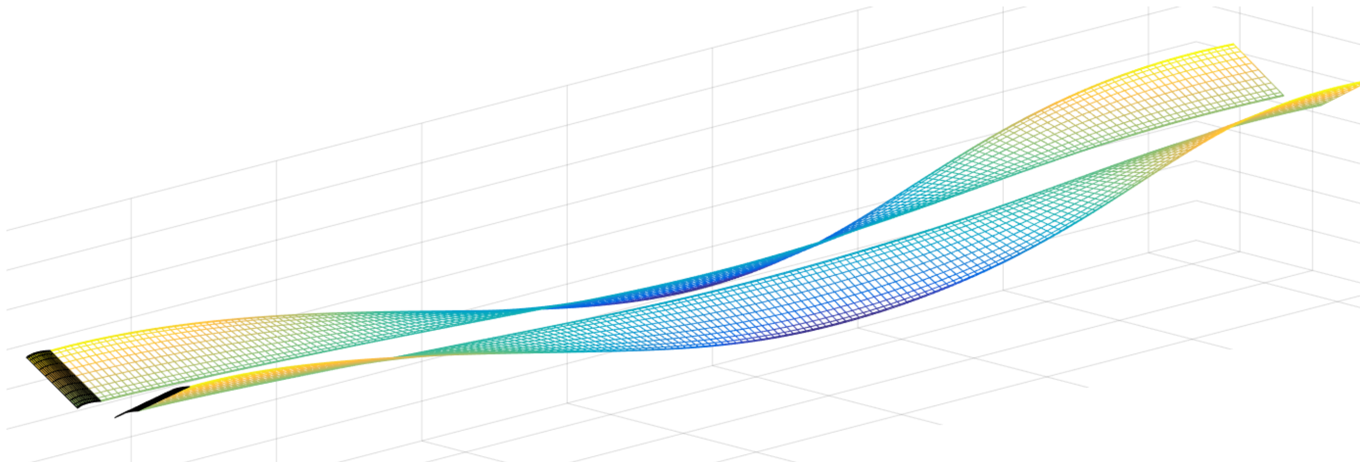
Modeling of aerodynamic forces in flapping flight with the UVLM



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Introduction

Objective

Compare two methods used to compute the aerodynamic forces for the UVLM

- Validity
- Convergence

Motivation

Verify and extend the results presented in an article* for flat plates

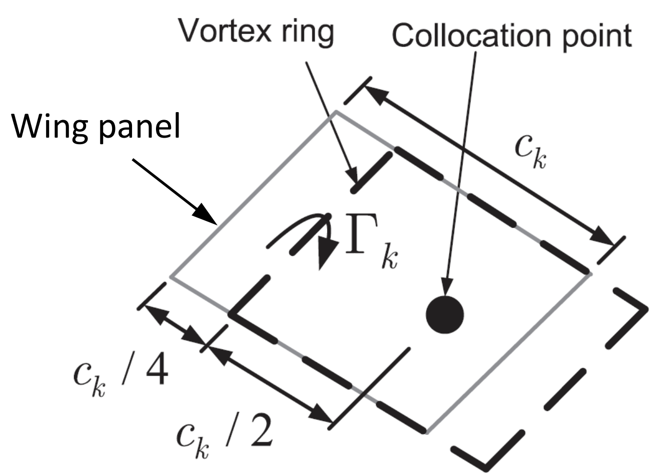
Contents

Test cases (harmonic pitching and plunging)

Flapping with pitching

*Simpson, Palacios and Murua, *Induced-drag calculations in the unsteady vortex lattice method.* AIAA Journal, 51(7):1775-1779, July 2013.

