GRIFFIN

erc Advanced Grant

Reduced Order Numerical Model of Flapping Wing Unsteady Aerodynamics

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grvc

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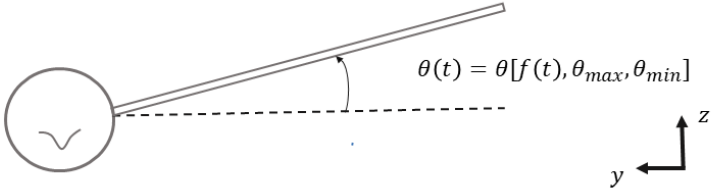
1. Proposed approach

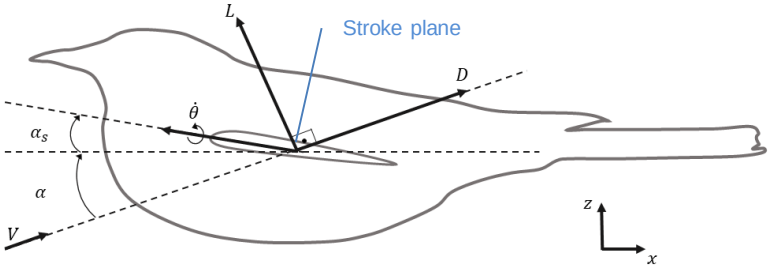
ROM=Reduced Order Model

- **Analytical models:**
  Small perturbations.
  Applicability problems

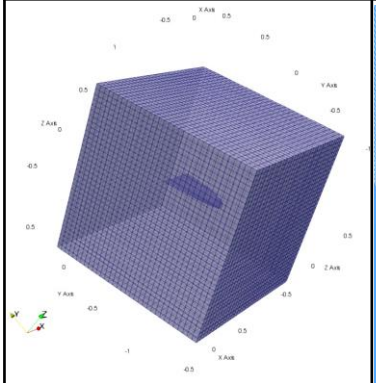
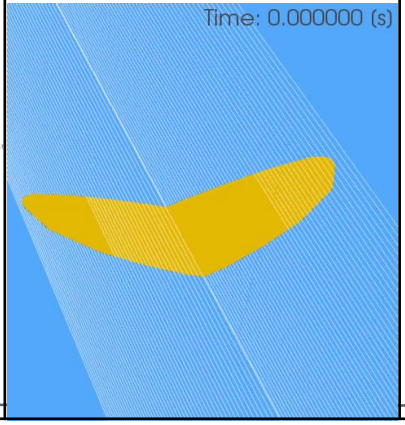
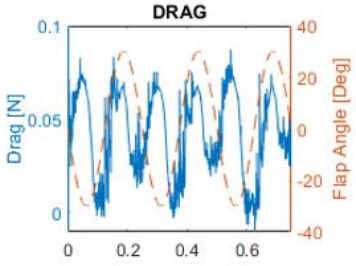
- **Quasi-steady models:**
  flapping frequency ≈0.

- **Full unsteady CFD:**
  Unaffordable for full envelope.





