Simplified Model for Forward-Flight Transitions of a Bio-Inspired UAV

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Introduction

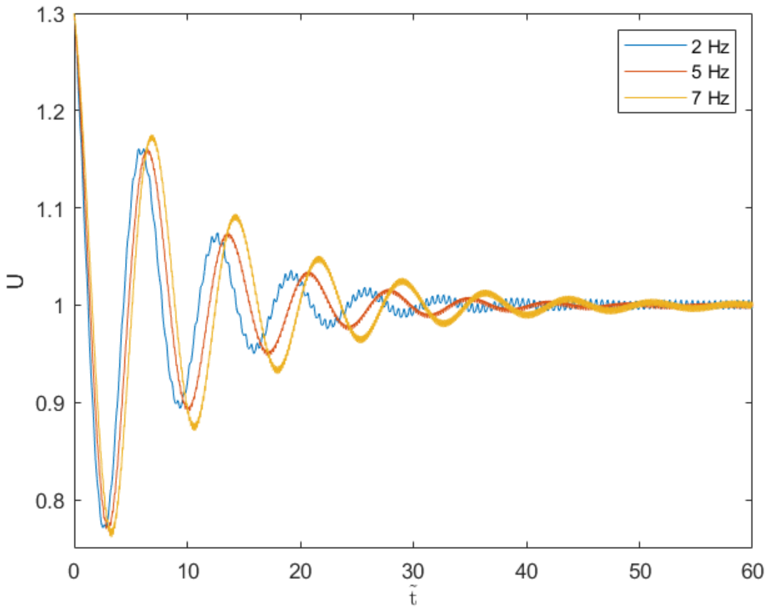
- Bio-inspired UAVs: GRIFFIN
- State of the art: mainly MAVs. Forward flight with simplified aerodynamics
- Contribution
  - Forward flight model with aerodynamics based on potential theory
  - Simplification by perturbation methods in order to make real-time predictions