Unsteady Vortex Lattice Method

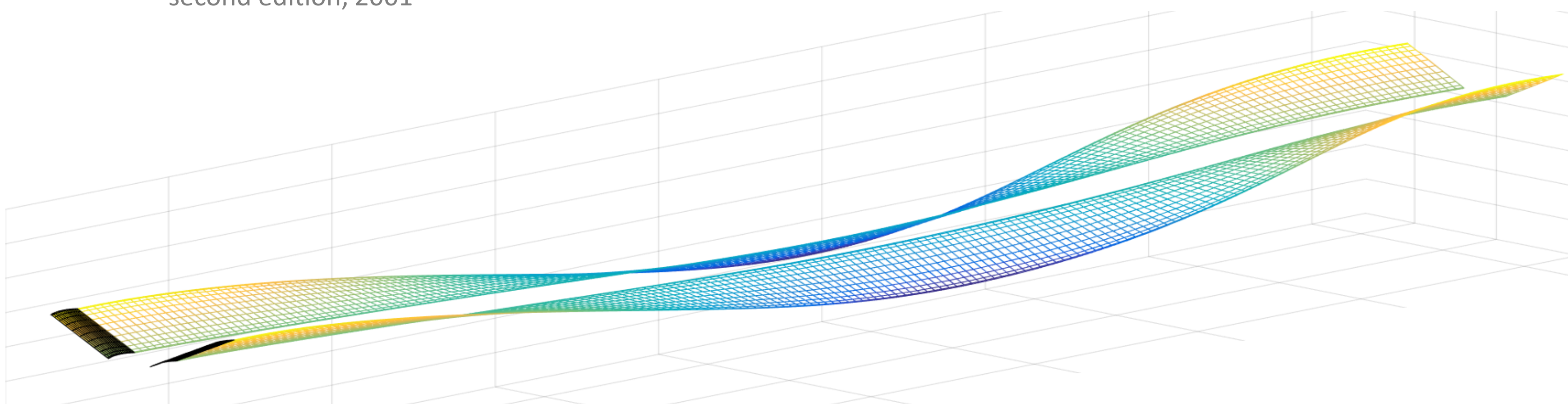


Source: Katz and Plotkin, *Low-Speed Aerodynamics*. Cambridge University Press, second edition, 2001

Hypotheses

- Sub-sonic
- Non-viscous
- Incompressible
- Irrotational
- **Attached flow**

- Thin airfoil



Aerodynamic forces

Katz method

- Bernoulli's equations
  - Small angle assumption
- Velocities at collocation points
- Need correction for induced-drag

Joukowski method

- Joukowski's equations
- Velocities at mid point of vortex segments
- No correction required