2. CFD Identification procedure: Simulations + Wind Tunnel Validation

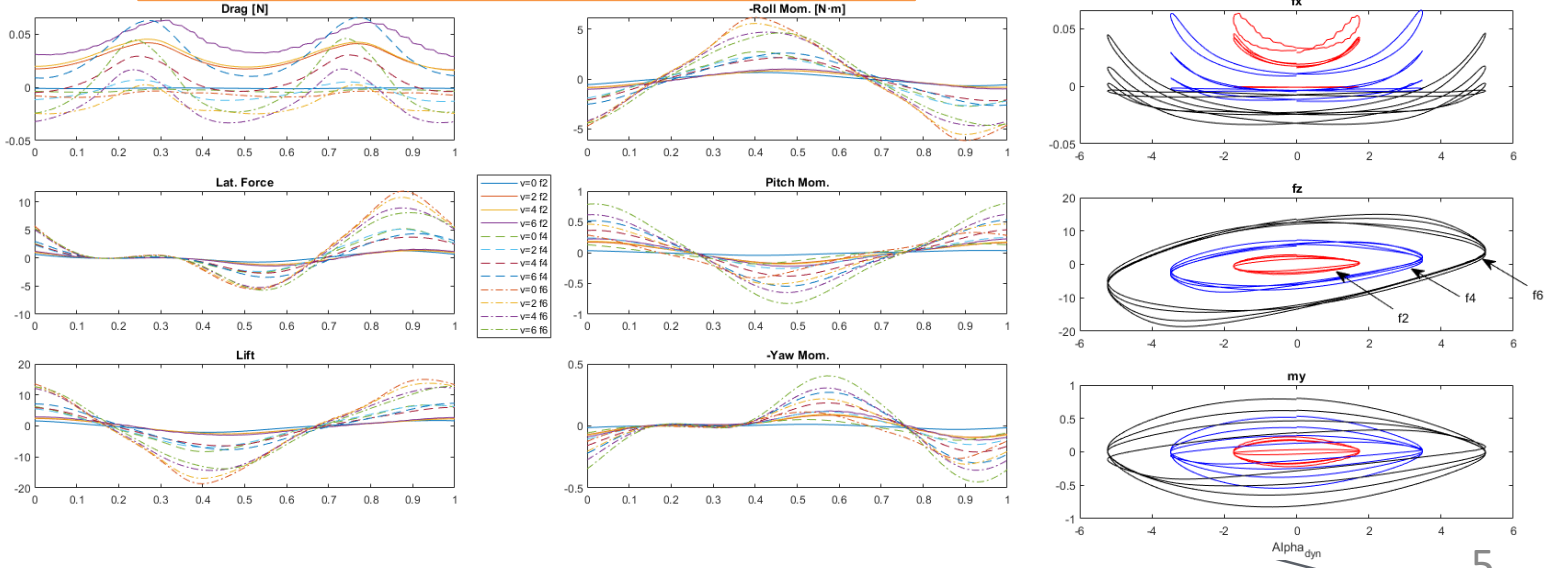
PREPROCESSING OVERSET MESH	SIMULATION ANSYS FLUENT	POSTPROCESSING PARAVIEW	VALIDATION WIND TUNNEL
NEW TECHNIC: Overset mesh	1 Day 1 Flapping. Batch mode.	Forces and moments in desired reference frame	Experimental data provided by wind tunnel
			

2. CFD Simulations: Results

72 simulations

- Free stream velocity: **[0 , 6] m/s**
- Flapping frecuency: **[2 , 6] Hz**
- Angle of attack: **[-8 , 8] deg.**
- Flapping kinematics/ platform: **TWEETY**

Dynamic induced AoA:
60% semi span
¾ chord

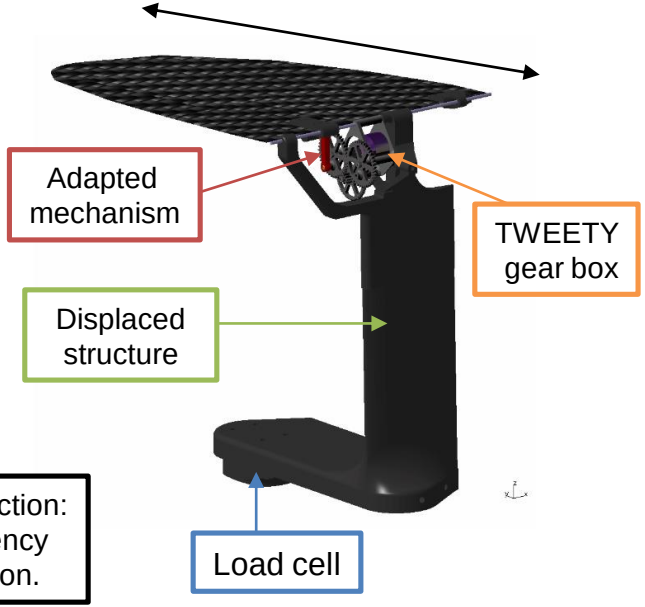


3. Wind tunnel preparation:

Challenge: **"As rigid as posible"** in order to neglect the elastic phenomenon.

