# Thrust coefficient of a heaving airfoil under harmonic chordwise gust

Problem definition and first results

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Robotics

Vision

Control

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# State of the art

- Oscillations of the incoming airspeed are typical in ornithopter flight
- The problem has not been addressed on a general form from the potential theory
- There are few experimental studies in the literature
- Known as surging, the results are interesting also for other cases, such as turbine or compressors.

# State of the art

- Oscillating airfoil, lift: Theodorsen
- Oscillating airfoil, thrust: Garrick
- General formulation of the lift: Von Karman and Sears
- Oscillating airfoil in chordwise gust, lift: Greenberg, Horlock, Sears
- General formulation of the thrust: Fernandez-Feria

# Problem definition

- Characteristic of the problem
  - $\dot{h} = i\omega_1 h_0 e^{i\omega_1 t}$
  - $\alpha = \alpha_s + \alpha_0 e^{i\omega_1 t}$
  - $\dot{\alpha} = i\omega_1 \alpha_0 e^{i\omega_1 t}$
  - $U = U_s + U_0 e^{i\omega_2 t}$
- Limitations:
  - $U_s > U_0$
  - $h_0, \alpha_0 \ll 1$

# Complexity of the problem

- Two frequencies: Airstream oscillations and airfoil movement
- Non-linear effects generate two additional frequencies in the circulation around the airfoil
- There are also constant terms by the average airspeed and angle of attack
- For the thrust, more frequencies appear

# Goals

- General formulation of lift and thrust
- Definition of particular cases: surging, surging + heaving, surging + pitching
- Obtention of different specific formulations for those cases
- Validation with experimental and analytical results in the literature

# Analytical development

- Airfoil vertical speed
  - $v_0\,(x,t) = -U\alpha + \dot{h} - (x-a)\dot{\alpha}$
- Forces from impulse theory
  - $D = \rho \frac{d}{dt}\int_{-1}^{1} z_s \varpi_s dx + \rho \frac{d}{dt}\int_{1}^{\infty} z_e \varpi_e dx$
  - $L = -\rho \frac{d}{dt}\int_{-1}^{1} x \varpi_s dx - \rho \frac{d}{dt}\int_{1}^{\infty} x \varpi_e dx$
  - $\boldsymbol{M} = M\boldsymbol{e}_y = -\rho \frac{dA}{dt} \approx -\frac{1}{2}\boldsymbol{e}_y\left(\int_{-1}^{1} x^2 \varpi_s dx + \int_{1}^{\infty} x^2 \varpi_e dx\right)$
- Mathematical development to characterise vorticity over the airfoil

# Preliminary results

- Lift and moment formulation: correction of Greenberg
- Thrust formulation: seven frequencies
  - $\omega_1, \omega_2, 2\omega_2, \omega_1 + \omega_2, \omega_2 - \omega_1, 2\omega_2 + \omega_1, 2\omega_2 - \omega_1$
- Formulation of particular cases
- Implementation in MATLAB for comparison

# Other works

- Submission of rejected paper of JGCD to AESCTE (major modifications)
- Article for ICUAS (presented by Cristina some weeks ago)
- Preparation of prototype for experiments
  - Electronics developed by Fran Ruiz
  - Design and manufacturing of pieces for optitrack and launching by Mario Hernández

# Next lines of research

- 3D manoeuvres during gliding. Characterization of ornithopters
- High amplitude flapping: forward flight models
- Flexibility: definition of structure characteristics and integration of aerodynamic models
- Power consumption on ornithopters. Estimation from aerodynamic forces and dynamic models