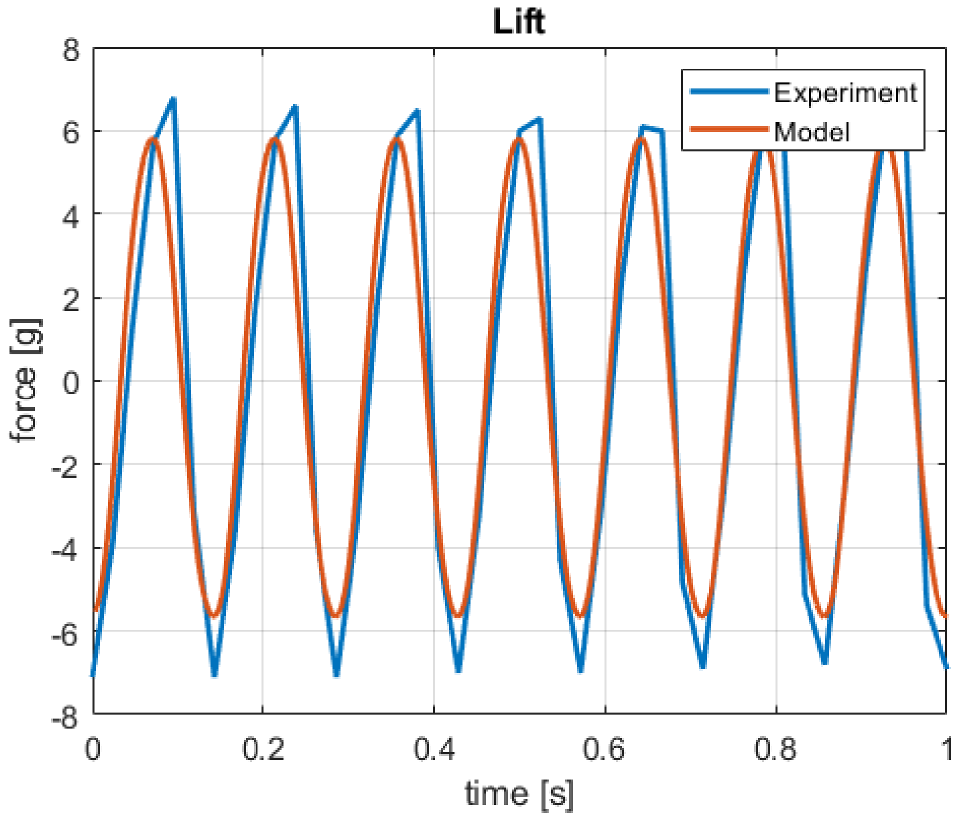
Air Accelerating Momentum

$$dD_i = \frac{1}{2}\rho\, V_{rel}^2\, C_{di}\,.\,c.\,dr \quad + \quad dD_p = \frac{1}{2}\rho\, V_{rel}^2\, C_{dp}\,.\,c.\,dr$$

Drag Component

Wing Flapping Model

Experiment

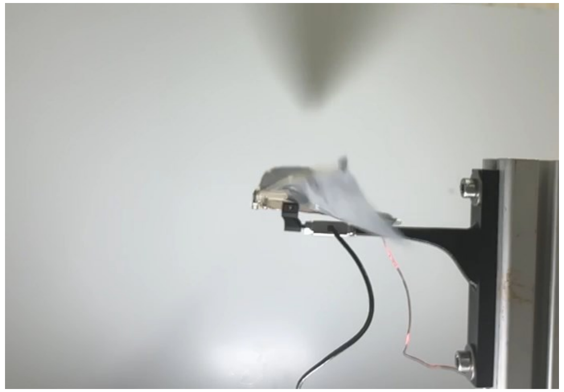


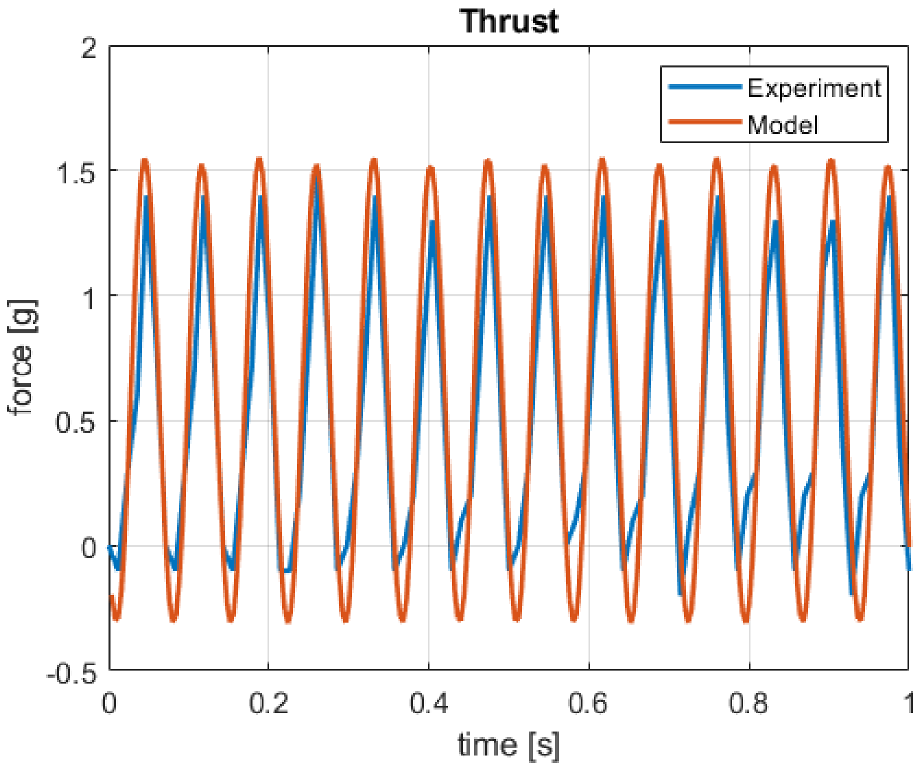
Simulation

4. Wing Aereodynamics

Wing Flapping Model

Experiment





Simulation