IMAV2017

Bond Graph based design tool for a passive rotation flapping wing

Le Anh Doan*, Christophe Delebarre, Eric Cattan, Sebastien Grondel
University of Valenciennes and Hainaut-Cambresis
*LeAnh.Doan@etu.univ-valenciennes.fr

iemn
Institut d'Electronique, de Microélectronique
et de Nanotechnologie
UMR CNRS 8520

Content

iemn
Institut d'Electronique, de Microélectronique et de Nanotechnologie
UMR CNRS 8520

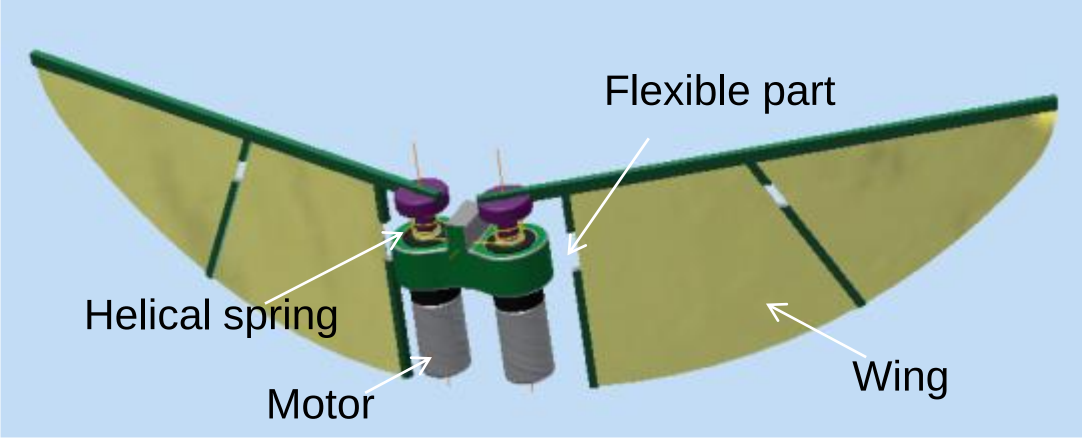
Introduction

Usually it is enough to predict the wing kinetics and aerodynamics of flapping MAV by a set of dynamic equations, there are still benefits in presenting the system by the Bond Graph (BG) formalism. Several advantage are listed as follows:

- Making simpler the building of models for **multi-disciplinary** systems.
- Showing up explicitly the **power flows** through the system
- Giving insight into the **inter-relationships** of the **state variables**.
- Making the system **clear** and **straight forward**. This may point out the possibility of **simplifying assumption**.

In this work, we build a BG model for our flapping MAV and use it **enhance** the **system performance** by **optimizing** the **key parameters**.

Introduction

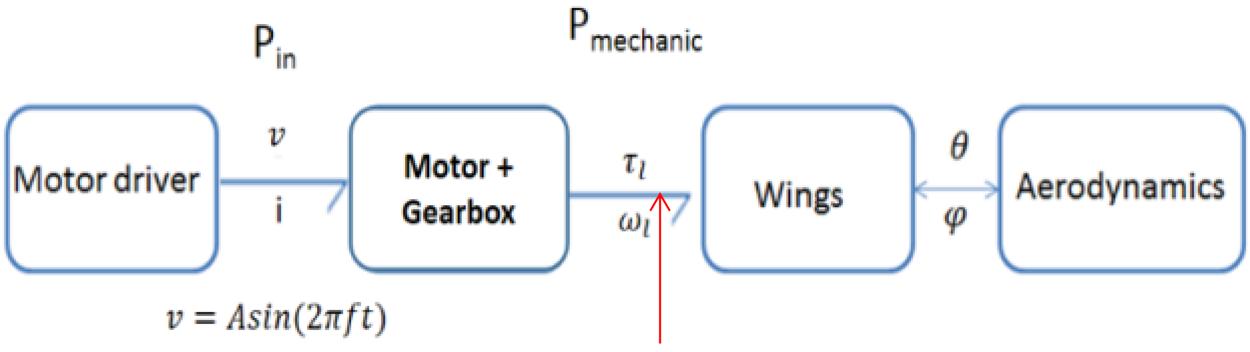


Bio-inspiration: humming bird (wing flaps and rotates during stroke)
Principle :

- Driven by motors
- Added helical spring (the system is capable to work at resonance)
- Passive rotational flapping wings (use of flexible parts)

MAV size: wing length: 8.5 cm; maximum chord length: 3.5 cm ,total mass: 2.8g.

Word Bond Graph of our flapping MAV



Bond

v, i: driving voltage and current

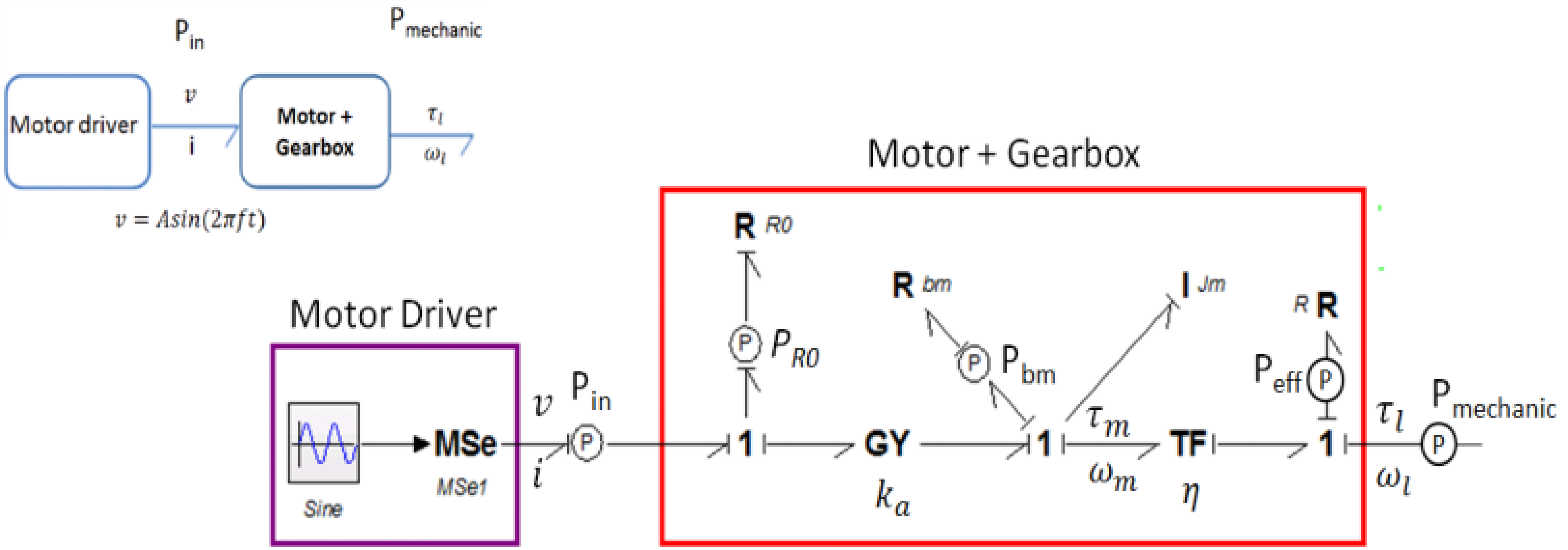
τ_l and ω_l : output torque and angular velocity of geared motor

