Dynamics-Aerodynamics Interactions

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Aerodynamics – oscillating airfoil

- Aerodynamic formulation: heaving and pitching of an airfoil
- Sinusoidal movements defined previously
- Forces have no effect on the movement
- Theodorsen: lift formulation
- Garrick: Thrust formulation
- Fernandez-Feria:
  thrust correction

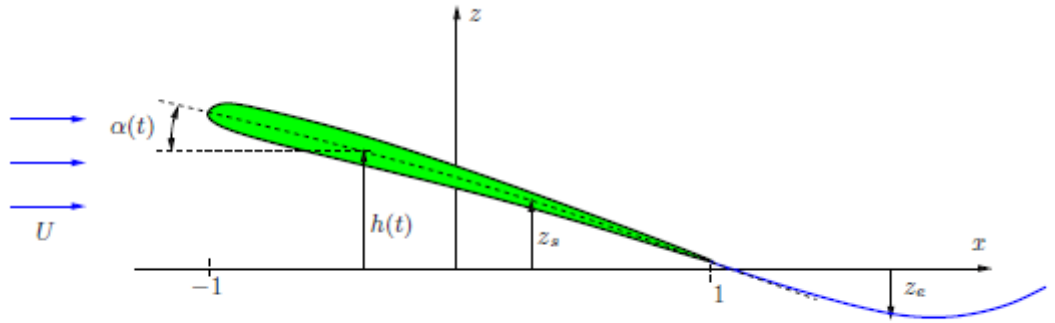


FIG. 1. Schematic of the oscillating airfoil and wake.

Aerodynamic – oscillating airfoil

- Formulation obtained as a function of the defined movement:

$$C_{L,T,m} = f(k, h_0, \alpha_0, a, \alpha)$$

- Does not consider variations in other variables
- Experimental studies:
  same considerations
- Platzer (2008)
- Smits (2019)

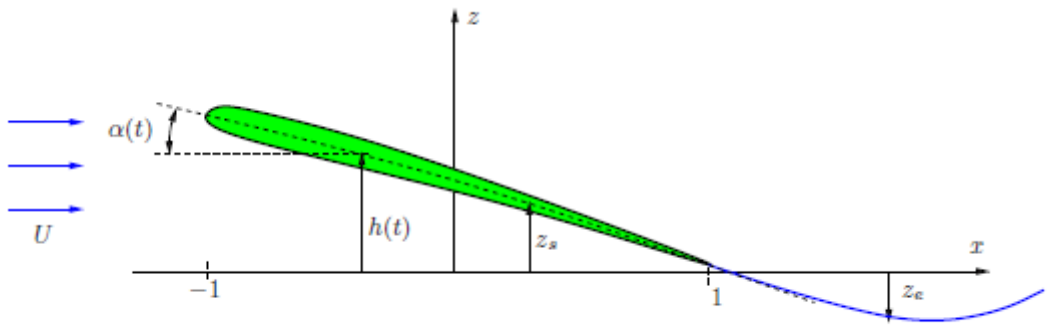
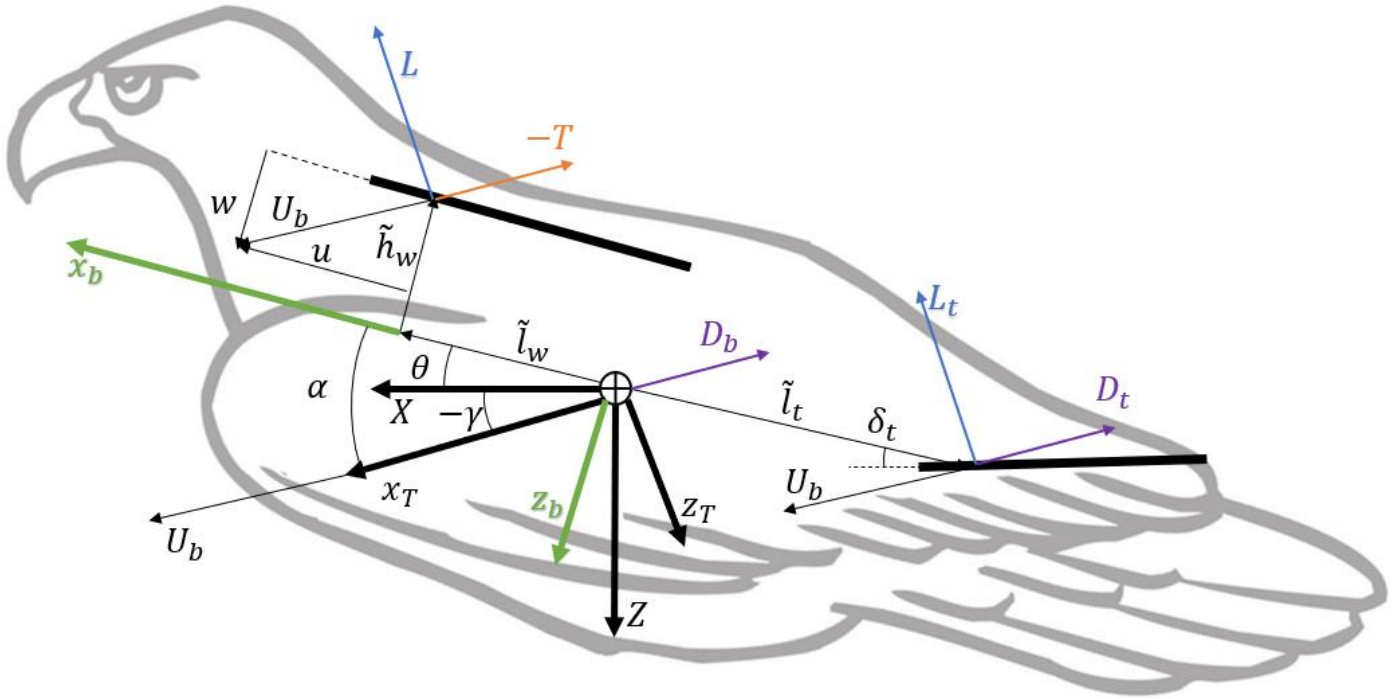


