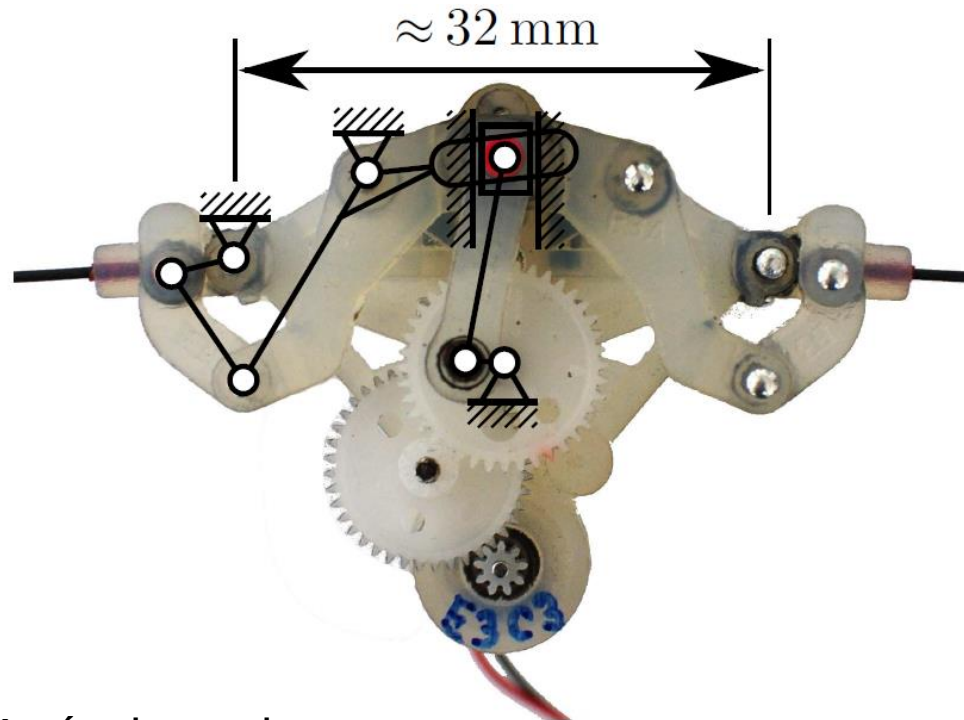
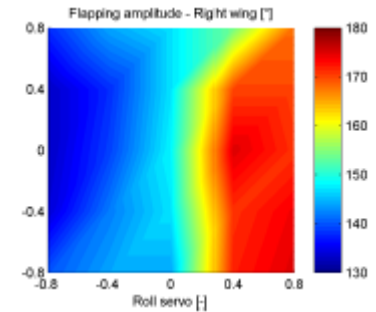
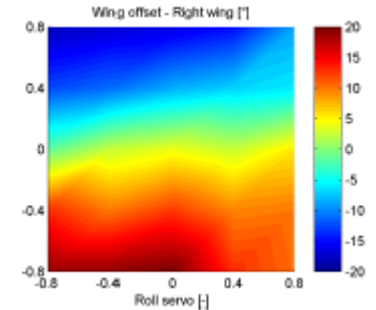


Tail-less

- Active Stability
- Turbulence rejection
- High body rates
 - Minimal damping surfaces
- Shorter vehicle
- Aerodynamic moments
 - Less dependent on airspeed



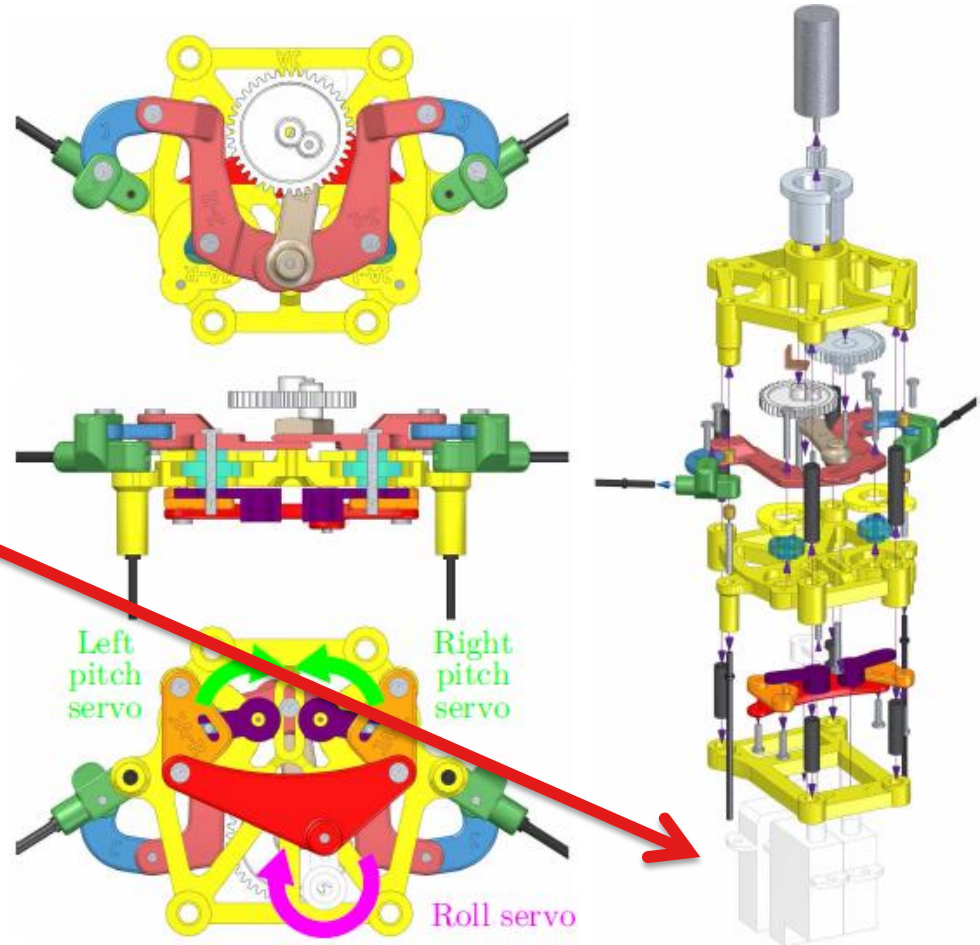
Lot of research on tail-less Flapping MAV



Karásek, et al

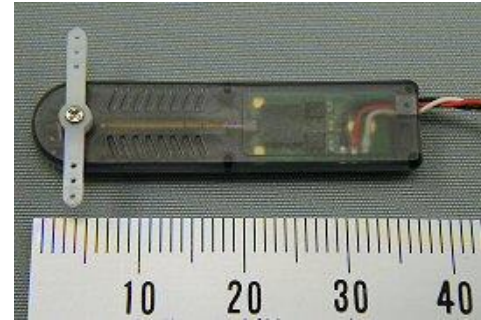
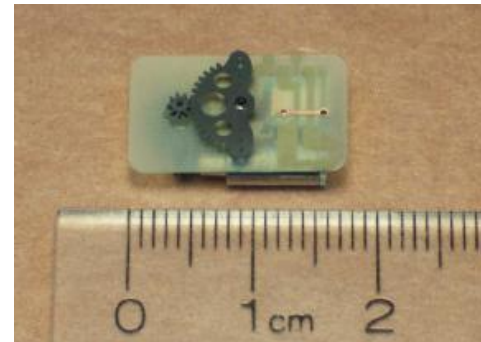
Complexity

- Flapping
- Control
- Actuators

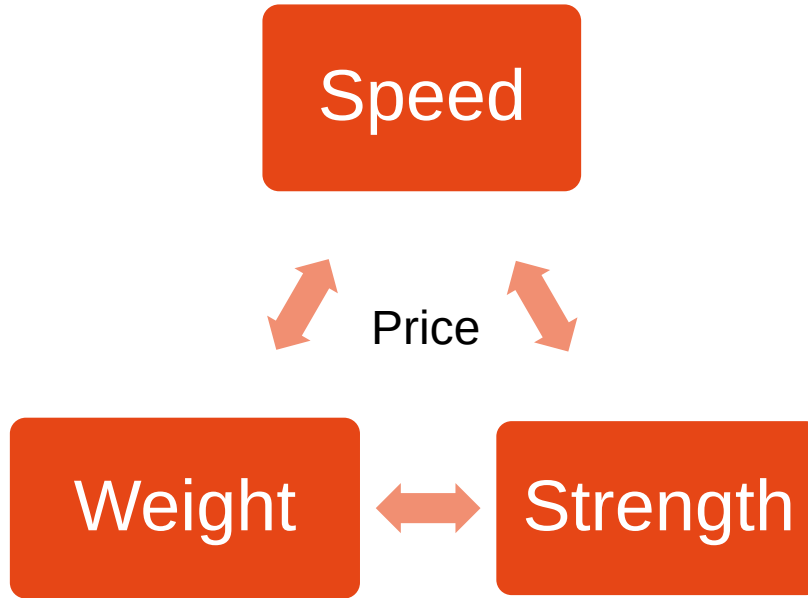
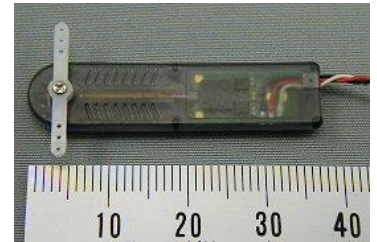