θ and φ : flapping and rotational angles

P_{in}: supplied power, $P_{mechanic}$: power given to wings

Model is built for ONLY half of prototype (1.4 g)

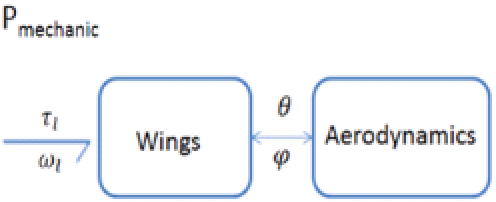
Motor driver and geared motor models



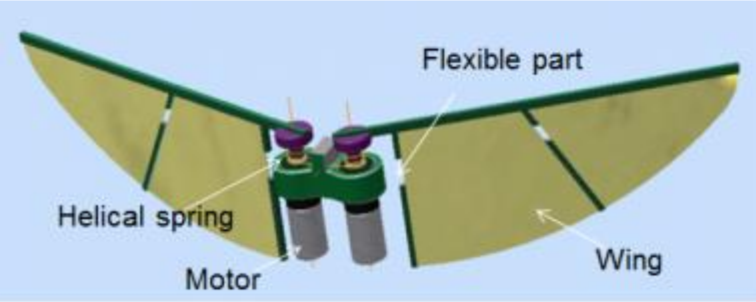
R_0 : the motor winding resistance
GY: the motor's armature constant, k_a.
J_m : the rotor inertia, b_m: the motor rotational damping
TF: the gearbox with the gears ratio, η.
R: the gearbox efficiency.

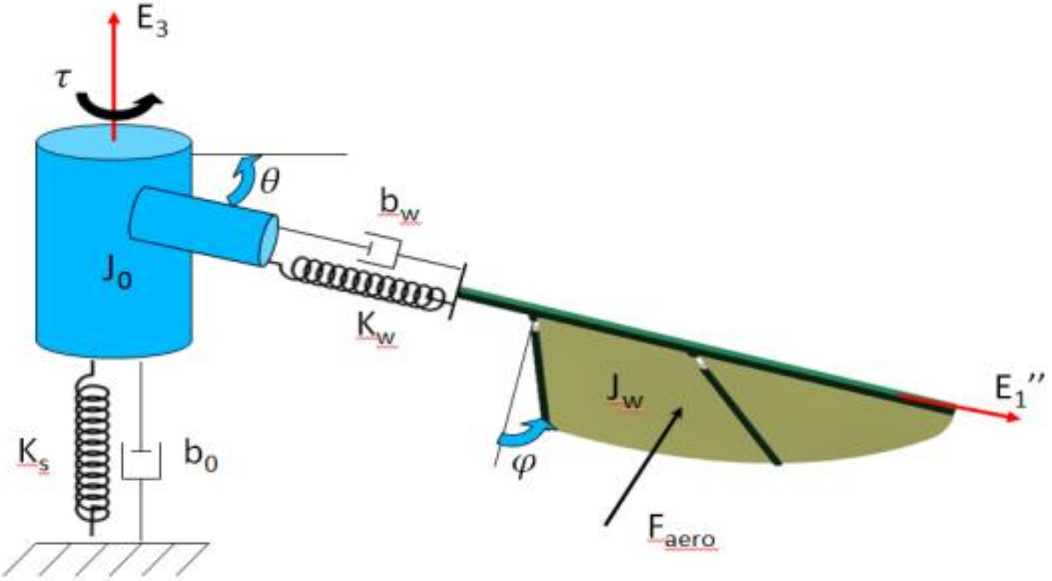
iemn
Institut d'Electronique, de Microélectronique et de Nanotechnologie
UMR CNRS 8520

Wing model



Wing is presented by two systems of mass spring and damper corresponding to its flapping and rotation movements





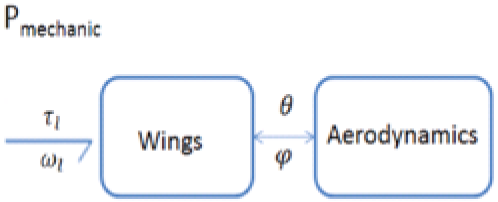
$J_0 = \eta^2 J_m$

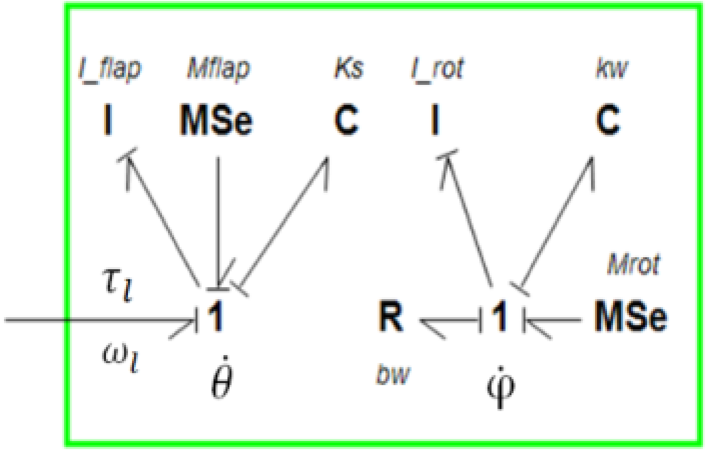
K_s: stiffness of added helical spring; $b_0 = \eta^2 b_m$

K_w and b_w : Wing rotational stiffness and damping related to flexible part

J_w: wing inertia moment; F_{aero}: aerodynamic forces

Wing model





Values of I_{flap} and I_{rot} can be found from Lagrangian equation describing the wing movements

$$L = T - V = \frac{1}{2} m_w \vec{v}.\vec{v} + \frac{1}{2} J_w \vec{\omega}.\vec{\omega} - \frac{1}{2} K_w \varphi^2 - \frac{1}{2} K_s \theta^2$$