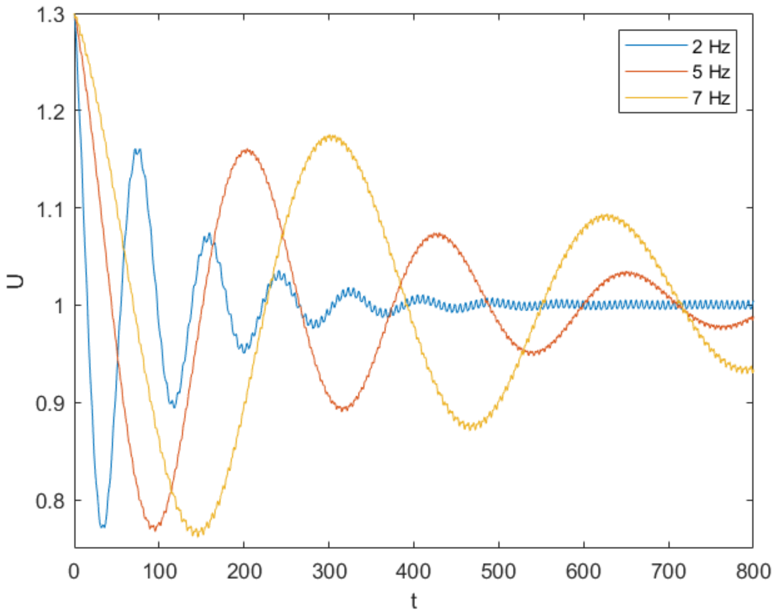
Model

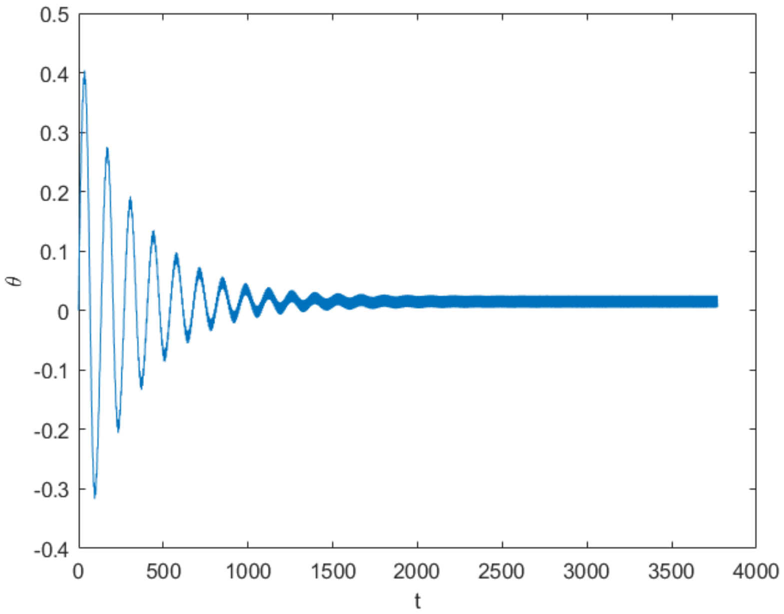
- Physic model: Dynamics of the UAV + Aerodynamic forces
- Dynamics
  - Based on previous works, only longitudinal
  - State variables: U, γ, θ
  - Non-dimensional equations → Velocity O(1)
- Aerodynamics
  - Based on Theodorsen and Fernandez-Feria equations
  - Plunging airfoil adapted to finite wings
  - Effect of dynamic variables considered

Numerical solutions

- Non-dimensional time → Flapping oscillations coincide
- Dimensional time → Transient phase very similar







Analysis of terms

- Time scales:

$$t; \quad \tau_1 = \frac{\epsilon t}{\mathcal{M} k_0}; \quad \tau_2 = \frac{\epsilon^2 t}{\mathcal{M} k_0}$$

- Small parameter: $h_0 \to \epsilon$;
- Angular variables: $\alpha, \theta, \gamma, \delta_t \to O(\epsilon)$
- Aerodynamic forces: $C_L \to O(\epsilon)$; $C_D, C_T \to O(\epsilon^2)$

$\tilde{f}$	$\mathcal{M}k_0$	$\mathcal{M}$	$\mathcal{M}^2\chi$	Λ	l_w	$l_t\Lambda$	h_w	Li^*	$\mathcal{R}$
2 Hz	0.64	1.72	0.97	0.21	0.34	−0.68	0.38	0.0016	5.14
5 Hz	1.59								
7 Hz	2.23								

Perturbative approach

- Mathematical development

$$U = U_0 + \epsilon U_1 + \cdots$$

$$U_0(t, \tau_1, \tau_2) = V_0; \quad U_1(t, \tau_1, \tau_2) = V_1(\tau_1, \tau_2);$$

$$U_2(t, \tau_1, \tau_2) = V_2(\tau_1, \tau_2) + V_3(\tau_1, \tau_2)e^{it} + V_4(\tau_1, \tau_2)e^{2it}$$

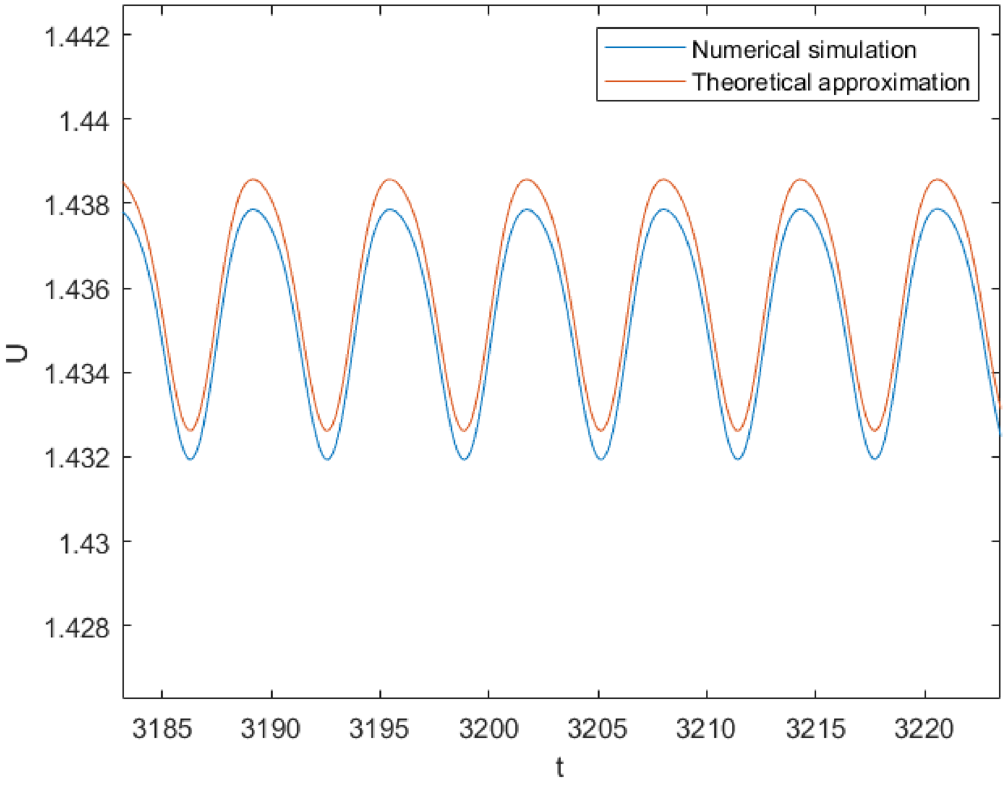
$$\theta = \epsilon\theta_0 + \epsilon^2\theta_1 + \cdots$$