Actuator selection

- Need actuators

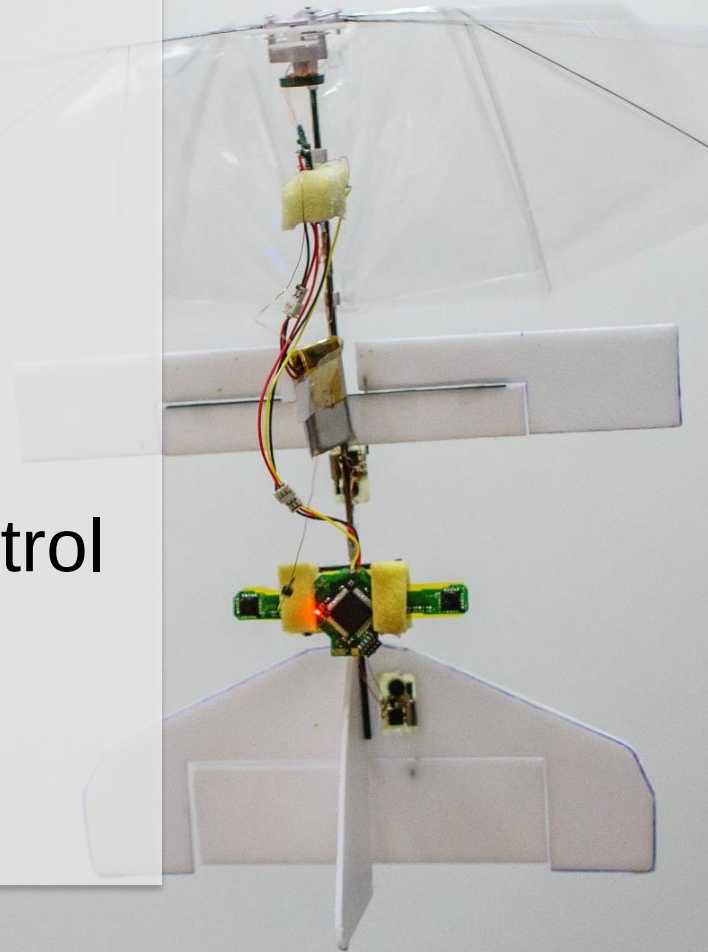


Actuator trade-off

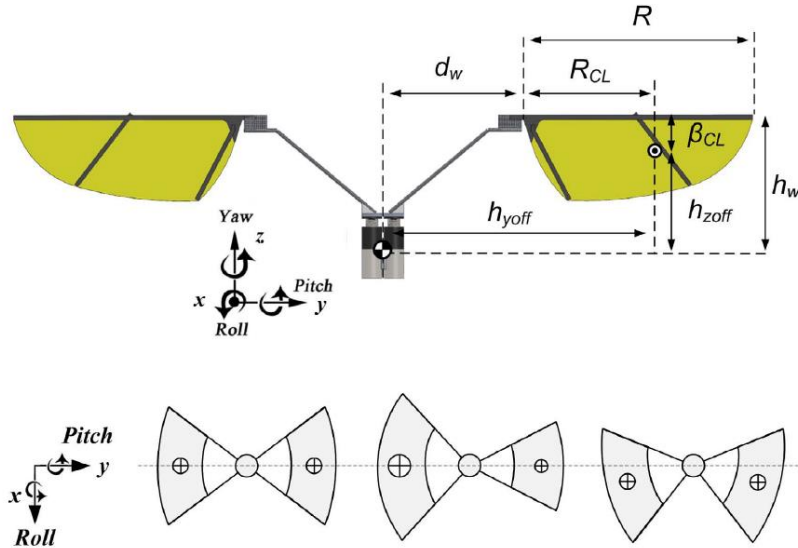


Flight efficiency

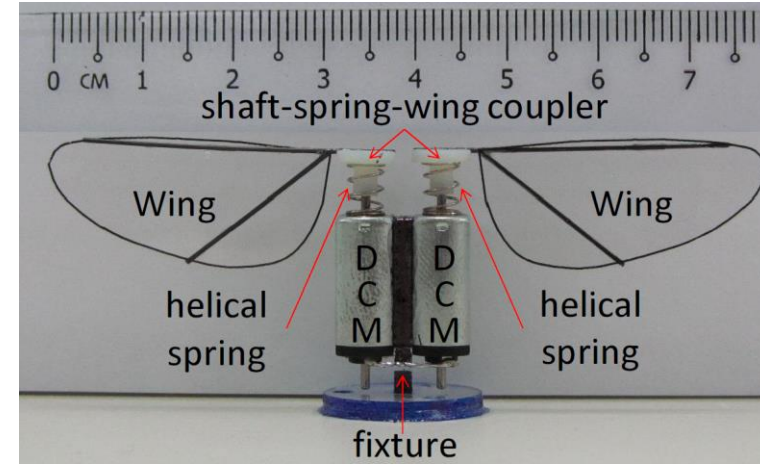
- Weight of propulsion
 - Flapping mechanism
 - Flapping motor
- Weight of moment control
 - Tail sections, rudders,
 - Rods, actuators



Flapping actuator for control

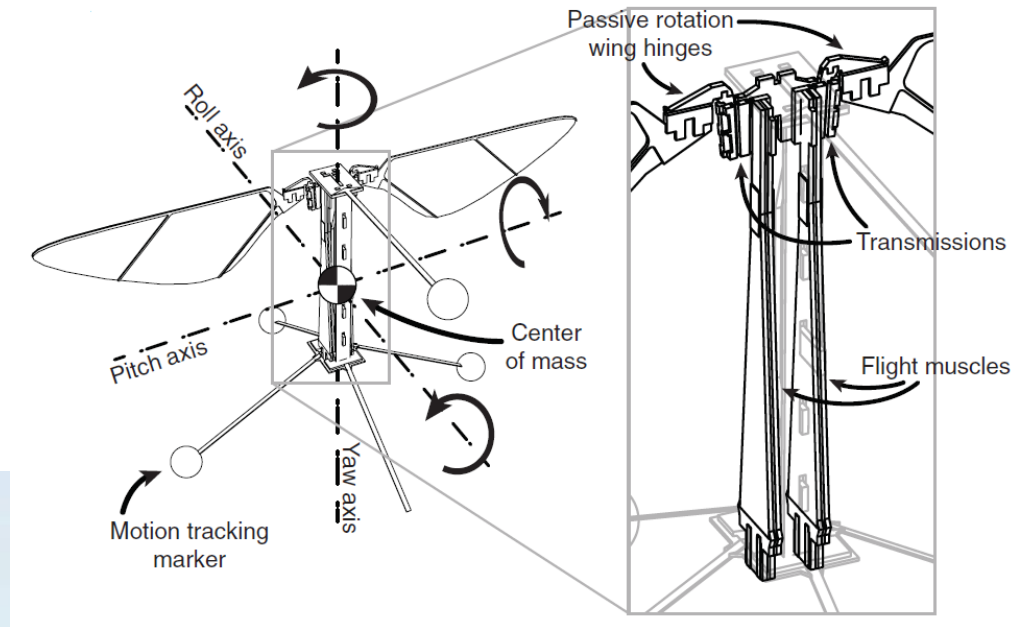
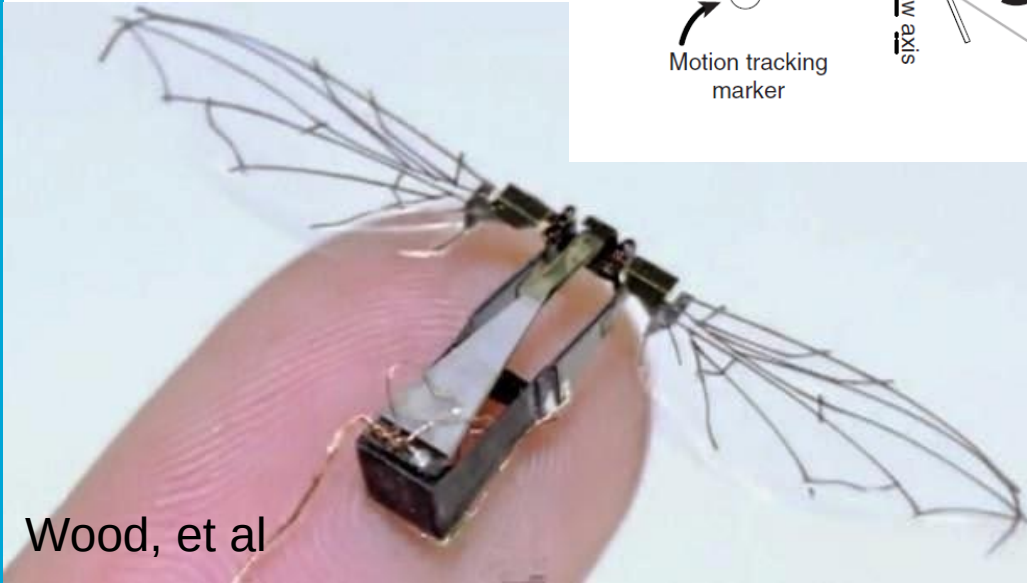