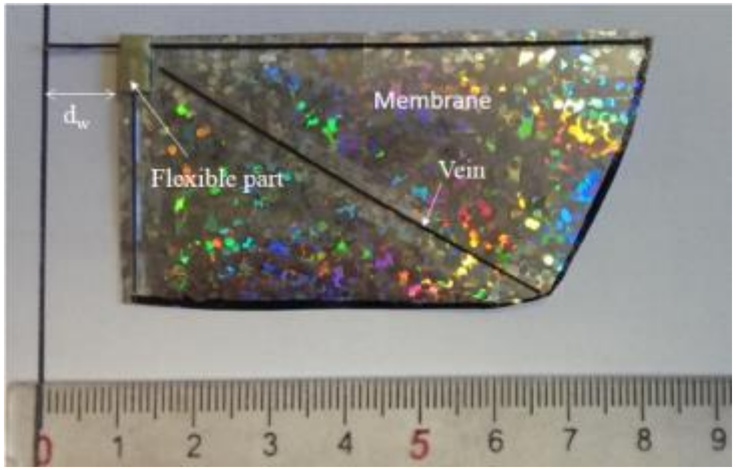
$$\frac{d}{dt}\left(\frac{\partial L}{\partial \dot{\varphi}}\right) - \frac{\partial L}{\partial \varphi} = \vec{M}_{aero\_rot} - b_w \dot{\varphi} \qquad \frac{d}{dt}\left(\frac{\partial L}{\partial \dot{\theta}}\right) - \frac{\partial L}{\partial \theta} = \vec{M}_{drive} + \vec{M}_{aero\_flap}$$

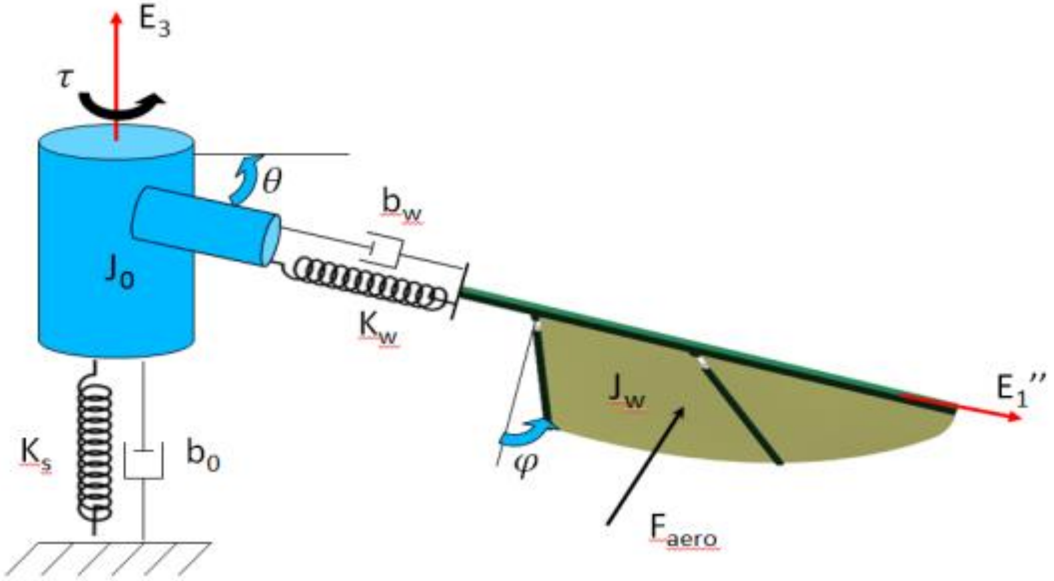
where $\vec{M}_{aero\_rot}$ and $\vec{M}_{aero\_flap}$ are moment generated by F_{aero} on corresponding axes

Aerodynamic: $F_{aero} = F_{trans} + F_{rot} + F_{air}$ (Quasi-steady)

Optimization

Objective:
Find values of key parameters for a proper wing kinetics which enhance the F_{aero}





Key parameters
- Driving voltage: v and frequency: f
- Rotational stiffness of helical spring: K_s
- Rotational stiffness of wing: K_w
- Wing offset: d_w

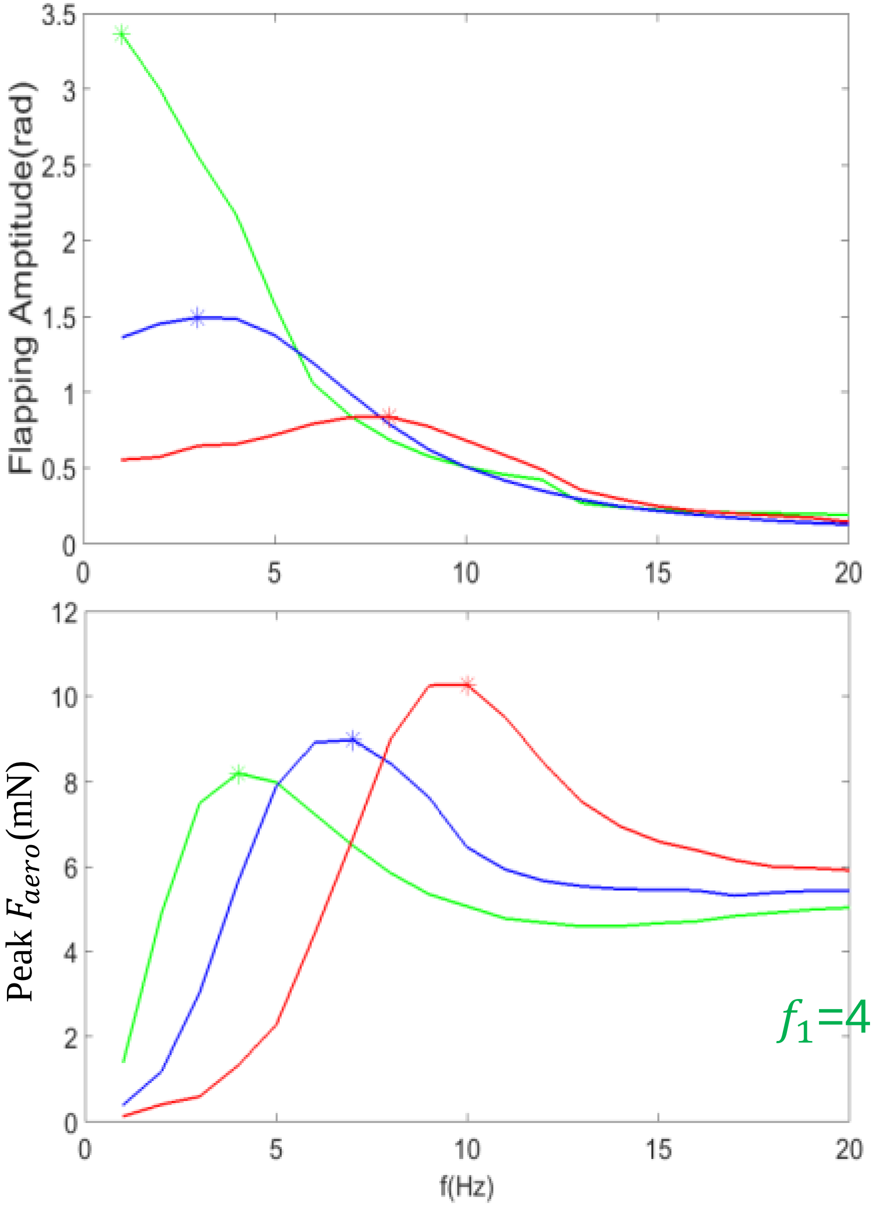
Sensitivity to spring stiffness (K_s) and driving frequency (f)

Three system with difference values of Springs' stiffnesses

🟩 0.5503 N.mm/rad
🟦 1.3934 N.mm/rad
🟥 2.956 N.mm/rad

Input voltage

$v = 2sin(2\pi f t)$



Peak lift force happens beyond the flapping resonance.