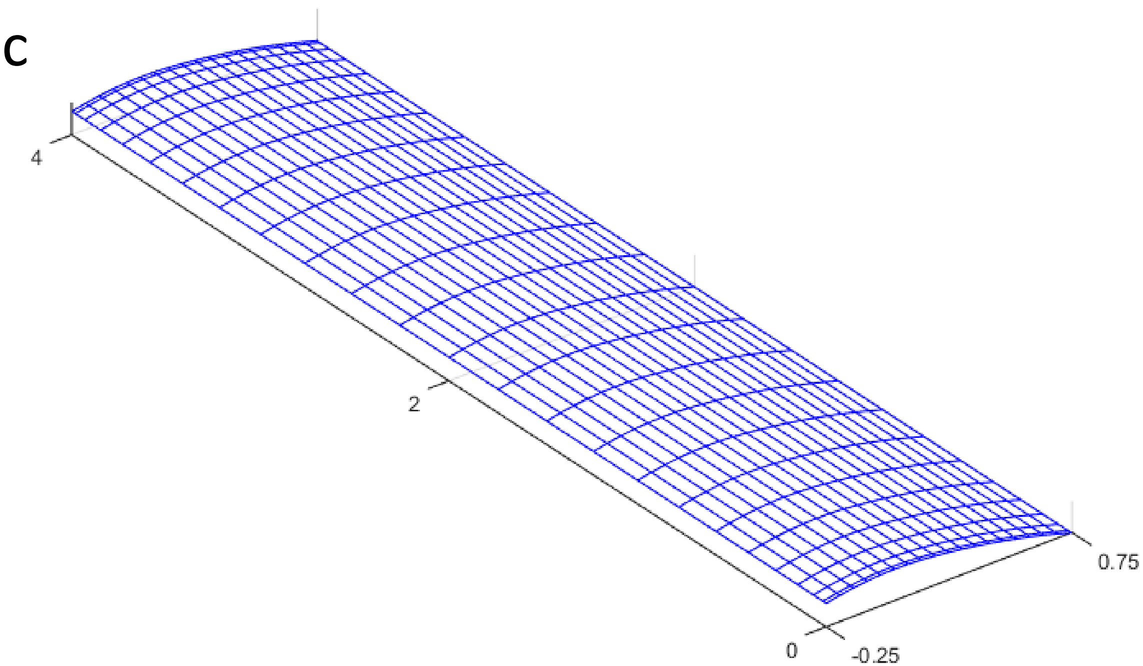
Test cases - Introduction

Geometry

- 2D or 3D
- Cambered or symmetric

Wings

- Perfectly rectangular
- $\mathrm{AR}_{2D} = 4000$
- $\mathrm{AR}_{3D} = 4$



Kinematics

- Pitching: $\alpha = \overline{\alpha}_p \sin(ks)$
- Plunging: $h = \overline{h} \cos(ks)$

Test cases – Pitch 2D

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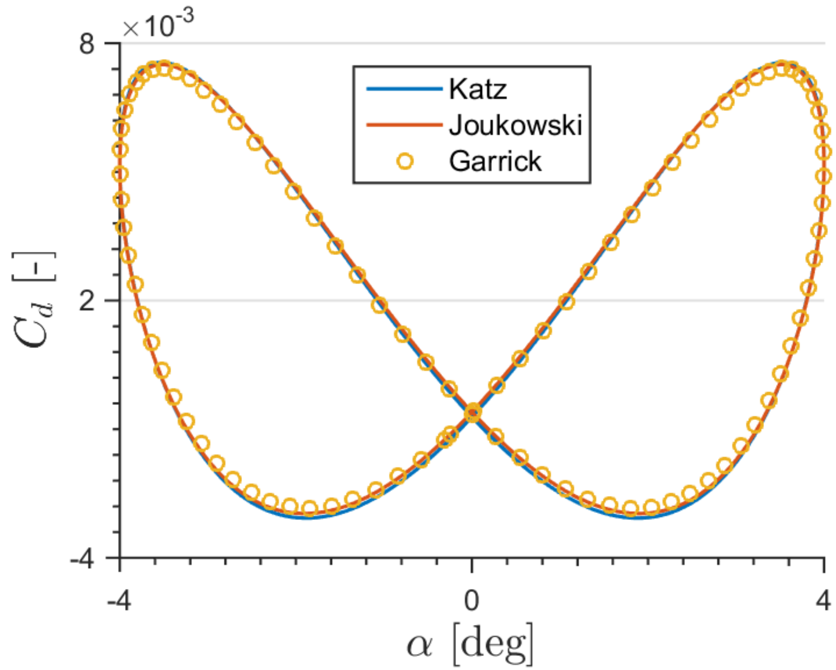

- Similar results for both methods
- Good approximation of the analytical solution