FIG. 1. Schematic of the oscillating airfoil and wake.

Dynamic – ornithopter movement

- Longitudinal movement
- Variables (V, α, θ)
- Flapping movement (k, h_0)
- Unsteady aerodynamics:
  - $\dot{\theta} \rightarrow$ Vertical displacement
  - $\dot{\alpha} \rightarrow$ Angle of attack
  - $\dot{V} \rightarrow$ Airspeed



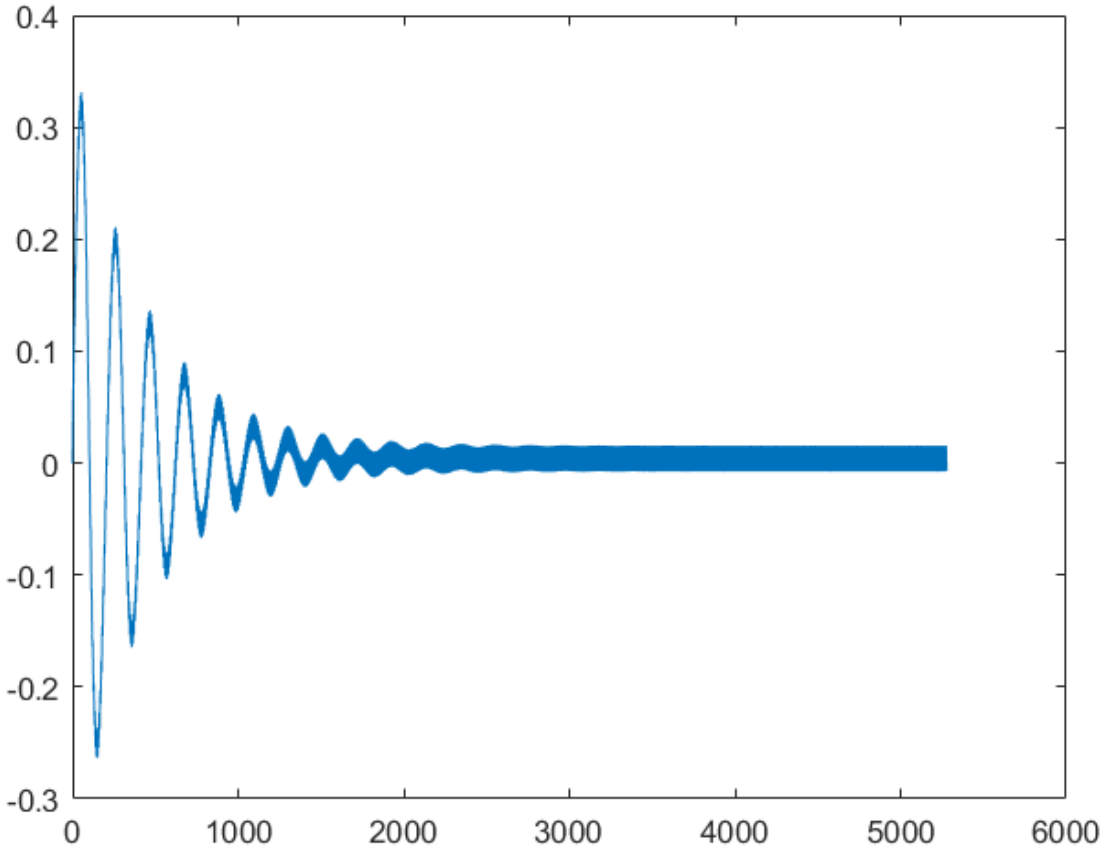
Aerodynamic-Dynamic Interaction

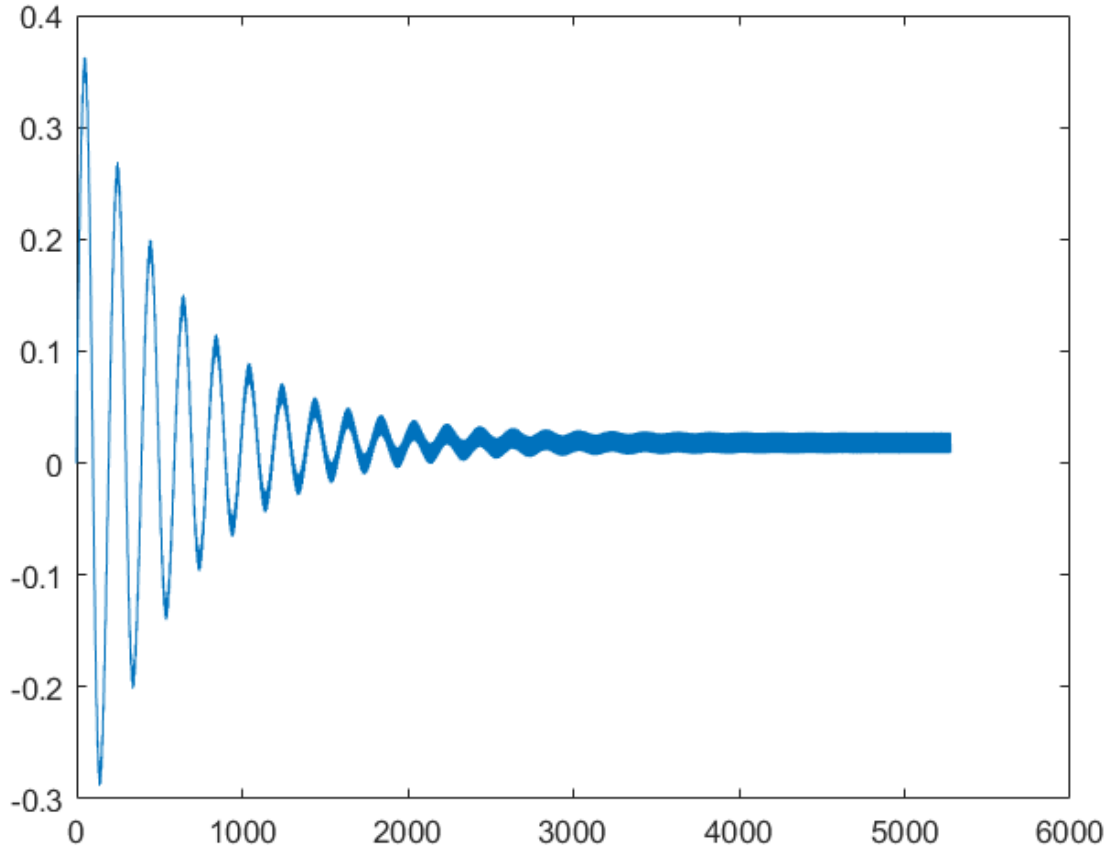
- Unsteady aerodynamics:
  - $\dot{\theta} \rightarrow$ Vertical displacement
  - $\dot{\alpha} \rightarrow$ Angle of attack
  - $\dot{V} \rightarrow$ Airspeed
- New formulation:

$$C_{L,T,m} = f\left(k_0, h_0, V, \dot{V}, \alpha, \dot{\alpha}, \dot{\theta}\right)$$

- Obtained from potential theory (Fernandez-Feria,2016)

Results comparision





Perturbative solution without oscillations

- Airspeed $\left(O(1)\right)$

$$U_0 = f(\alpha_0, \delta_t, C_{L\alpha}, \Lambda) = f'(\delta_t, C_{L\alpha}, \Lambda, l_w, l_t)$$

- Angle of attack $\left(O(\epsilon)\right)$

$$\alpha_0 = f(\delta_t, C_{L\alpha}, \Lambda, l_w, l_t)$$

- Pitch angle (flight path angle) $\left(O(\epsilon)\right)$

$$\gamma_0 = \theta_0 - \alpha_0 = f(\alpha_0, \alpha_{0t}, \theta_{0t}, U_0, h_0, k_0, C_{Tx}, C_D)$$

Perturbative solution: oscillations

- Airspeed $\left(O(\epsilon^2)\right)$

$$U_{2t} = f(\alpha_0, \alpha_{0t}, \theta_{0t}, U_0, h_0, k_0, C_{Tx})$$

- Angle of attack $\left(O(\epsilon)\right)$

$$\alpha_{0t} = f(U_0, h_0, k_0, C_{Lx})$$

- Pitch angle $\left(O(\epsilon)\right)$

$$\theta_{0t} = f(U_0, h_0, k_0, C_{Lx})$$