Result

f_1=4Hz f_2=7Hz f_3=10Hz

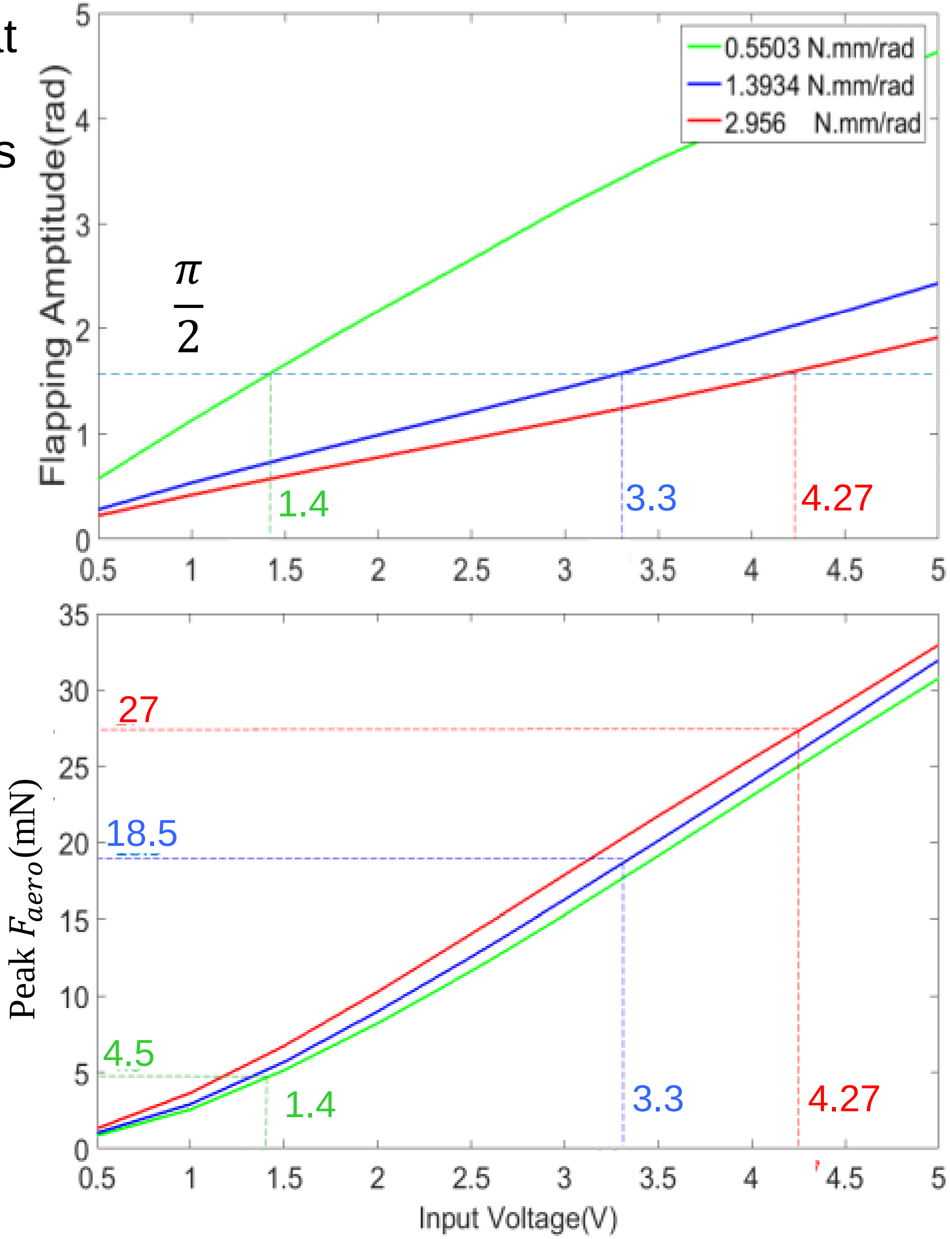
Sensitivity to input volatage (v)

Systems operate at frequencies where maximum peak-lifts occur

f_1=5HZ

f_2=7HZ

f_3=10HZ



🟩 0.5503 N.mm/rad

🟦 1.3934 N.mm/rad

🟥 2.956 N.mm/rad

In reality, flapping amplitude should not exceed $\pi/2$ to avoid wings collision