- 5 different manufacturing:

Material	Thickness [mm]	Weight [g]
Reinforced Wood	2	0.124
	1.2	0.084
Carbon Fiber	2	0.208
	1.5	0.160
	1	0.110



Considerations:

- Wall effect.
- Dynamic similarity: flapping **frequency ~k^2**
- **Torque ~l*f^2**

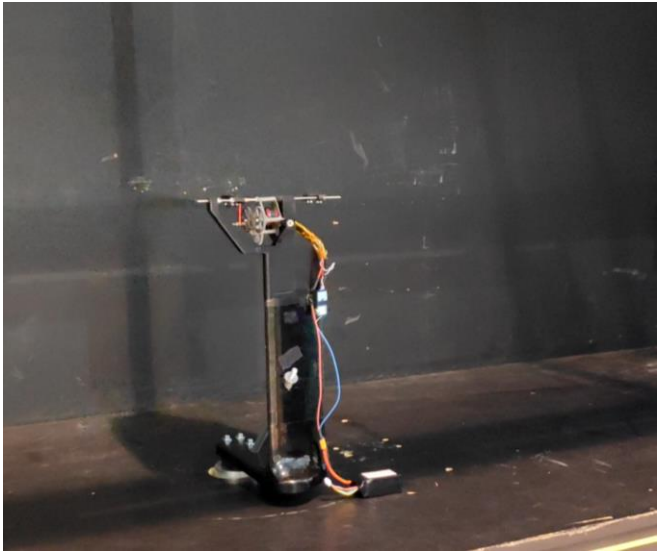
Frequency selection: Power-Frequency characterization.

3. Wind tunnel experiments:

-UMA 1x1m section Wind tunnel.

- **Velocity limit:** 6 m/s
- **Power limit:** 4 Hz (2 Hz)

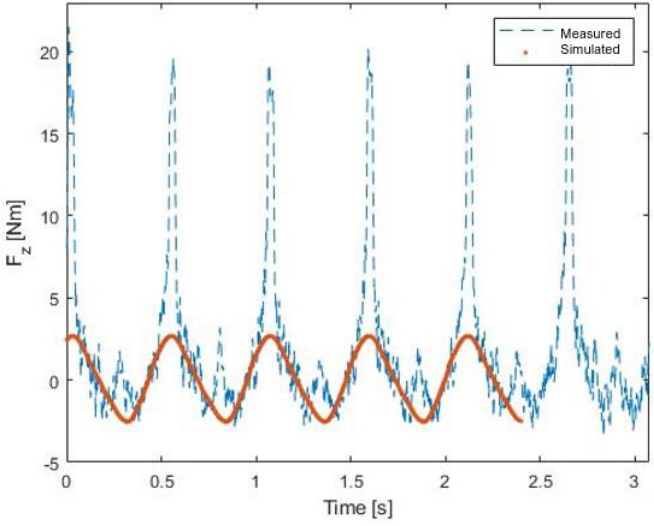
-**Unstable control** of the gauge cell.



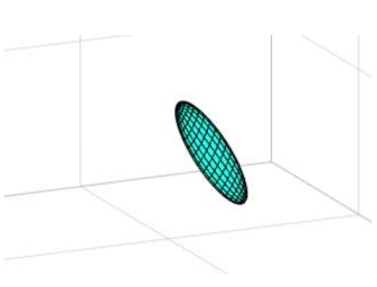
3. Wind tunnel results:

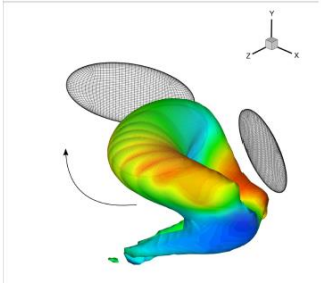
Validation

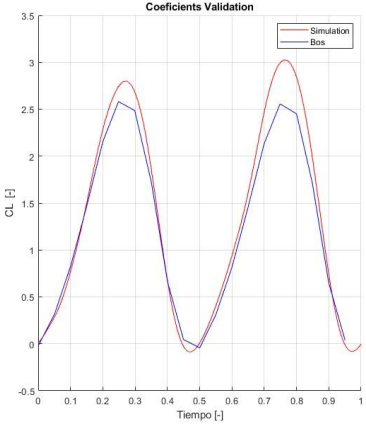
- **Noisy measurements**: Aerodynamic harmonic signals due to structure excitation and unstable control of the load cell.
- **72 experiments:** V inlet: [0, 4, 6] m/s.
  Frequency: [0,4] Hz.
  Conducted in triplicate.

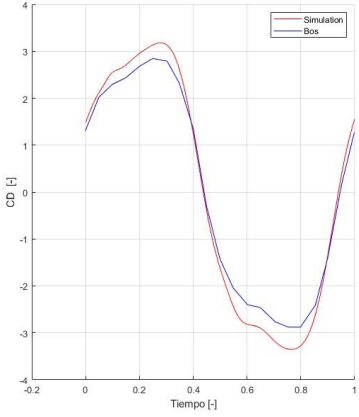


Verification: Literature data, Figure of eight shape.