Hines, et al



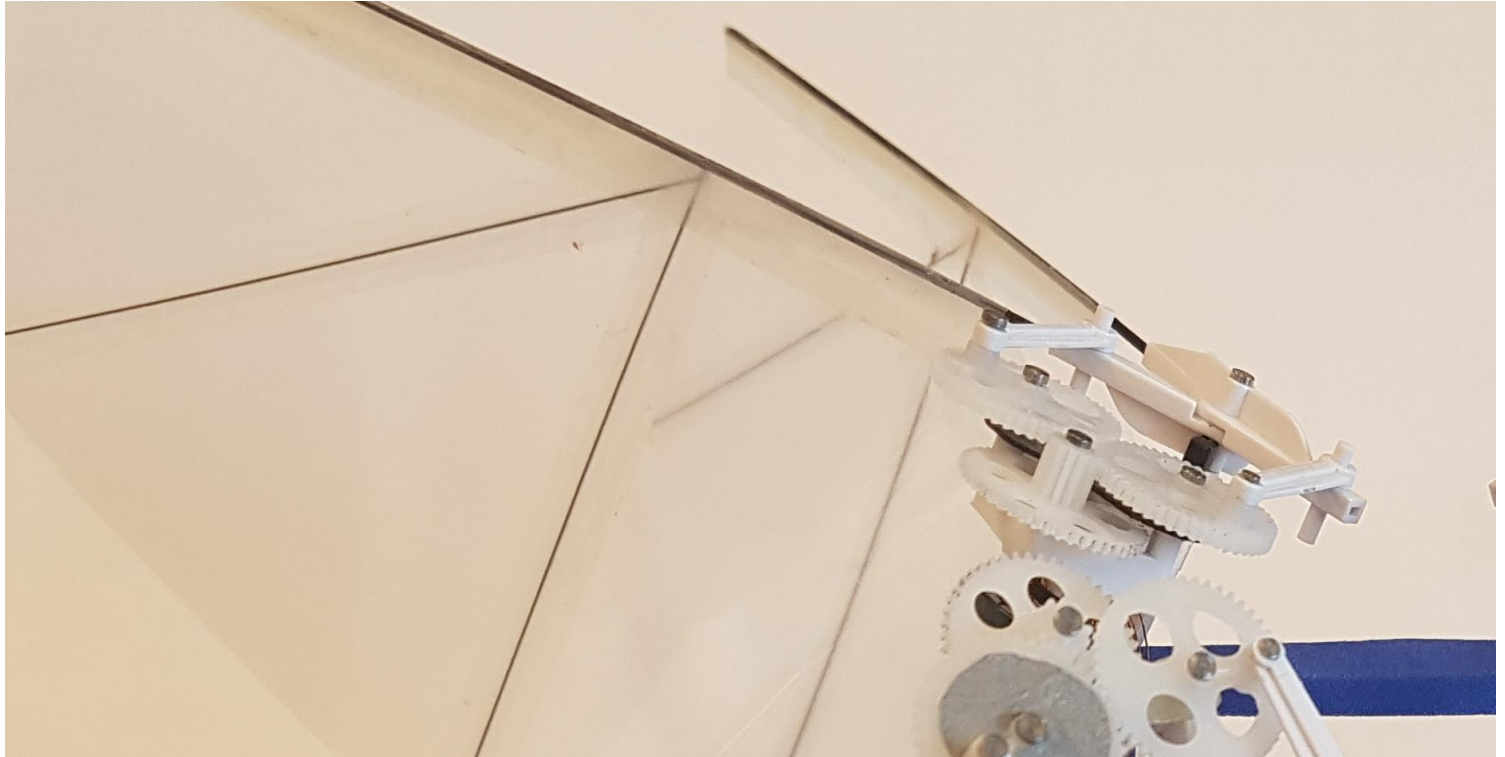
*Motor used far outside efficient range.
Attempt to use resonance to reduce the losses.*