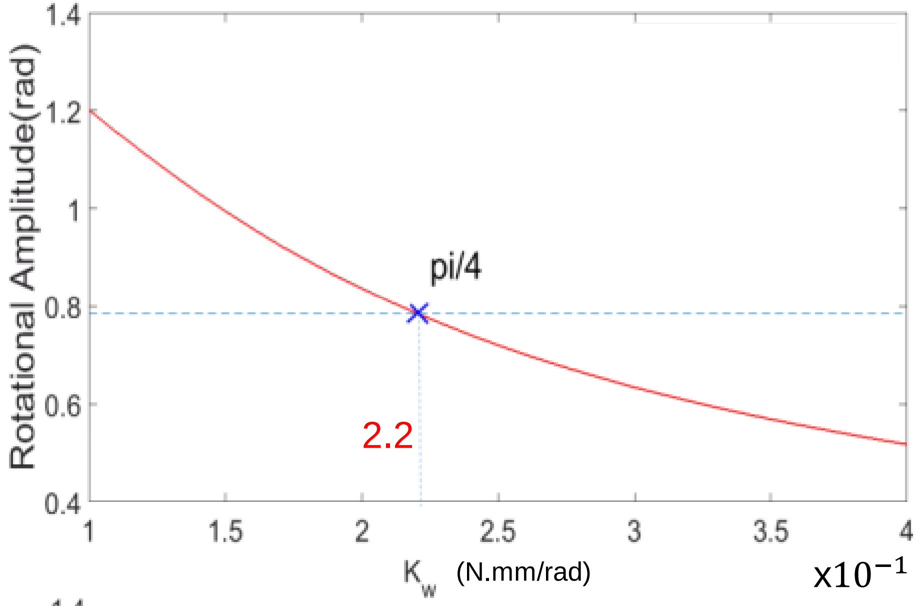
Result

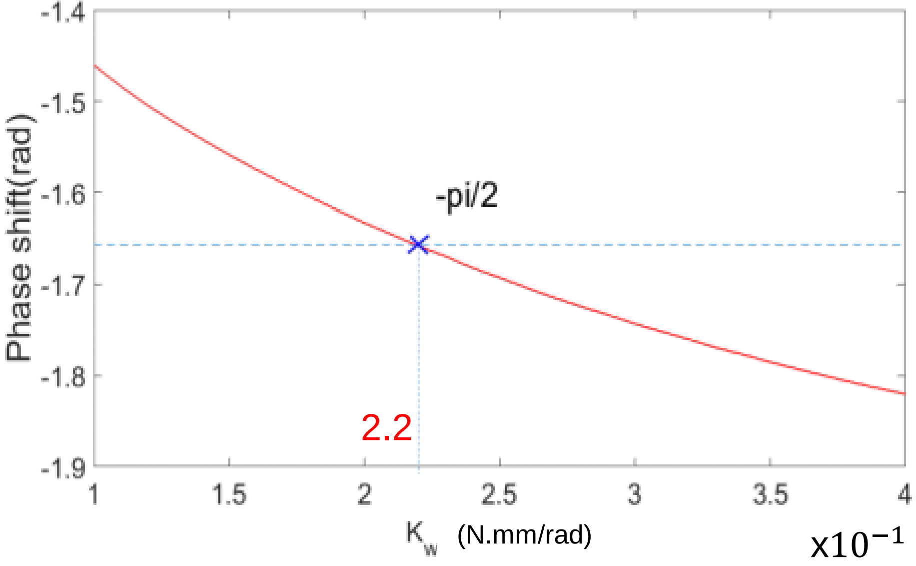
f_3=10Hz

v = 4.27 V

K_S=2.956 N.mm/rad

Sensitivity to wing stiffness (K_w) and wing offset (d_w)