4. Volterra-Wiener Model

$$\bar{L}(t) = \rho_\infty \pi b^2 \left[-\omega^2 \bar{h}_e(t) - \left(\frac{c}{2} - x_e \right) \omega^2 \bar{\alpha}(t) \right] + \rho_\infty \pi b^2 i\omega \bar{\alpha}(t) +$$

$$+ 2\pi \rho_\infty b U_\infty \int_{-\infty}^{t} dt' i\omega \bar{w}_{3/4}(t') \Phi \left(\frac{U_\infty}{b}(t - t') \right)$$

Allows memory: Analogous to traditional analytical models: Convolution integral.

Ex.: Theodorsen theory (2D, small AoA, inviscid…).

$$y(t) = \int_{-\infty}^{\infty} u(\tau)\, h(t - \tau) \mathrm{d}\tau$$

-Volterra model: LTI, time and frequency domain.

$$y[n] = \sum_{i=1}^{p} \mathbb{H}_i$$

$$= \sum_{k=0}^{n} H_1[n-k]x[k]$$

$$+ \sum_{k_1=0}^{n} \sum_{k_2=0}^{n} H_2[n-k_1, n-k_2]x[k_1]x[k_2]$$

$$\vdots$$

$$+ \sum_{k_1=0}^{n} \cdots \sum_{k_p=0}^{n} H_p[n-k_1, \cdots, n-k_p] \prod_{i=1}^{p} x[k_i]$$

Kernels to identify

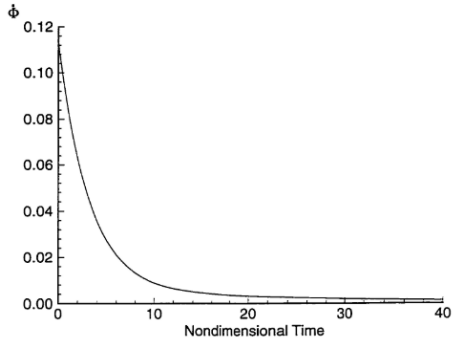
Order

5. Current sate:

- **Kernel Supervised Identification Methods:**

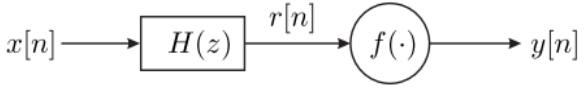
- **Least Squares based methods:** Fixed memory -> Overfitting.

- **Kernel shape functions:** based in Theodorsen function.



Wagner's function of AoA impulse.

- **Block based models:**
  Wiener and Hammerstein simplifications.

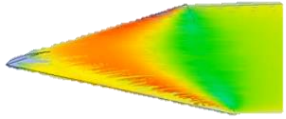


Wiener system: Volterra simplification.

- **Kernel Canonical Correlation Analysis (KCCA):** Feature space analysis.

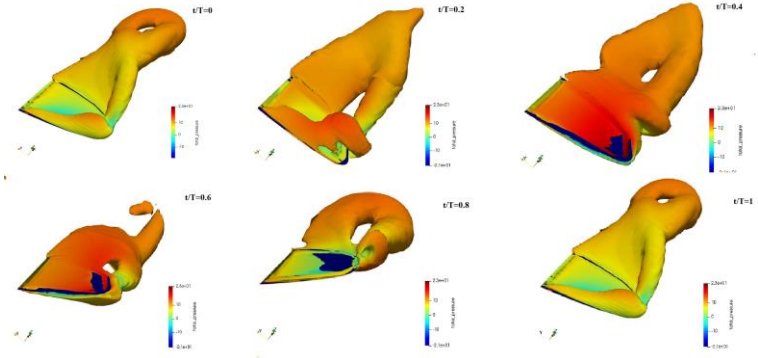
- **Overfitting:** Regularization technics.

6. Future work



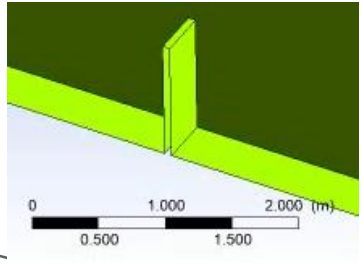
- **Improve wind tunnel experiment**: New support structure.

- **Bioinspired tail identification.**



- Volterra MIMO identification.

Pitching+Flapping simulations.



- Further: Elastic and Aeroelastic kernels identification

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Thanks for your attention!

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