Piezo

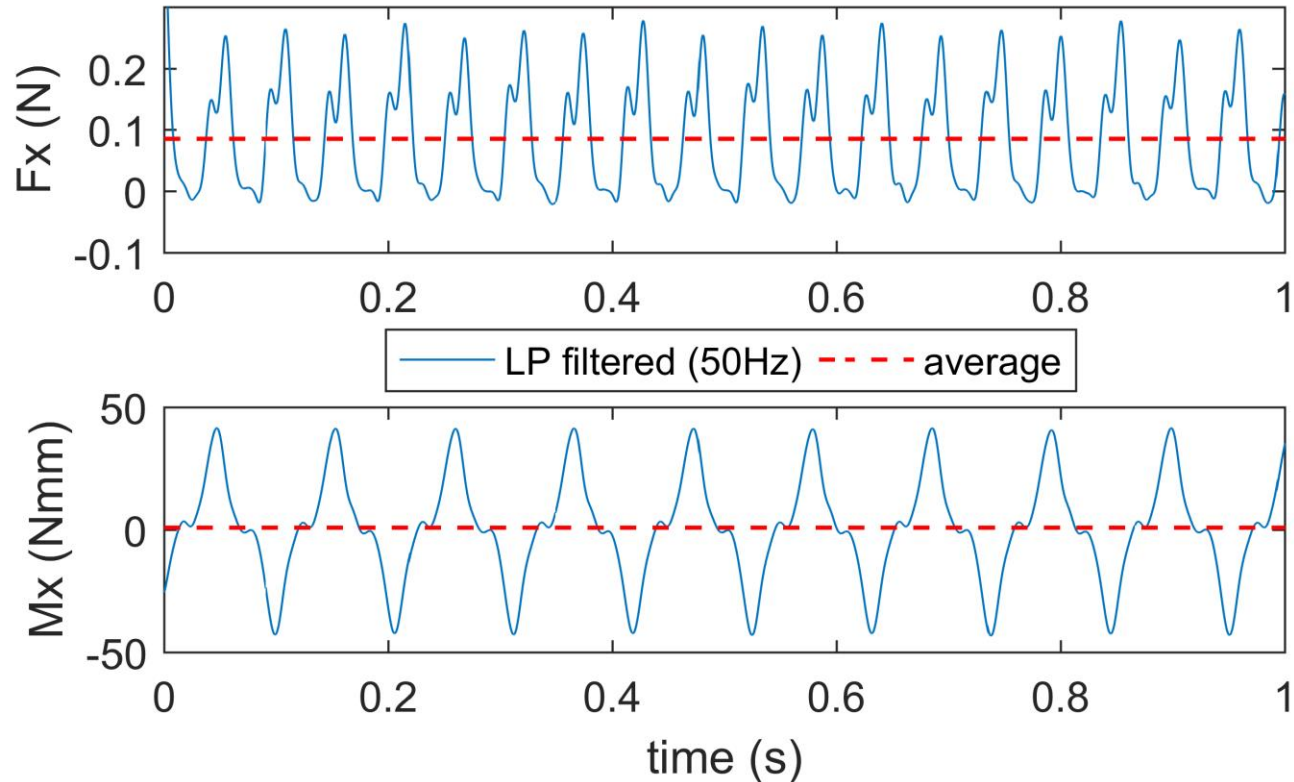


High voltage

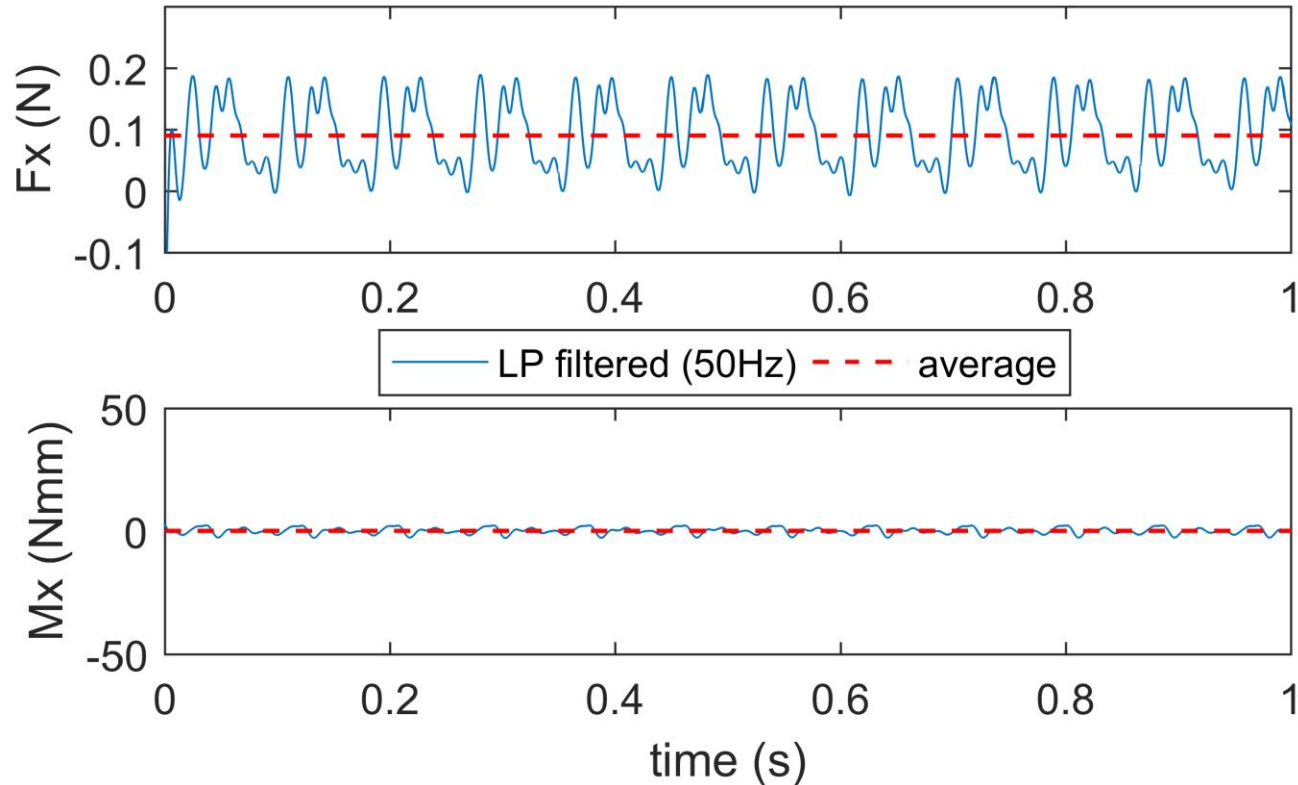
Fixed-amplitude, variable frequency



Single Flapping Wing Force

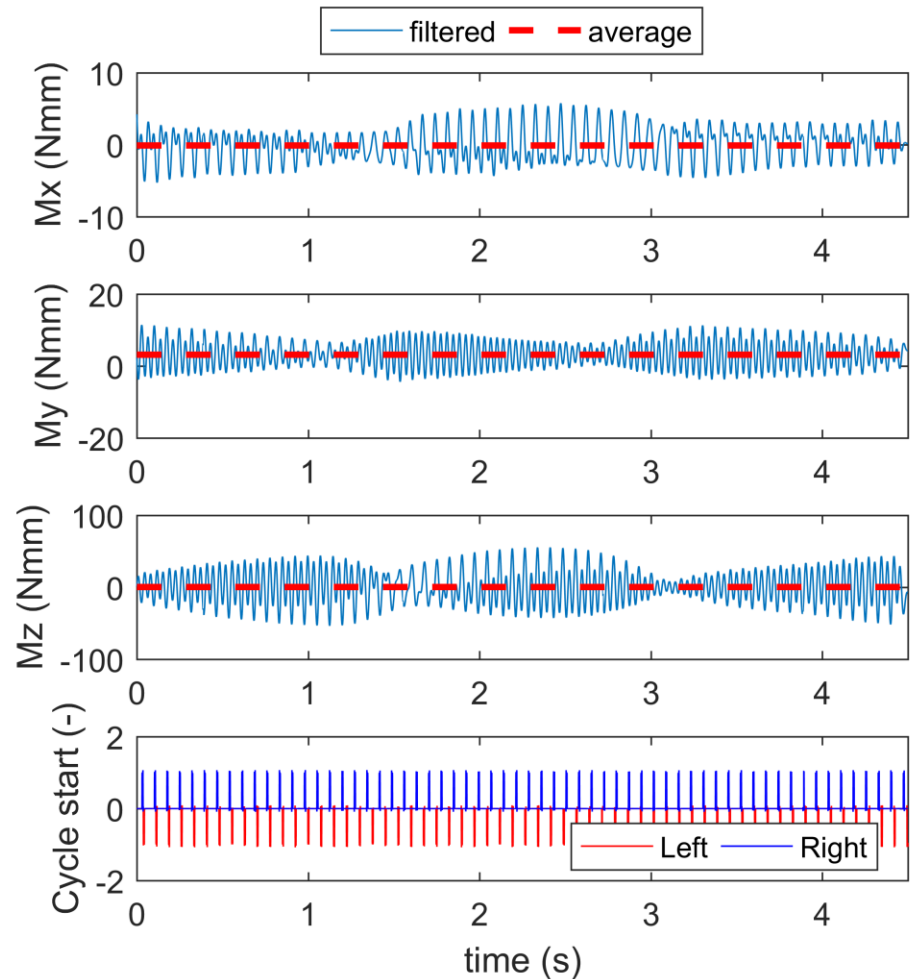


Pair of Flapping Wings