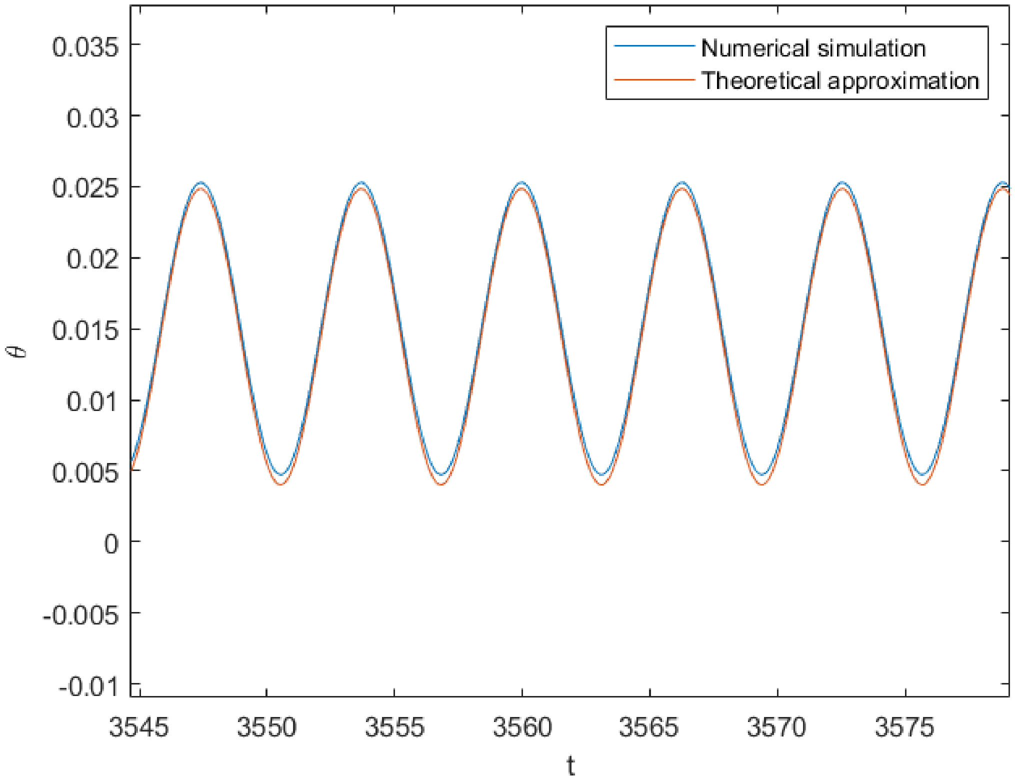
$$\theta_0(t, \tau_1, \tau_2) = T_0(\tau_1, \tau_2) + T_1(\tau_1, \tau_2)e^{it}$$

$$\theta_1(t, \tau_1, \tau_2) = T_2(\tau_1, \tau_2) + T_3(\tau_1, \tau_2)e^{it} + T_4(\tau_1, \tau_2)e^{2it}$$