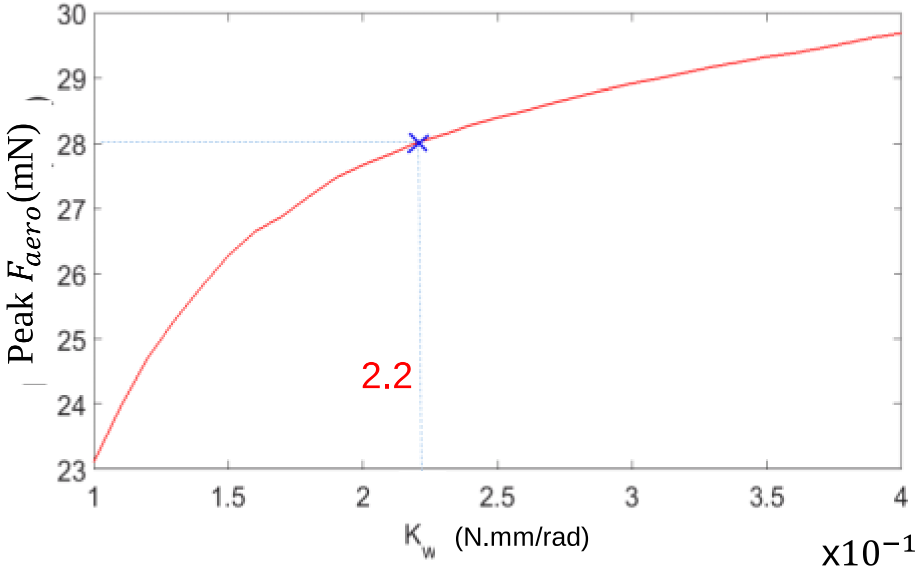


Input voltage

$v = 4.27 sin(2\pi 10t)$

Springs' stiffnesses

K_S = 2.956 N.mm/rad



Result

K_w=2.2e-1 N.mm/rad

Sensitivity to wing offset

Input voltage

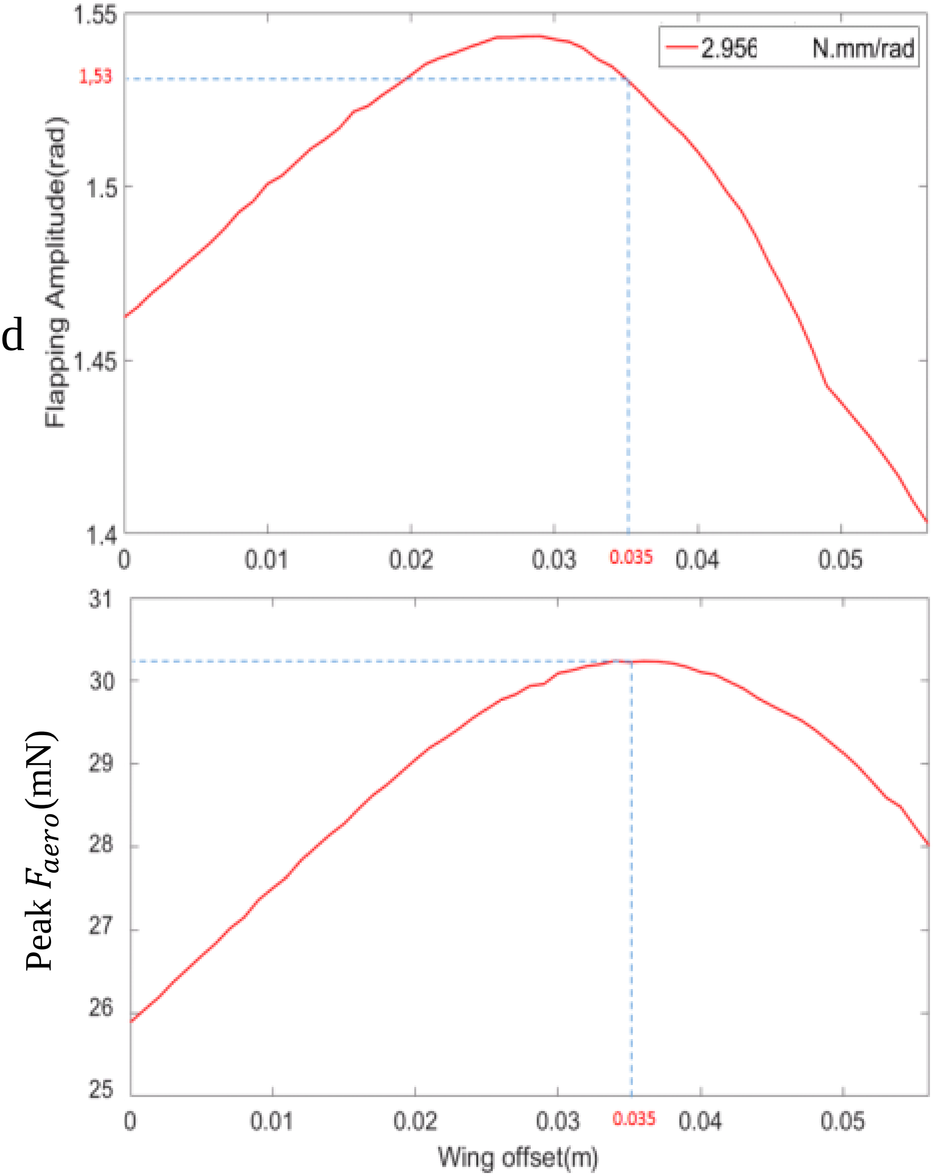
$v = 4.27 sin(2\pi 10t)$

Spring's stiffnesses

K_S = 2.956 N.mm/rad

Wing's stiffnesses

K_w = 2.2e-1 N.mm/rad



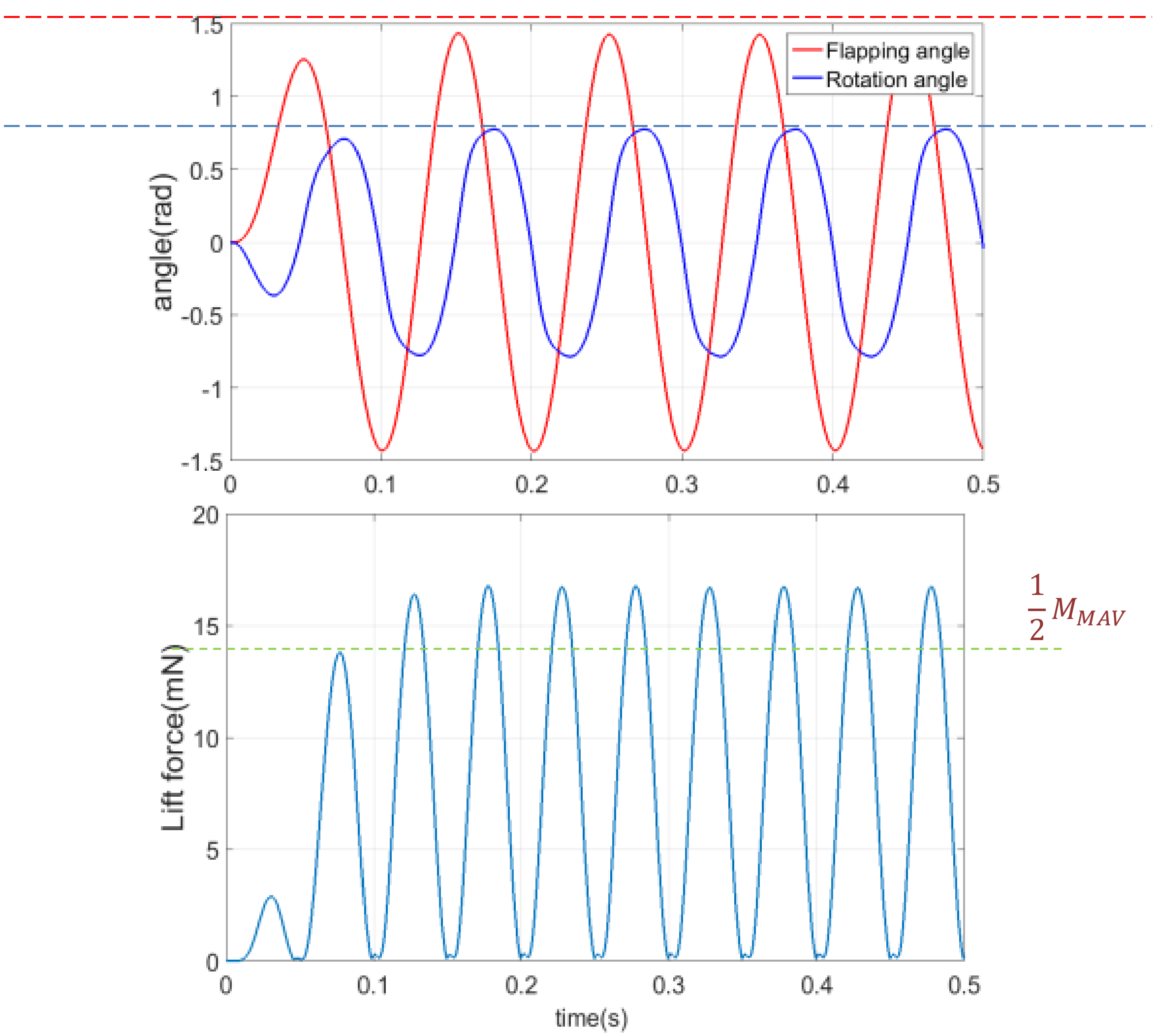
Result

d_w= 35 mm

Optimized parameters

	Parameter	Value	Unit
Motor and motor driver	K_s	2.956e3	mN.mm/rad
	A	4.27	V
	f_0	10	Hz
Wing mechanical characteristics	K_w	220	mN.mm.rad
	d_w	35	mm
	b_w	1.5	mN.mm.s/rad
Wing kinematic	$\varphi_{amplitude}$	$\pi\backslash 4$	rad
	$\theta_{amplitude}$	$\pi\backslash 2$	rad
	ϕ_{lag}	$\pi\backslash 2$	rad
Aerodynamic force	F_{peak}	0.03	N