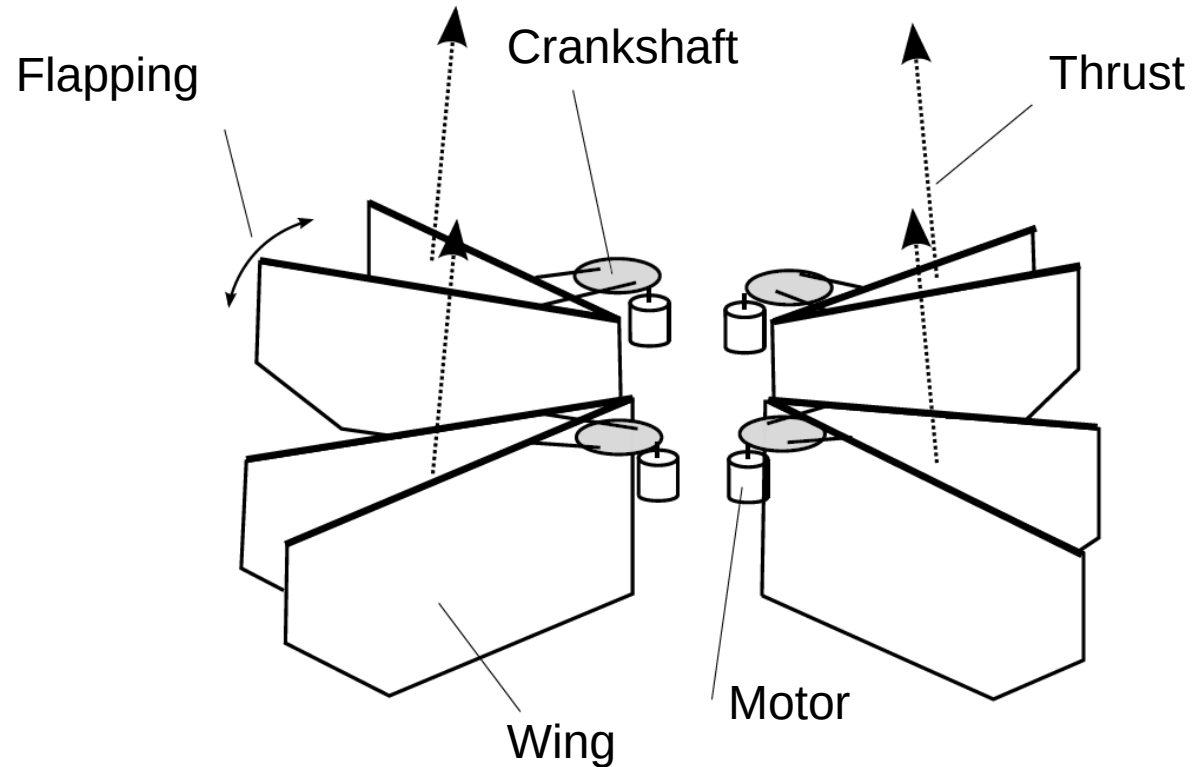


Ringling

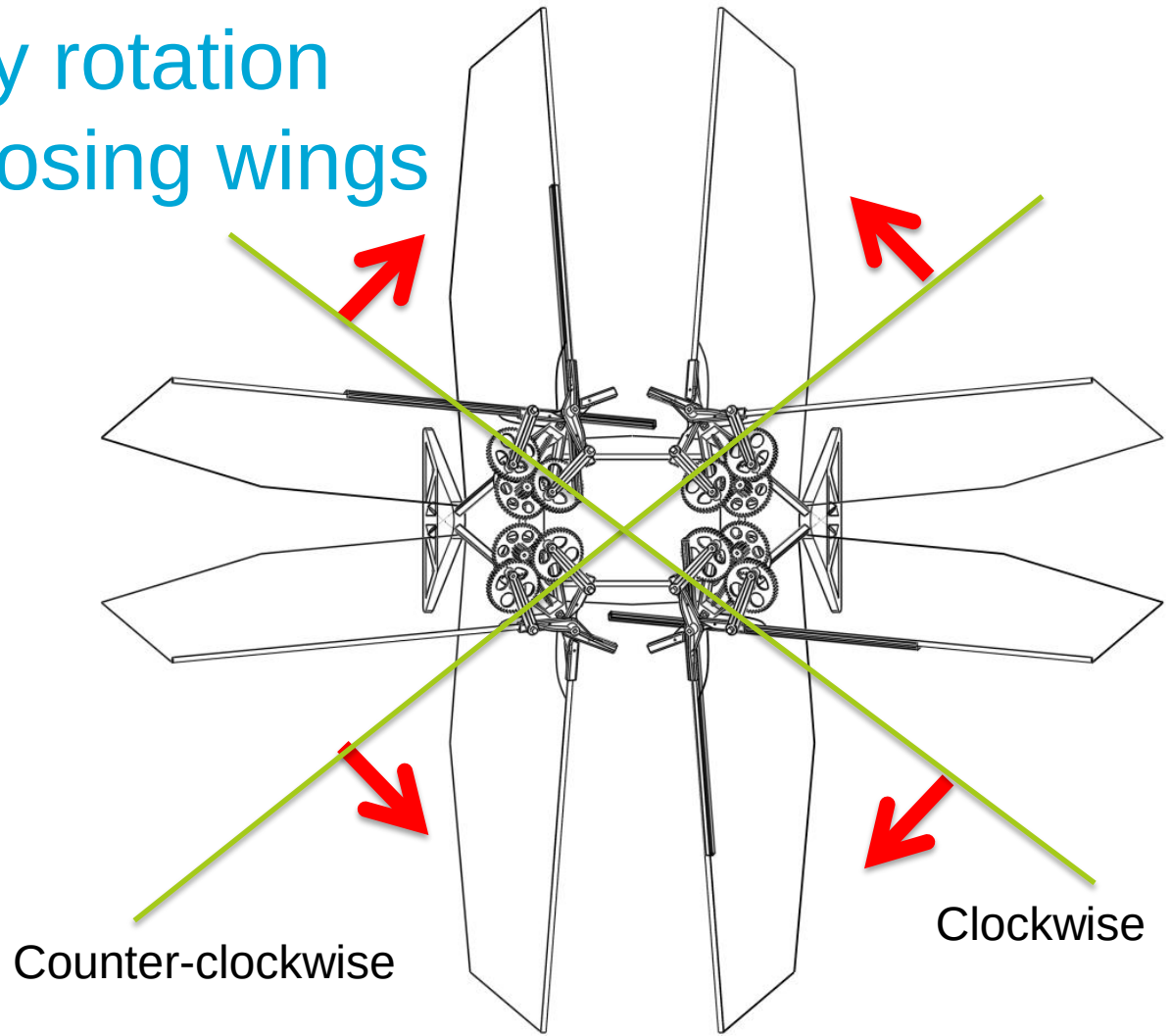
- In-phase
- Out-of-phase



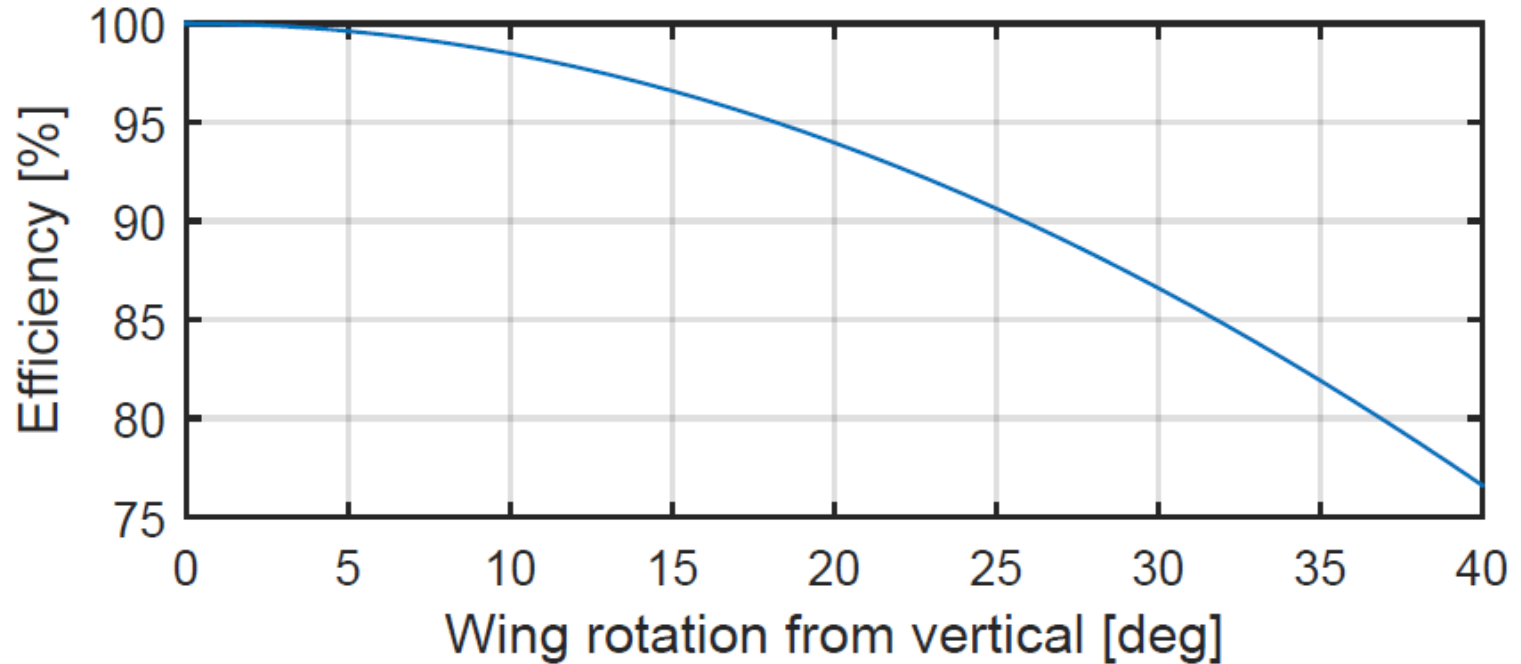
Four pairs of flapping wings

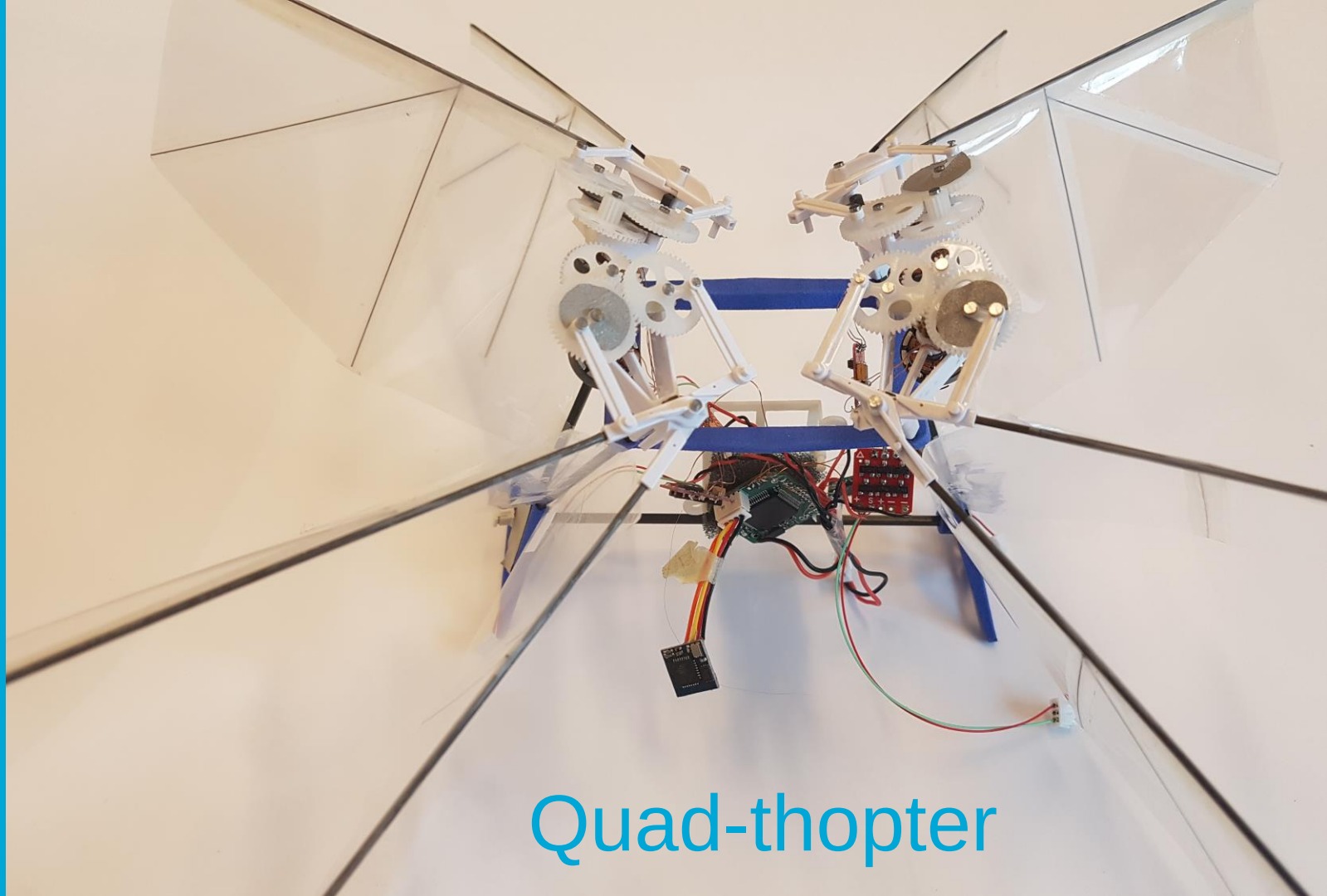