Final state approximation

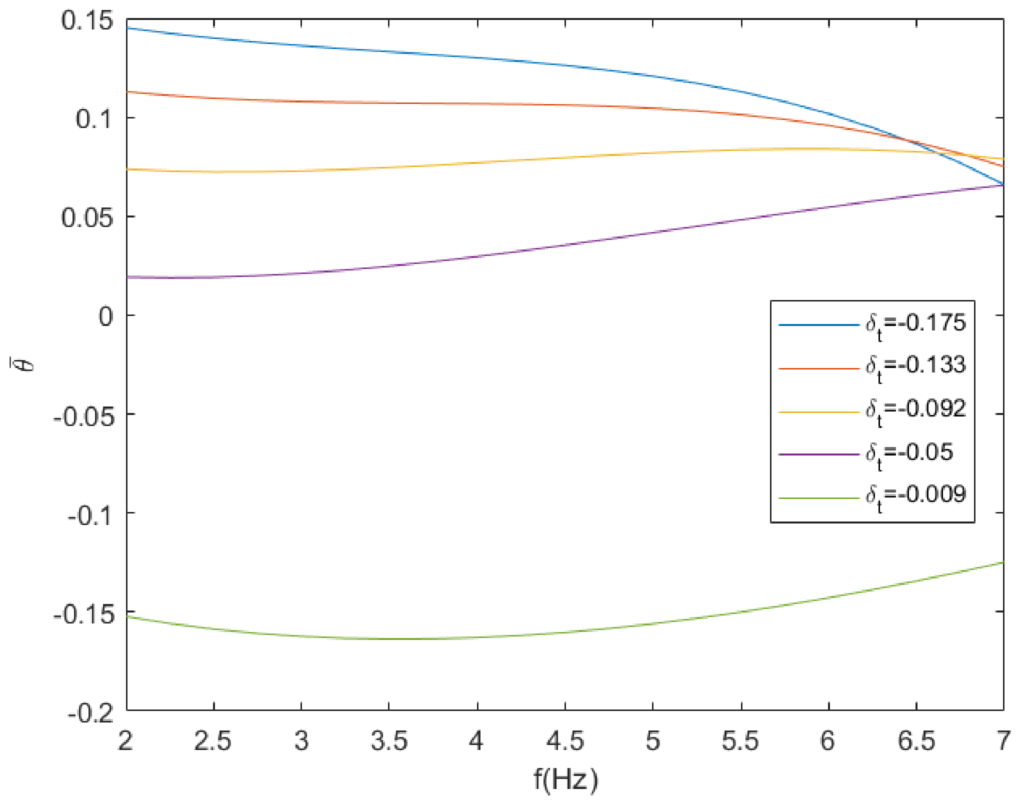
- Adjustment of both solutions

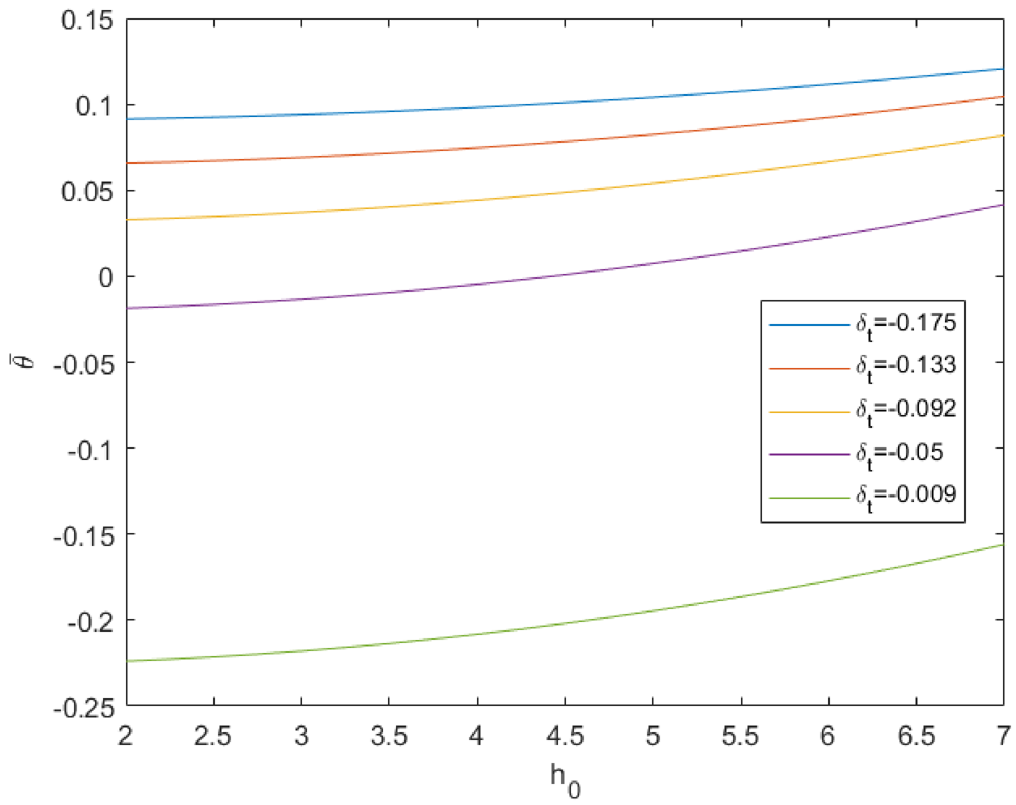




Final state analysis

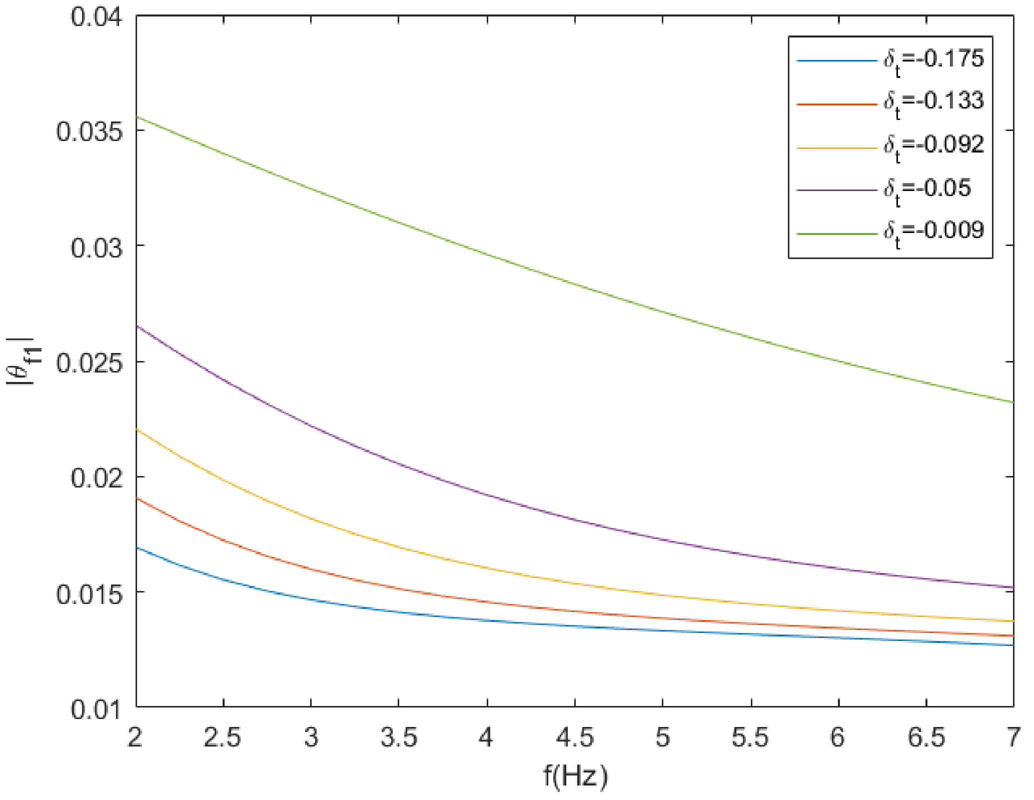