Simulation

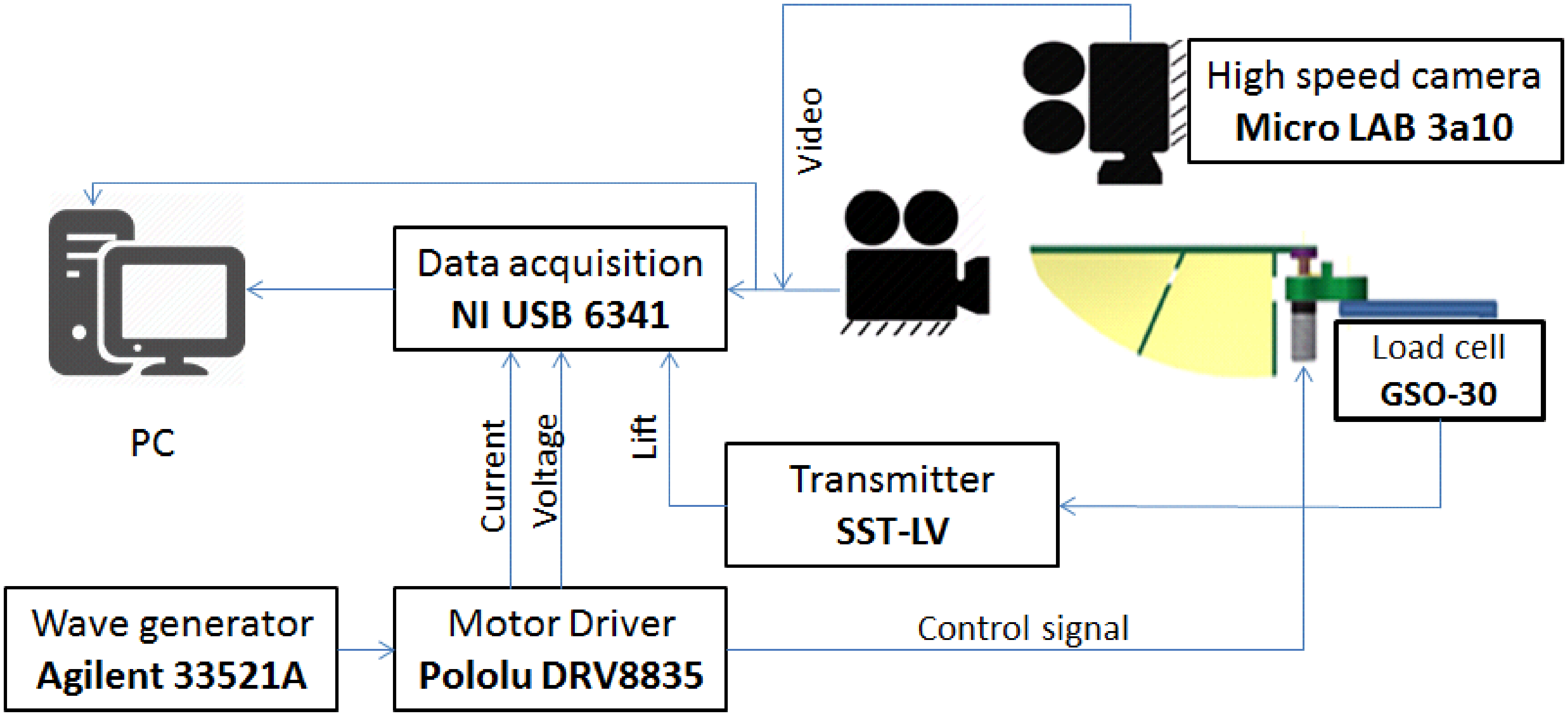


$\frac{\pi}{2}\ rad$

$\frac{\pi}{4}\ rad$

$\frac{1}{2}M_{MAV}$

Diagram of experiment set-up



High speed camera
Micro LAB 3a10

Video

PC

Data acquisition
NI USB 6341

Load cell
GSO-30

Current

Voltage

Lift

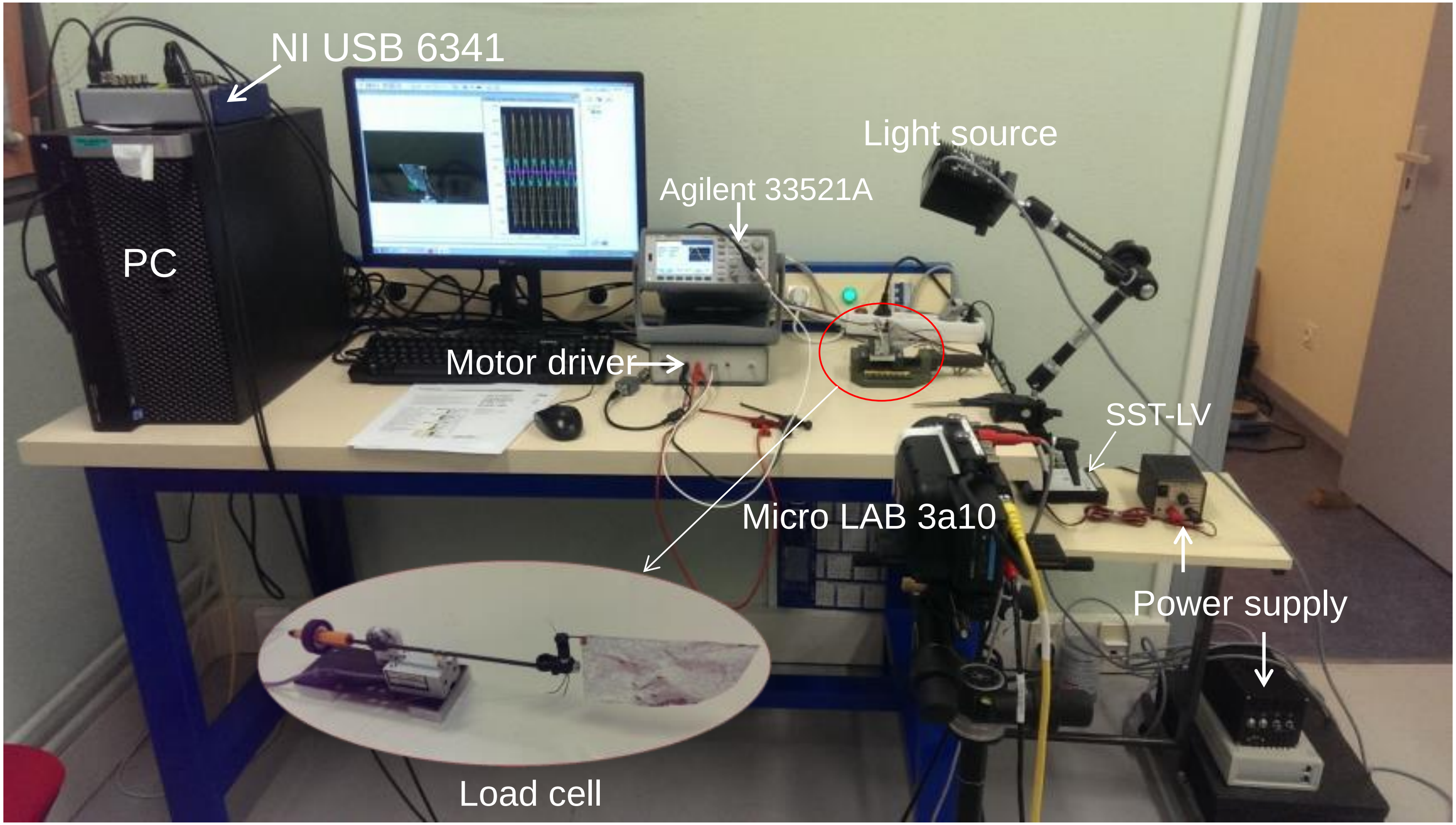
Transmitter
SST-LV

Wave generator
Agilent 33521A

Motor Driver
Pololu DRV8835

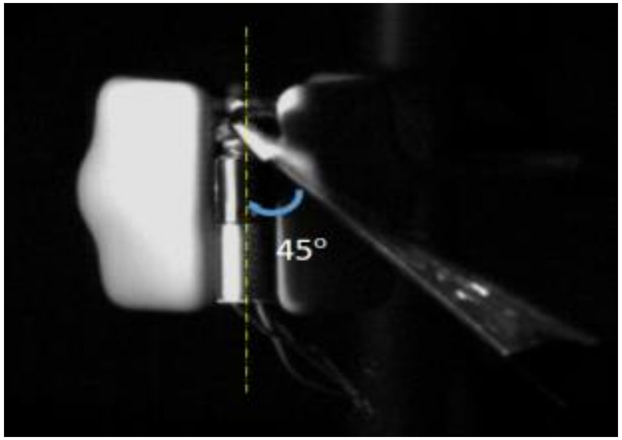
Control signal

Experiment set-up

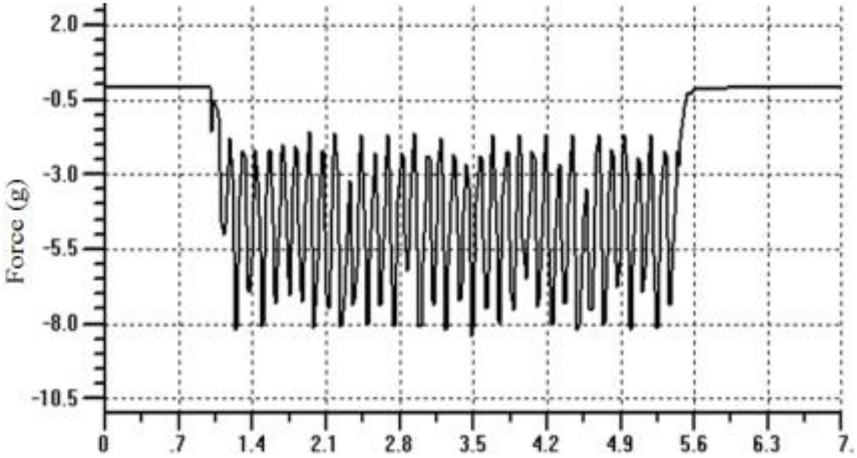


Experiment results

Rotation angle ($\varphi = 45^o$)



Measure force: 0.4 g => Lift force = 1.8 g

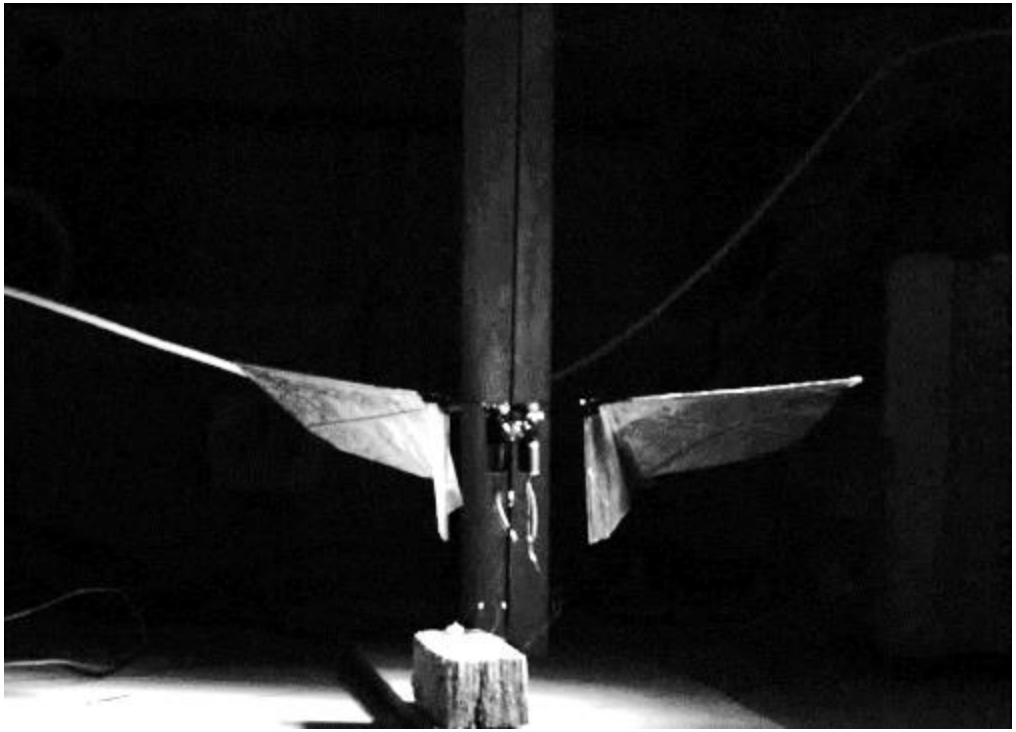


	Parameter	Simulation	Experiment	Unit
Wing kinematic	$\varphi_{amplitude}$	$\pi\backslash 4$	$\approx \pi\backslash 4$	rad
	$\theta_{amplitude}$	$\pi\backslash 2$	$\approx \pi\backslash 2$	rad