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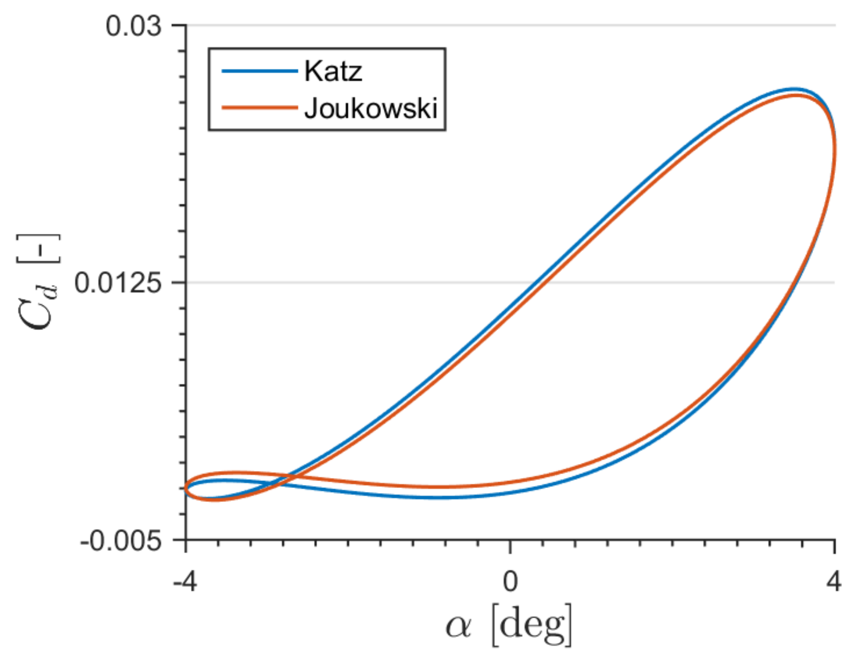

- Small differences between the two methods

Test cases – Pitch 2D

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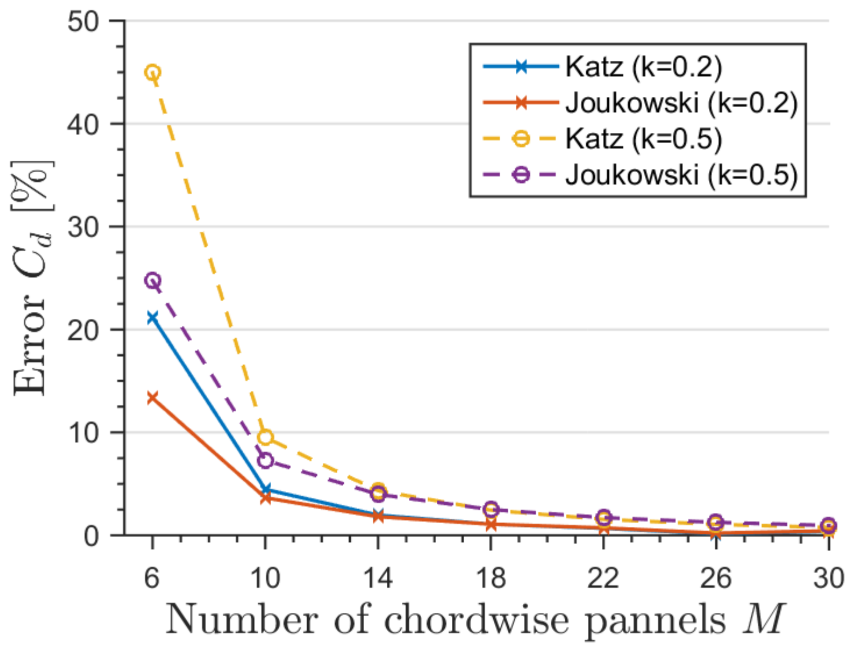

- Joukowski converges slightly better
- Convergence reached for the same M

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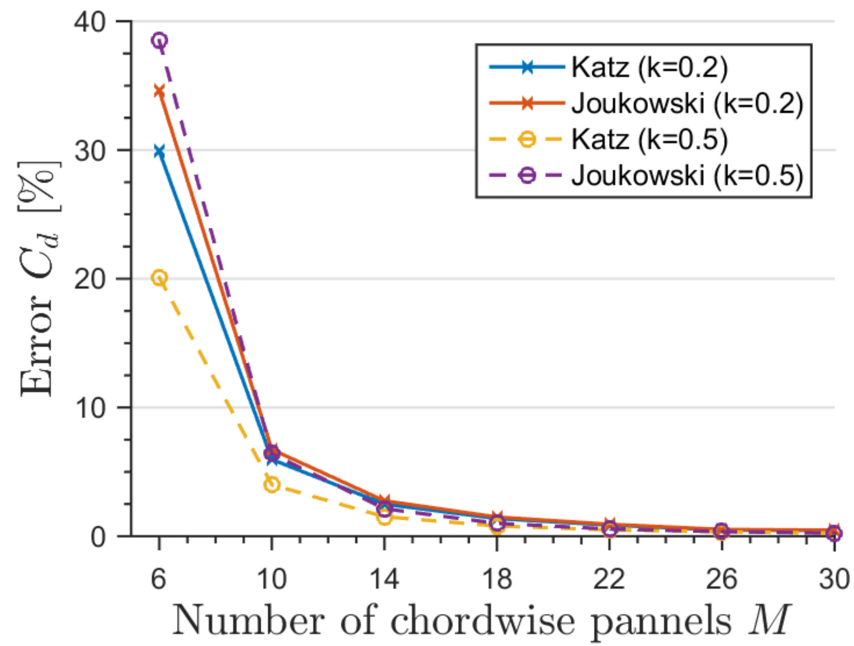