- Main values

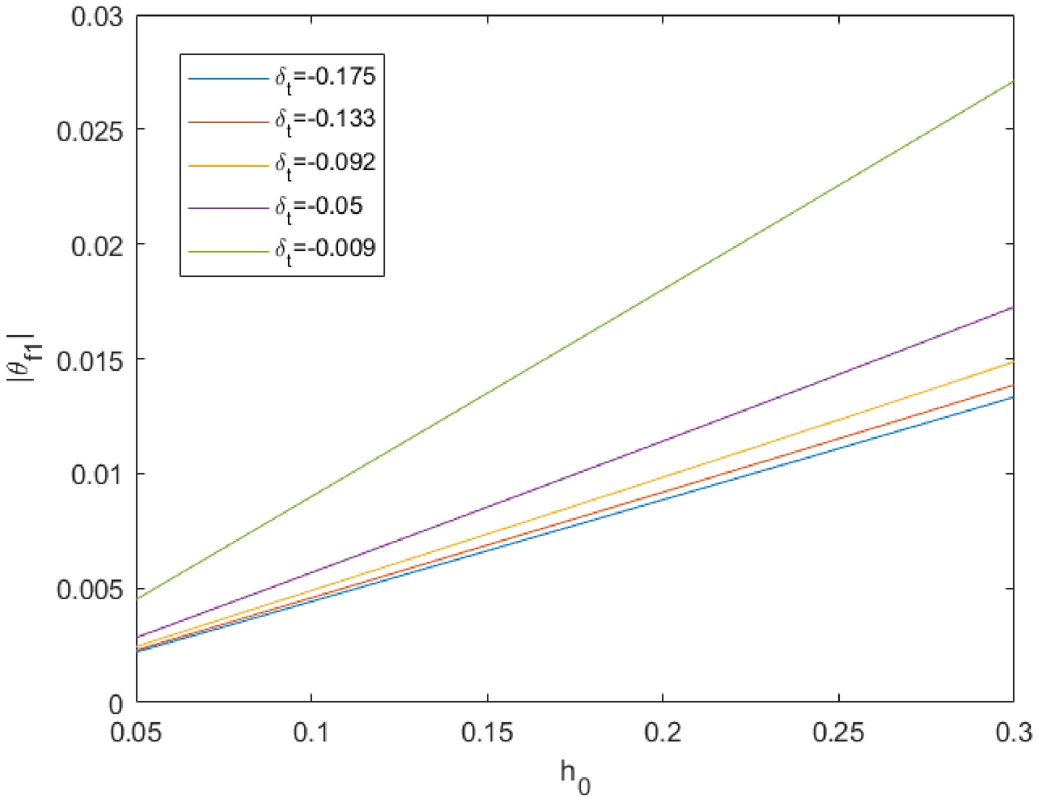




Final state approximation

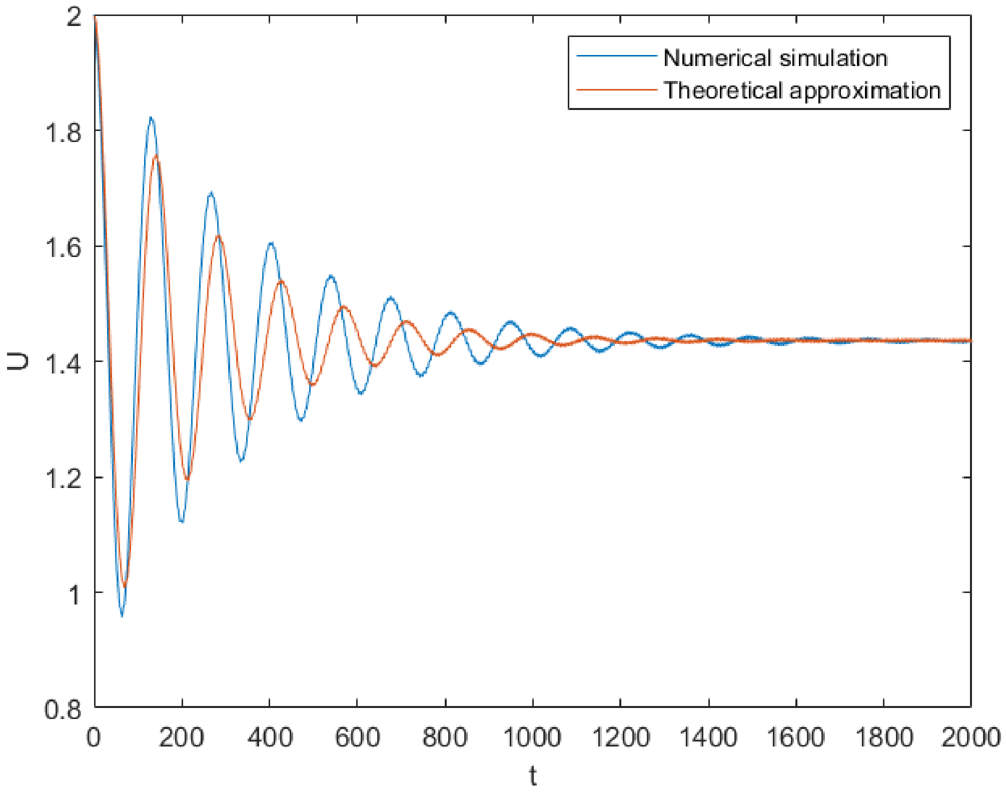
- Oscillations

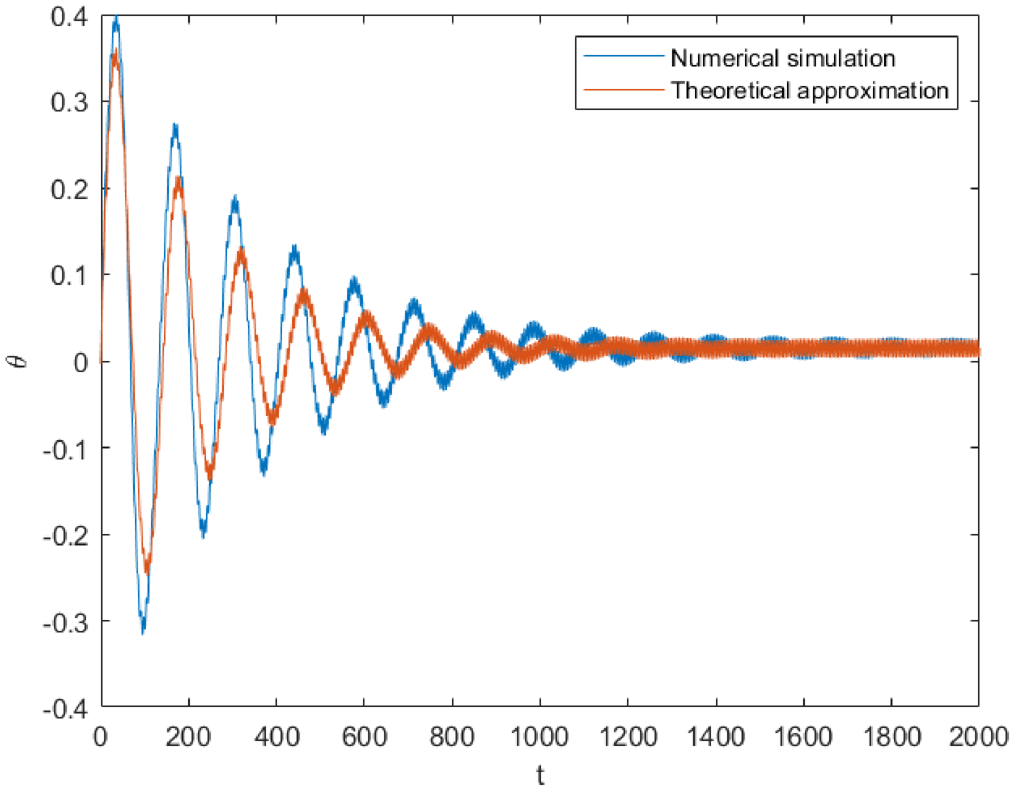