Yaw by rotation of opposing wings



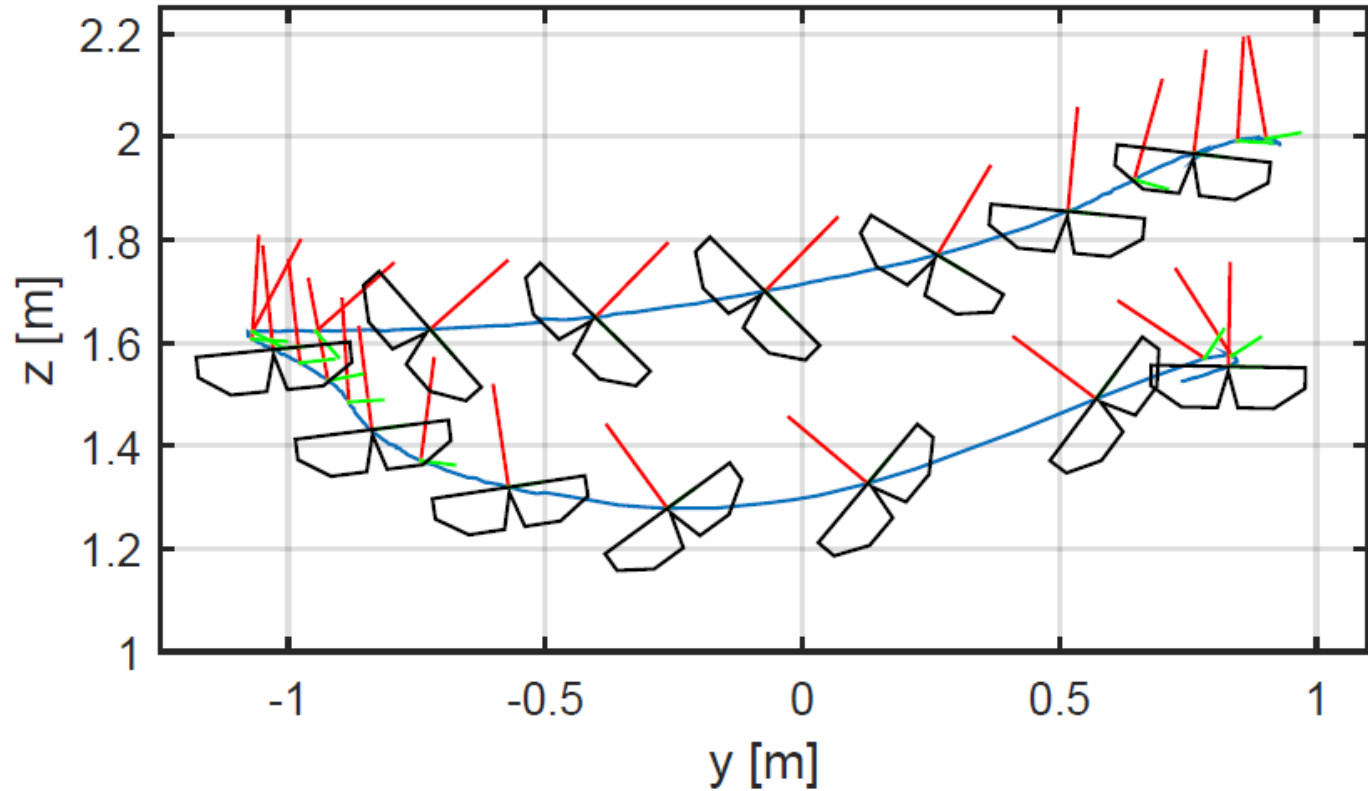
Efficiency in function of yaw



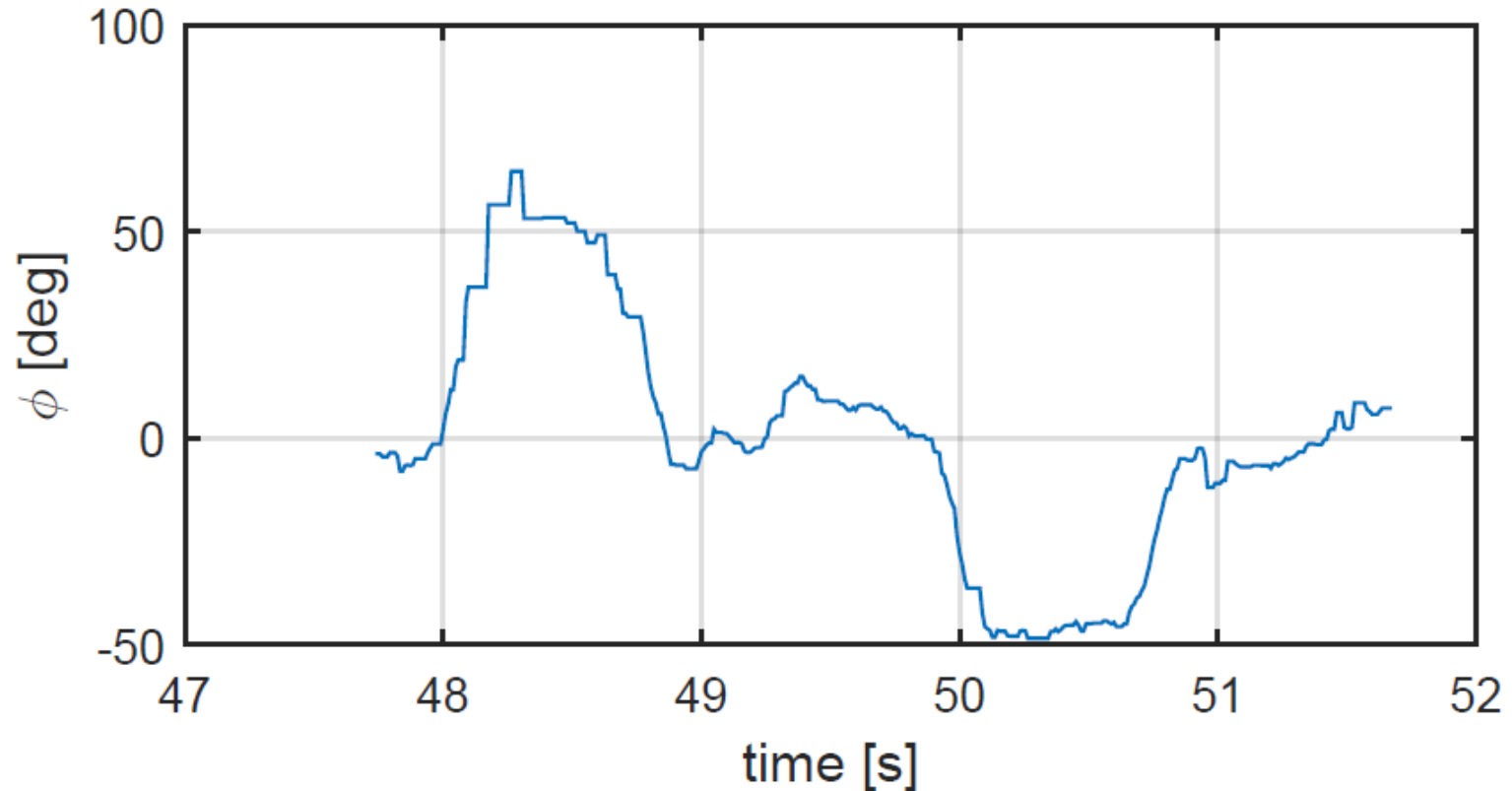


Quad-thopter

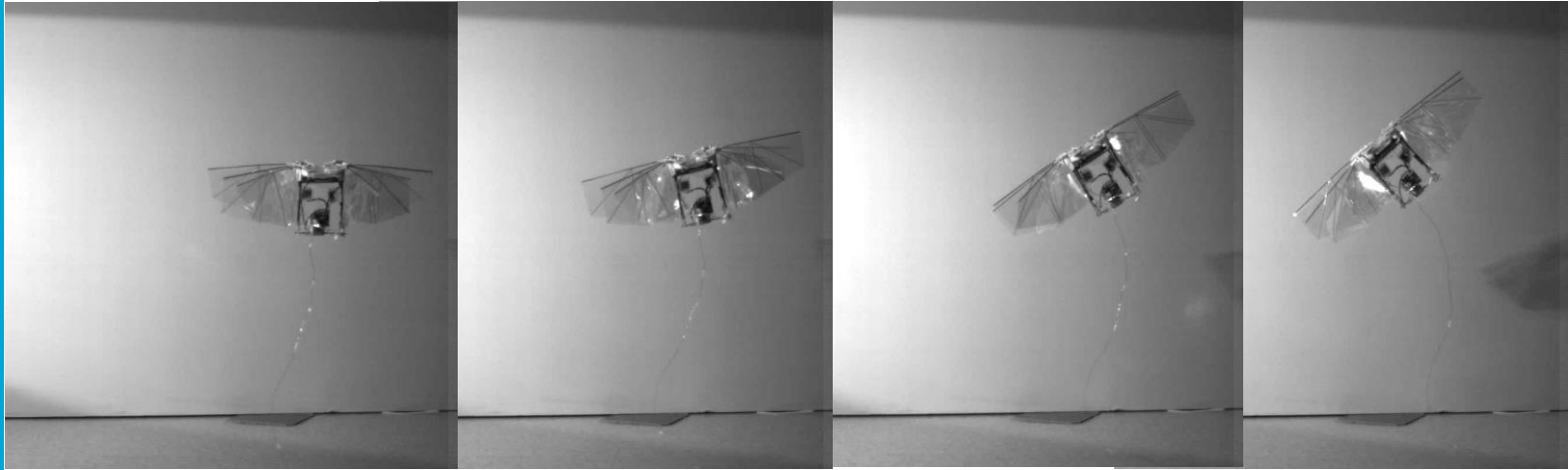
Lateral Step



Roll angle in time for 2 m side step