- Convergence rate nearly the same

Test cases – Pitch 3D

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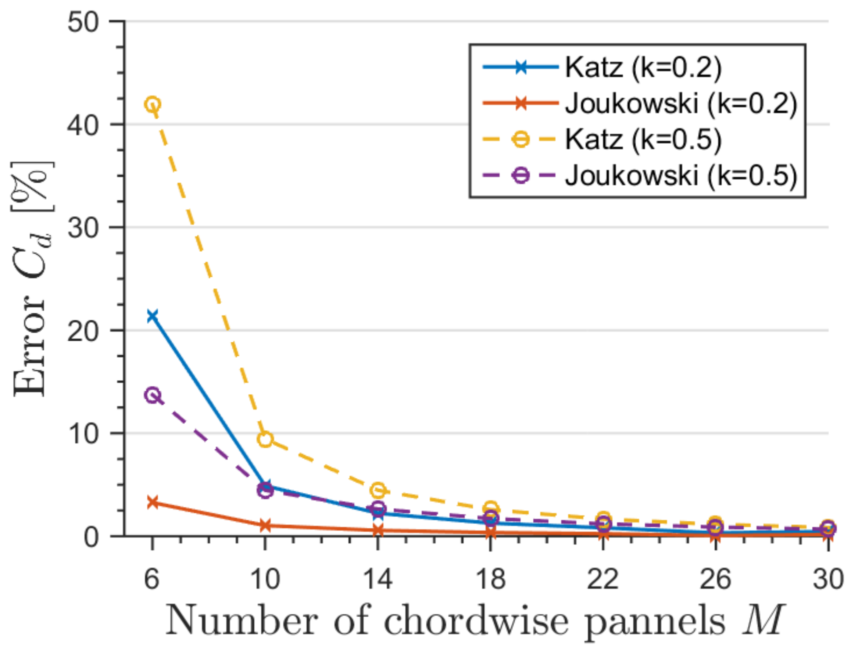

- Joukowski converges faster

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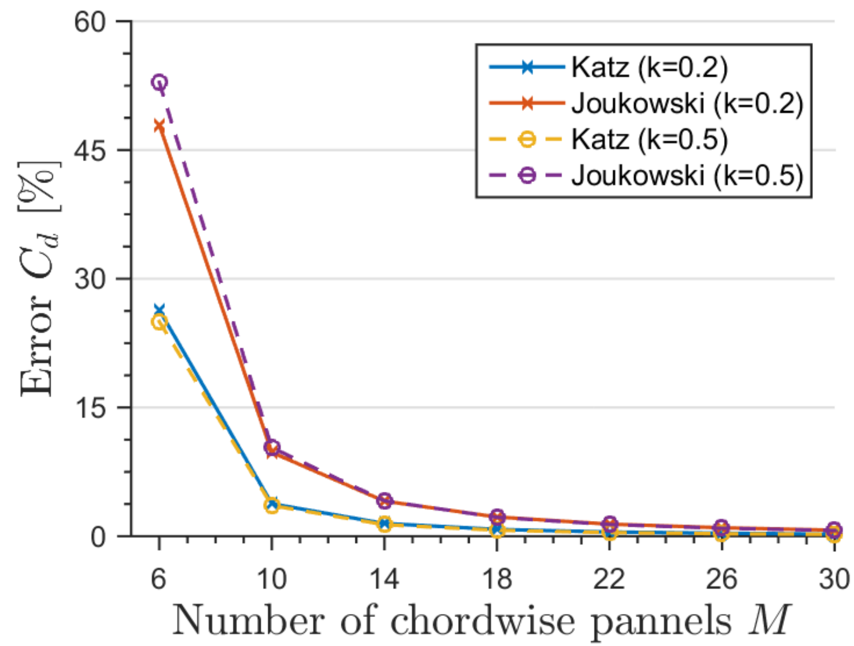

