



# Ornithopter Flight Models: Lines of Research

Ernesto Sánchez-Laulhé Cazorla, Ramón Fernández Feria

# Current Lines of Research

- Formulation of aerodynamic forces under an oscillating airstream
- Simple model for gliding maneuvers out of the longitudinal plane (3D gliding)
- Analysis of flapping forward flight for elastic wings and high amplitudes
- Analysis of gliding stability and control

# Oscillating Airfoil: Overview

- Oscillations of the airspeed observed in ornithopters flight with different frequencies – effect on the flapping wing aerodynamics
- Theoretical formulation – vortical impulse theory
- Comparison with experimental and theoretical studies

# Theoretical Formulation

- Considerations:
  - Flapping movement
    - $\dot{h} = i\omega_1 h_0 e^{i\omega_1 t}$
    - $\alpha = \alpha_s + \alpha_0 e^{i\omega_1 t}$
  - Oscillating airstream
    - $U = U_s + U_0 e^{i\omega_2 t}$
- Final formulation: Crossed frequencies
  - Lift – 7 frequencies.

# Previous Works

- Harris, Salil, and Sunetra Sarkar. "Effect of sinusoidal gust on thrust generated by a plunging airfoil." *Fluid Mechanics and Fluid Power—Contemporary Research*. Springer, New Delhi, 2017. 1401-1409.
- Lian, Yongsheng. "Numerical study of a flapping airfoil in gusty environments." *27th AIAA Applied Aerodynamics Conference*. 2009.
- Greenberg, J. Mayo. "Airfoil in sinusoidal motion in a pulsating stream." No. NACA-TN-1326. 1947.

# 3D Gliding: Overview

- Dynamics outside longitudinal plane with tail actuation
- Following article from this year of ornithopters tails
- Developing a model with lateral approximations based on aerodynamics theory and distribution of forces in the ornithopter
- Experimental validation: analysis of appropriated maneuvers

# Gliding model

- Forces with longitudinal variables: classical aerodynamic theories. Defined in previous works
- Forces with sideslip angles: vertical tail + dihedral angle
- Forces with angular velocities: Differential of lift between wings
- Use of flight mechanics formulations for dihedral and sweep angle effects (fitted for ornithopter scale)

# Gliding experimentation

- Optitrack:
  - Launching the ornithopter from certain height
  - Flapping to gain height and then gliding
- Selection of maneuvers:
  - Maintained deflection of the lateral control
  - Deflect the lateral control during glide
- Comparison with wing actuation?



# Flapping Forward Flight : Overview

- Elastic wings:
  - Aerodynamic model developed by Ramón
  - Elastic model of the wing needed – Structural study
- High amplitude
  - Aerodynamic forces needed
  - Experimental adjustment
  - Cristina's models

# Gliding Stability and Control: Overview

- Linearisation of gliding model
- Obtention of stability characteristics
- Analysis on birds' data
- Effect of control on the stability
- Experimental validation