Experimental Analysis of a Large-Scale Tandem Flapping Wing System

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Contents

Introduction

Context

In nature

- Tandem flapping very common in insects
- No living example of larger scale animals
  - Evidence of 4-winged dinosaurs (*Microraptor*)
  - ~ 1 m wingspan

In engineering

- Low $\mathcal{R}e$
- Moderate reduced frequency ($k \sim 0.1 - 0.3$)
- Gap for $\mathcal{R}e > 5 \times 10^4$ and $0.3 < k < 1$

Animal Dynamics Skeeter

Introduction

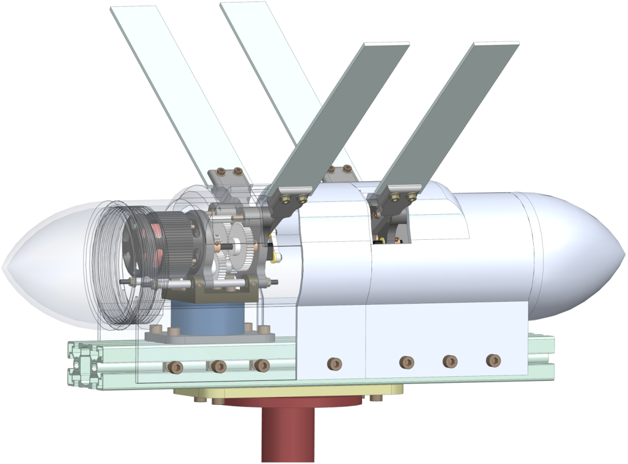
Objectives

- Design and build a **macro-scale tandem flapping** wing system
  - Modular
  - > 10 Hz flapping
  - Different phases and frequencies
- Single wing flapping
- Full tandem flapping
- Influence of
  - Reduced frequency (V_∞, f)
  - Phase offset
  - Horizontal distance

Experimental setup

Experimental setup

Flapping wing model

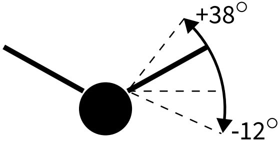


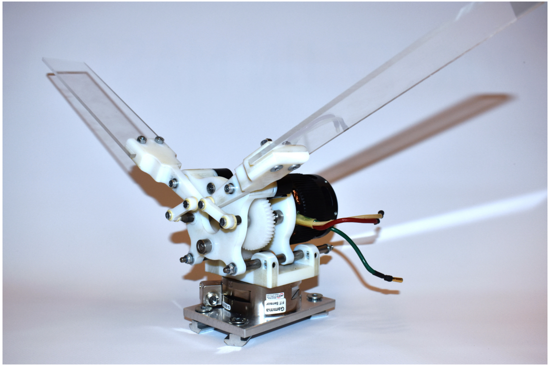
- Independent modules
- Variable horizontal spacing
- Separate load cells
- Half-wing
  - Rect. flat plate
  - Chord = 0.05 m
  - Span = 0.2 m
  - Pitch = 0°

Experimental setup

Flapping wing model

- Dual crank mechanism
- 1.5 kW motor w/ 1:10 gearbox
- Mainly 3D printed (VeroWhite™)
  - Arms will be replaced by steel ones
- Asymmetric amplitude





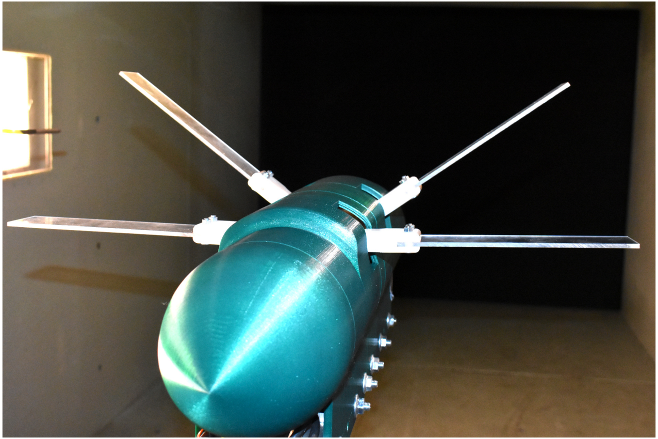
Experimental setup

Kinematics

- Pure flapping only, no active pitching
- Reduced frequency: $k = \dfrac{\pi f c}{V_\infty}$
    - 0.05 – 0.25

- Module synchronization issues
    - Frequencies not perfectly equal or stable
      $\Rightarrow$ Variable phase offset
    - Long acquisition time (>200 periods)
    - Average of periods with similar phase difference