- Katz converges faster
- No influence of the frequency

Test cases – Plunge 3D

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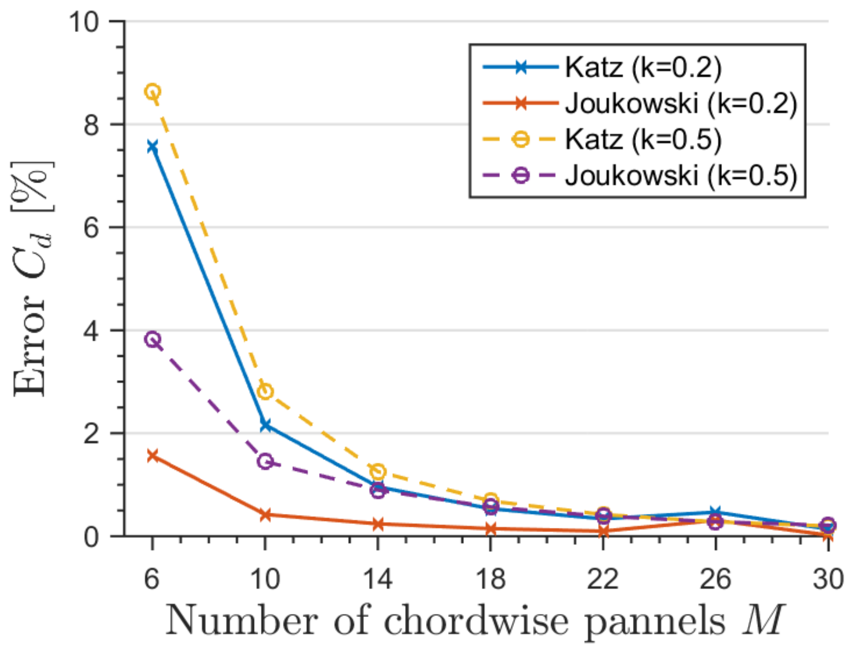

- Joukowski converges faster

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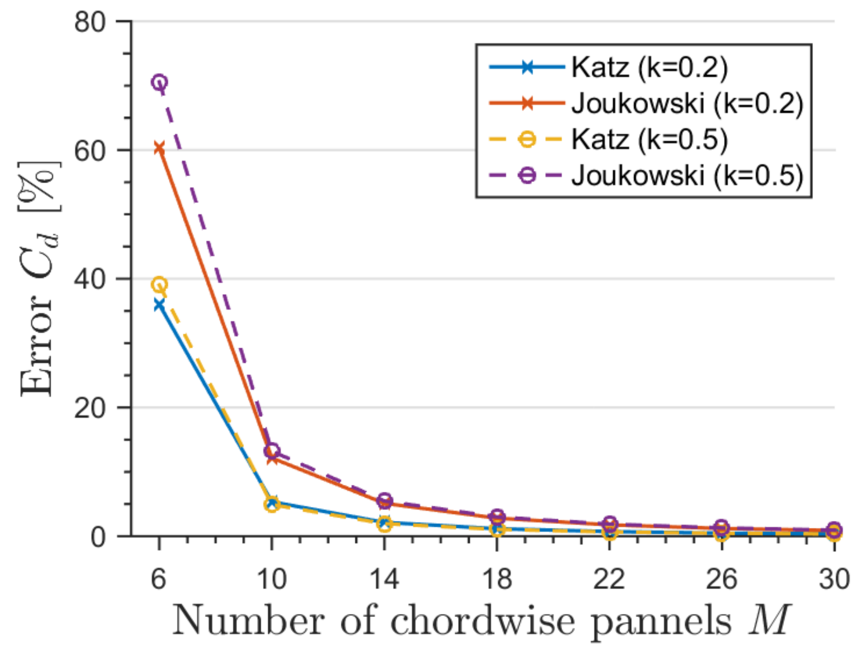