High speed camera footage



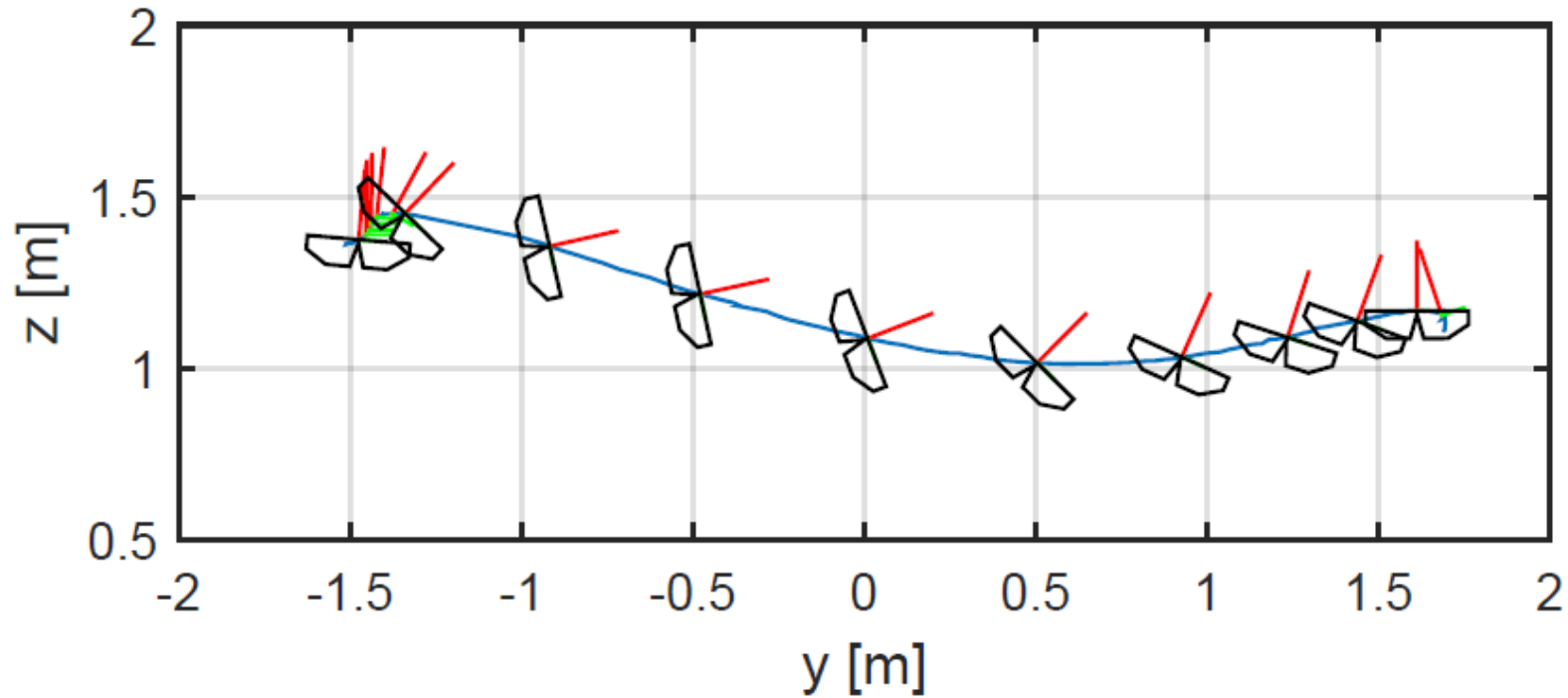
$t=0\text{ms}$

60ms

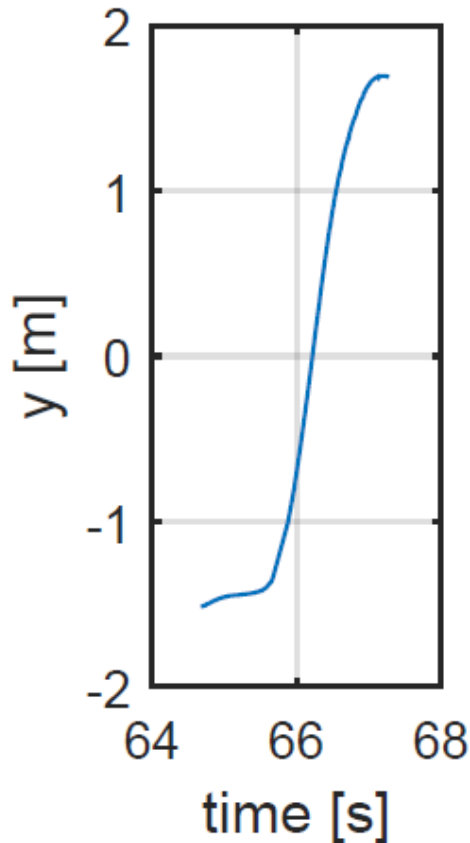
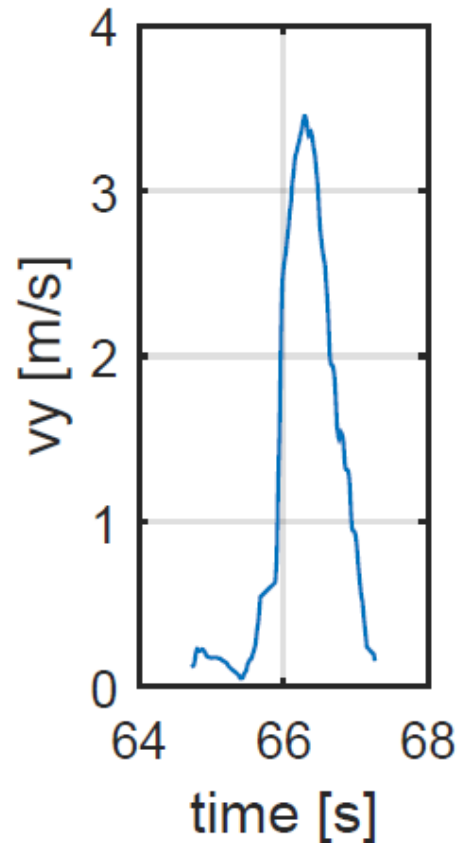
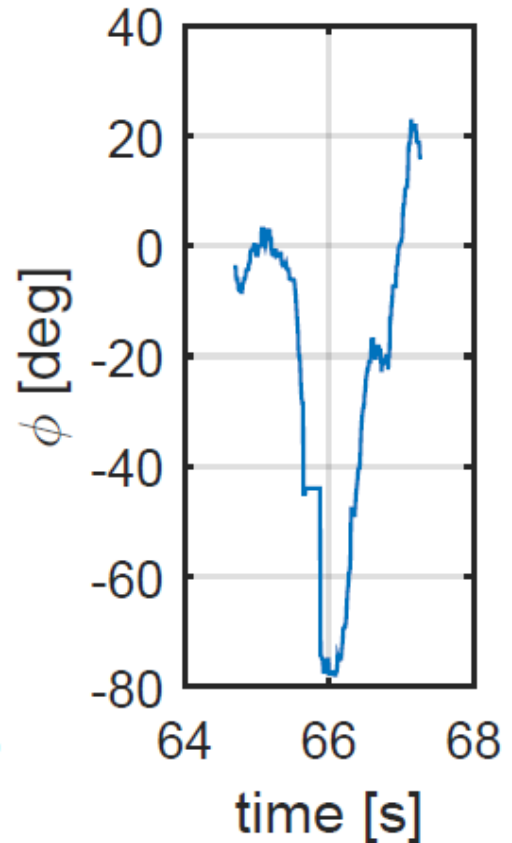
120ms