Experimental setup

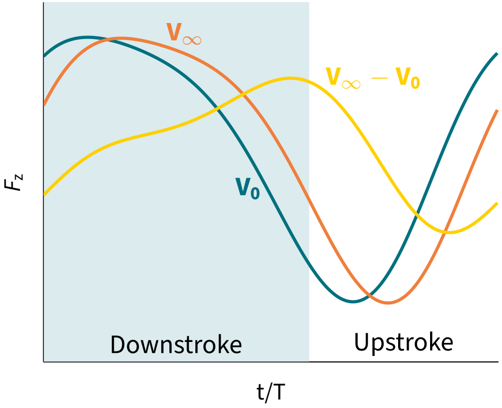


Test results

Test results

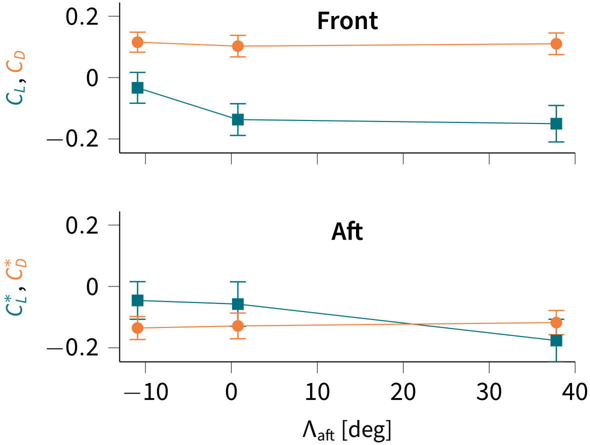
Inertia measurement

- Flapping with $V_\infty = 0$
  - Same trends
  - Different magnitude
- Aero forces = $F_i|_{V_\infty=0} - F_i|_{V_\infty=V}$



Test results

Front Flapping



- Aft wing **static** with **dihedral**
- Only front wing **flapping**

D_x	f	V_∞
0.05 m	1.98 Hz	7.7 m/s

- For both sets: Aft dihedral ↑
  - → C_L ↓
  - → C_D =
- Aft wing generates thrust

Test results

Tandem Flapping

D_x	f	V_∞
0.03 m	3.25 Hz	4.6 m/s

Front

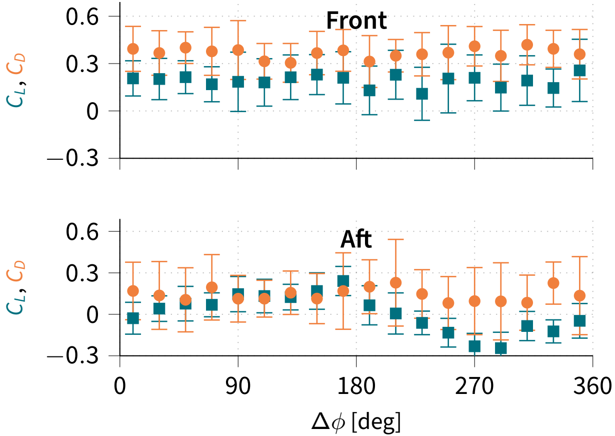
C_L: small variations

C_D: follows C_L variations

Aft

C_L: large variation with phase

C_D: large deviation from the mean



Test results

Tandem Flapping

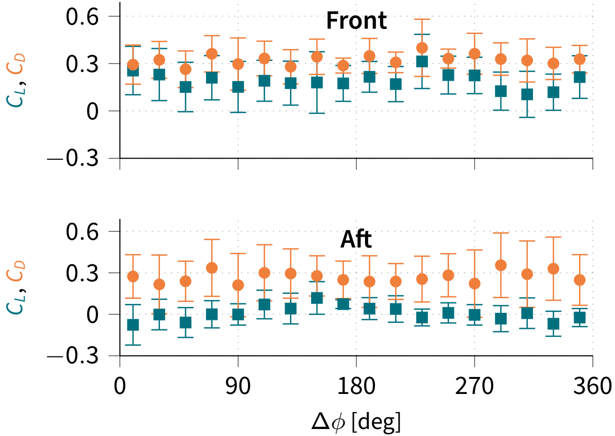
D_x	f	V_∞
0.03 m	2.67 Hz	4.6 m/s

Front

- Change in magnitude

Aft

- Peaks due to phase offset change position



Test results

Tandem Flapping

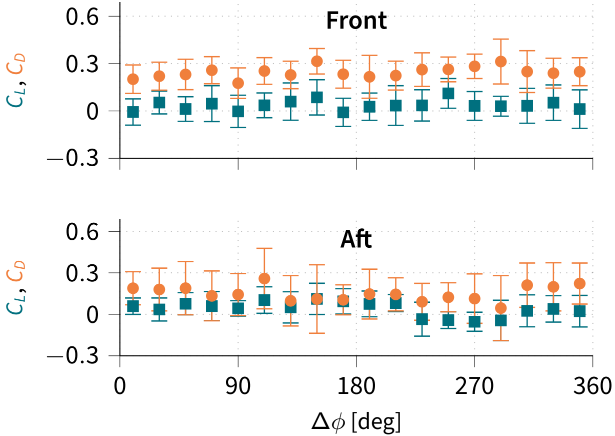
D_x	f	V_∞
0.10 m	2.67 Hz	4.6 m/s

Front

- **C_L**: significant decrease
- **C_D**: small decrease

Aft

- Peaks due to phase offset change position



Conclusion

Conclusion

Front flapping

- C_L decreases with increasing aft dihedral, **even for front wing**
- Aft wing produces thrust in all conditions

Tandem flapping

- Aft wing heavily influenced by phase offset
- Lift of aft wing significantly lower than front wing
- Lower lift for front wing when distance increases

Conclusion

Future work

- Small redesign of some critical parts
  - Steel and aluminum for the arms and clamps
- Increase frequency up to $\sim 10\,\mathrm{Hz}$ ($\rightarrow$ increase k)
- Increase airspeed up to 15 m/s ($\rightarrow$ increase *Re*)
- Vary pitch angles
- Use proper wing profiles
- Measure fuselage influence on the flow

Questions?