	ϕ_{lag}	$\pi\backslash 2$	$\approx \pi\backslash 2$	rad
Lift force	F_{peak}	0.017	0.018	N

Lift to weight ratio = $\frac{1.8}{1.4}$ = 1.28

Take-off demonstration

As the lift weight ratio is equal 1.28, it is possible to lift the prototype



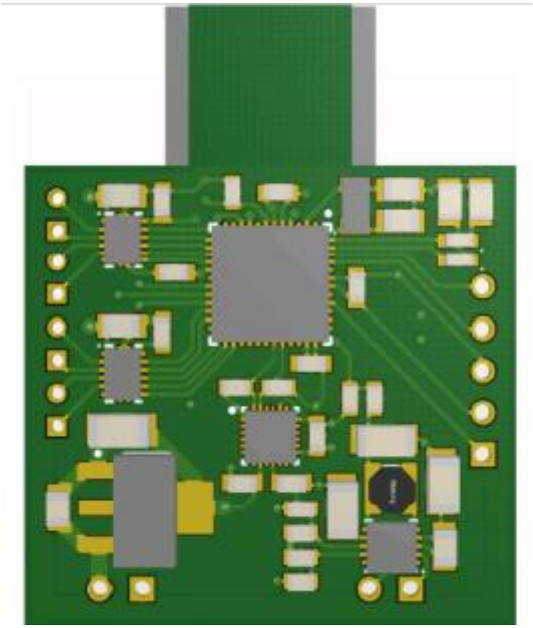
Conclusion and Perspective

- We can conclude that our flapping MAV generates enough force to lift our prototype, which validates the results of our Bond Graph model.

- A 2g electronic circuit including motor driver, IMU unit, microcontroller, and radio device has been developped by our group.

- Future work focuses on improving the lift force by increasing the wing speed (U) but remaining the same wing kinematic as before.

$$F_{trans} = \frac{1}{2}\rho U^2 c(r)\left[C_l^2(\alpha) + C_d^2(\alpha)\right]^2 dr$$



Electronic circuit (2g)

THANKS FOR YOUR ATTENTION