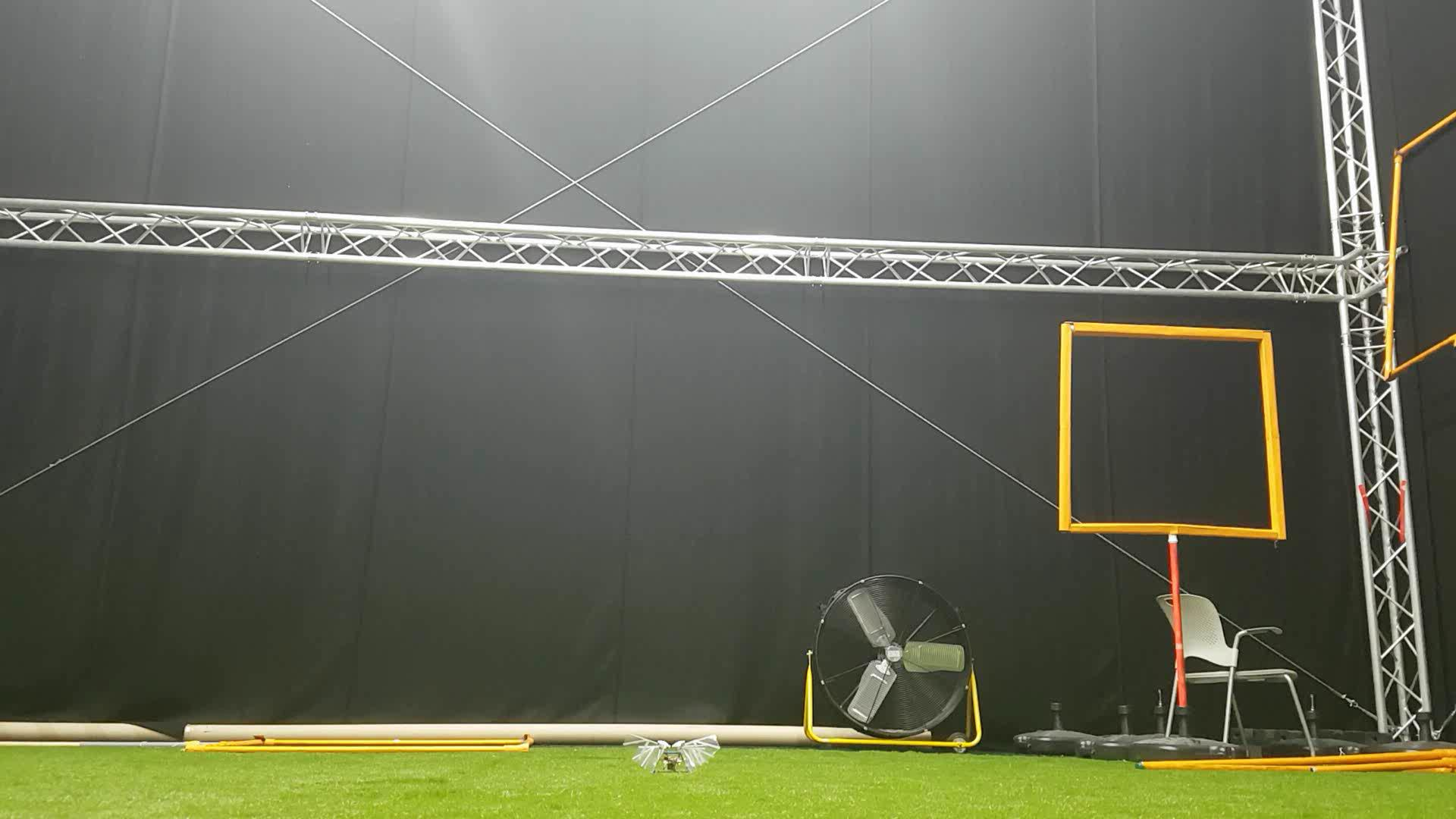
180ms

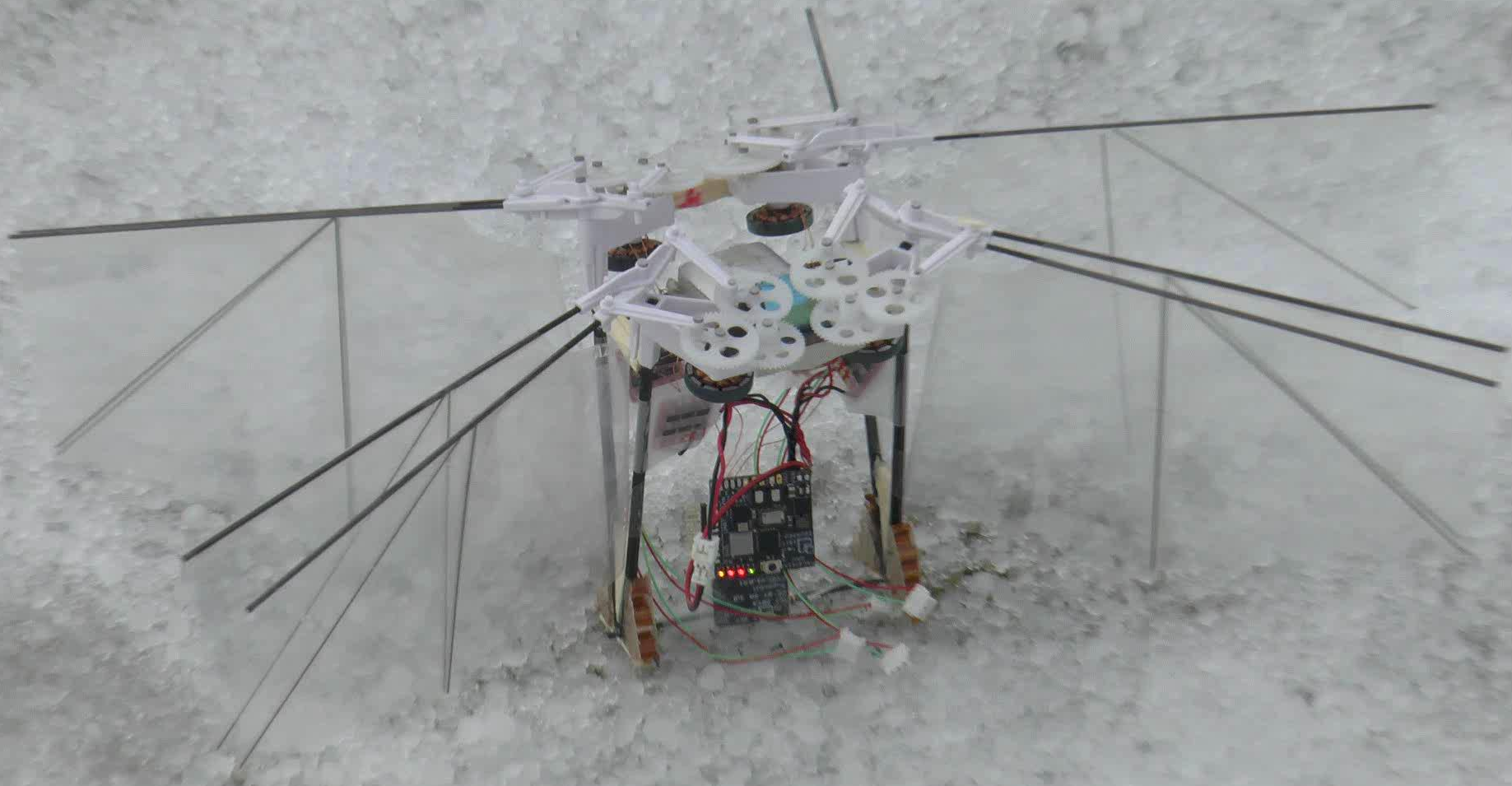
Lateral 3m Step



Time sequence of 3m side step







Conclusion

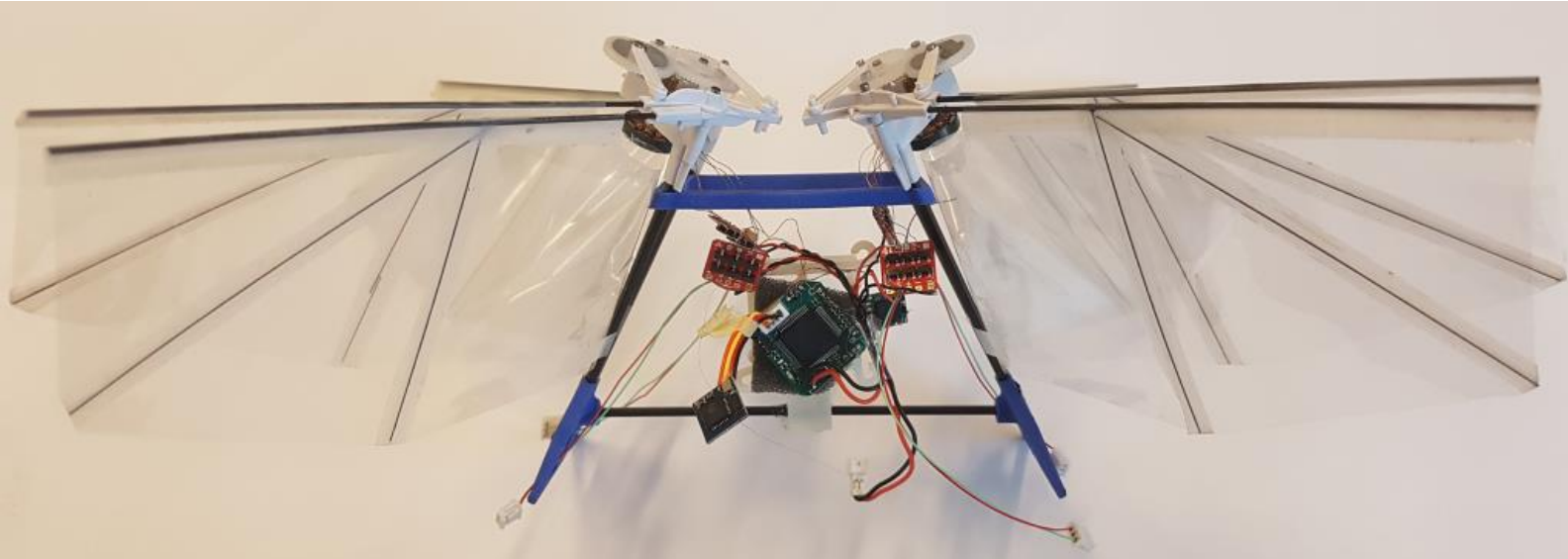
- Control similar to quadrotors
 - Control effectiveness little influence of airspeed
- Actuators: Fast, Strong (Heavy) -> but used for thrust as well.
- Half of theoretical maximum authority:
 - 100% power on 1 wing, 0% on other

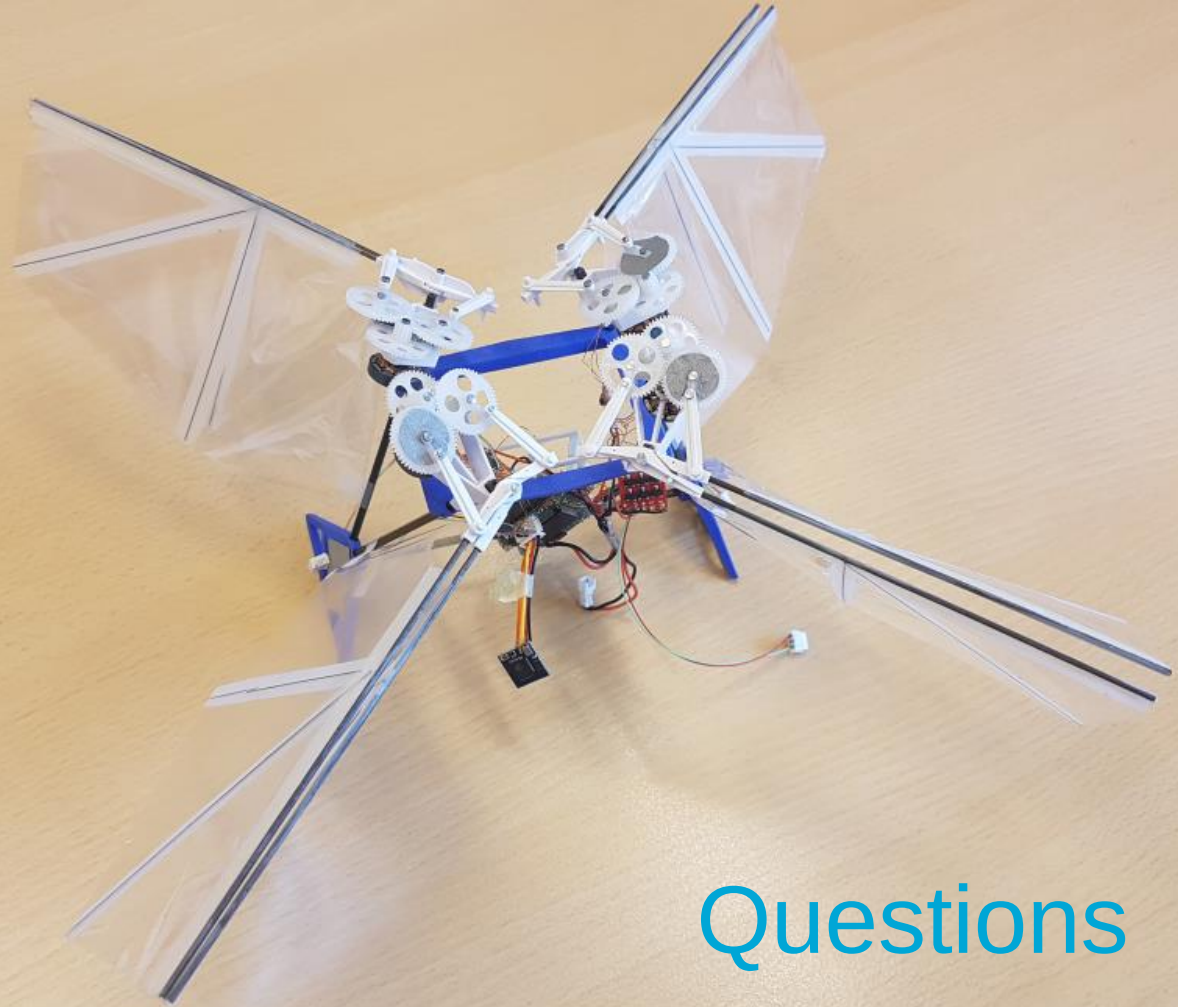
Conclusion

- Flapping moments fully balanced
 - Dual pair of wings
- Acceptably low residual vibration
 - Due to non-uniform lift in function of time
- Trade off efficiency with yaw authority

Recommendations

- Yaw by moving trailing edge
- More research on fast forward flight

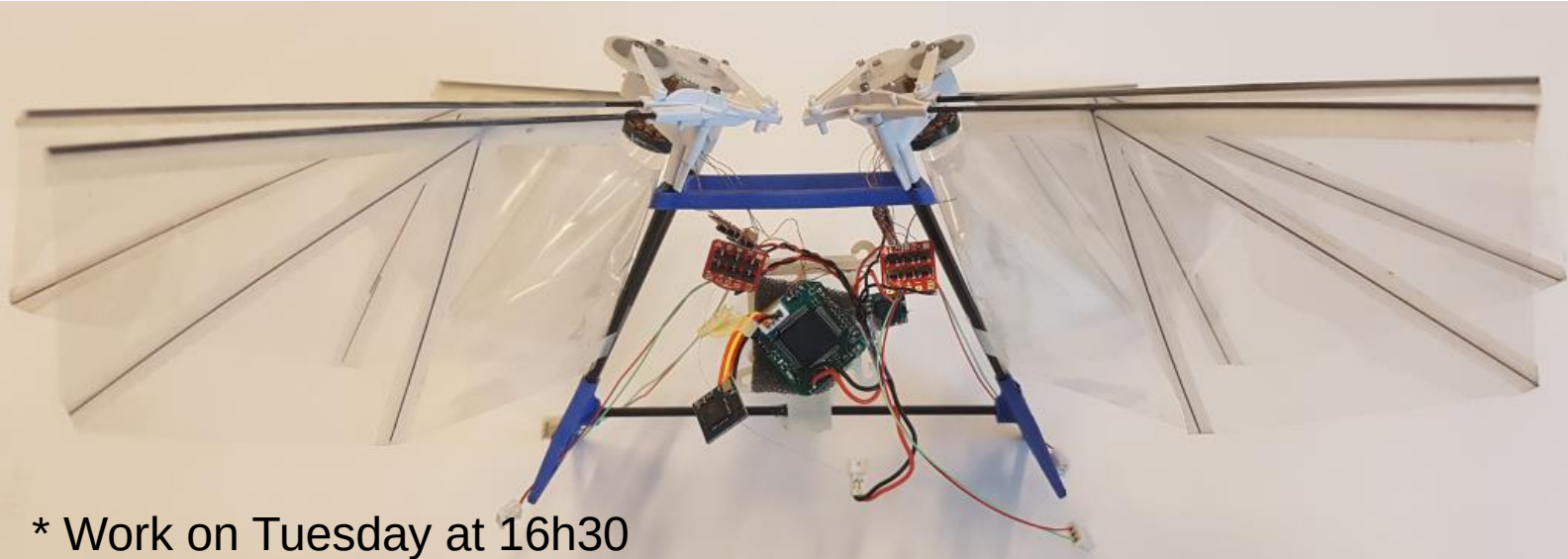




Questions

Demo

- ERL Level 3 shown in video
- Can it also reach ERL 4*?



* Work on Tuesday at 16h30