Transient phase approximation

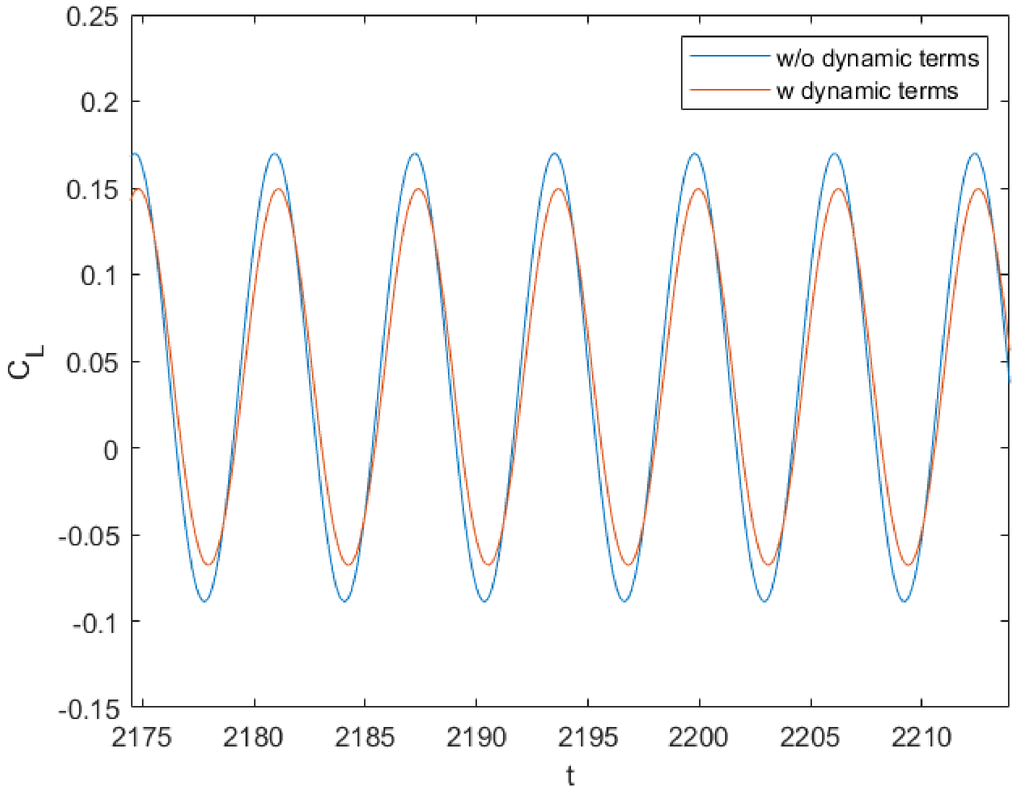
- Adjustment of both solutions

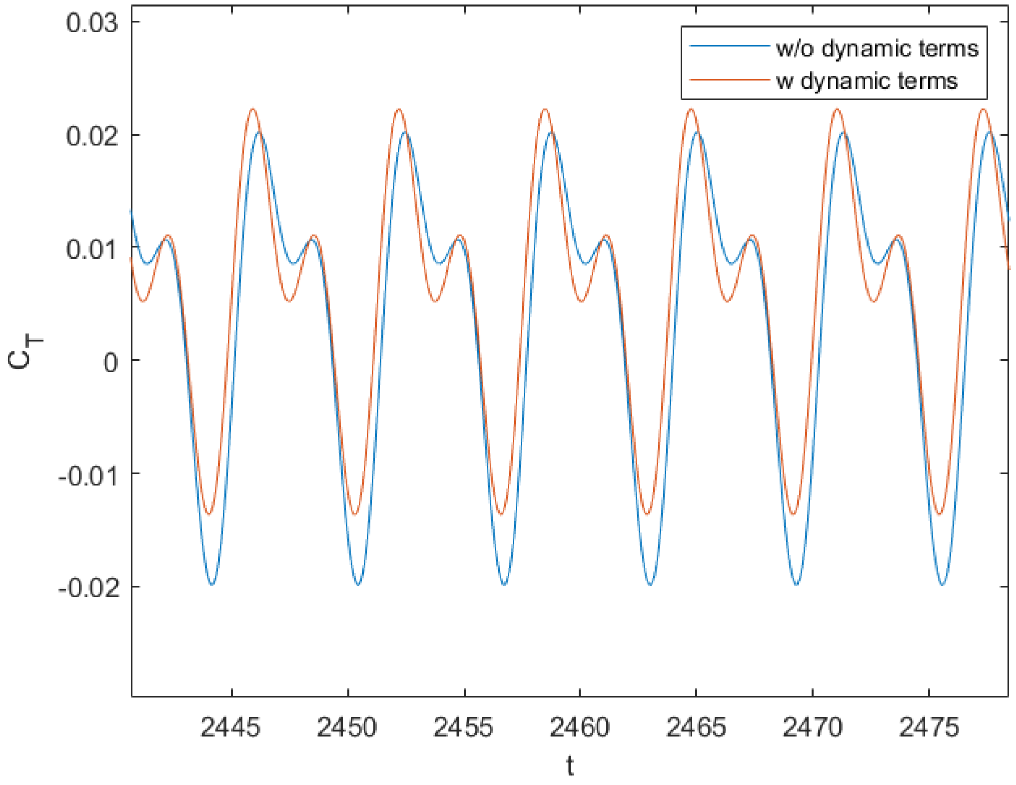




Dynamic-Aerodynamic interaction

- Effect of dynamic terms on the aerodynamic forces





Conclusions

- Model with potential aerodynamics and low amplitude
- Approach to simplify significantly the computation
- Validity of the approach proved
- Analysis of the control influence on the dynamics
- Limitations of the approach – Hypothesis
- Limitations of the aerodynamic model – rigid wing
- Real experimental validation – Flexible wing theory or rigid wing design
- Future work