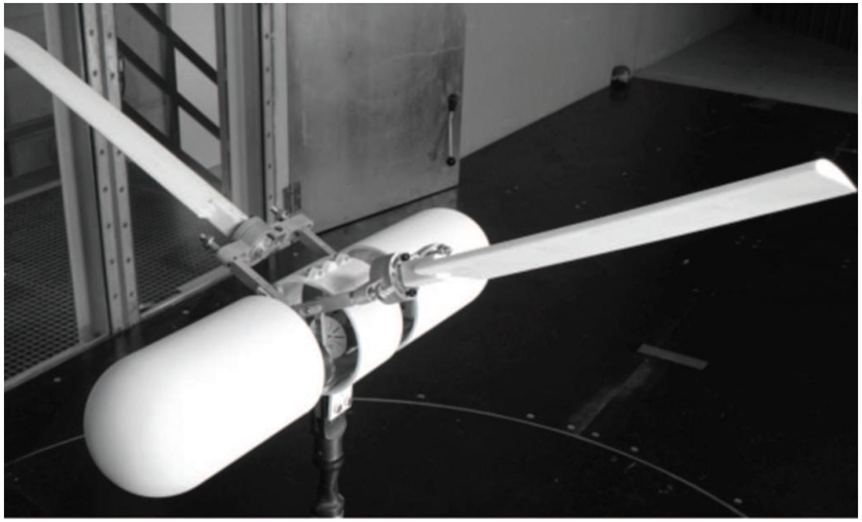
- Katz converges faster
- No influence of the frequency

Test cases - Summary

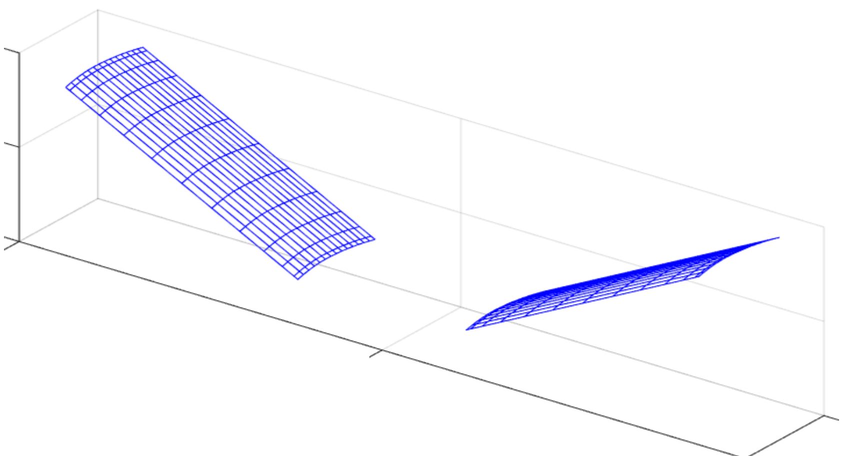
- Results
  - Similar C_d for both methods
  - Good match with analytical solution

- Convergence
  - Joukowski converges faster for uncambered wings but slower for cambered ones

Flapping – Experimental setup



Source: N. Abdul Razak, *Experimental Investigation of the Aerodynamics and Aeroelasticity of Flapping, Plunging and Pitching Wings*. PhD thesis, University of Liege, 2012



The measured force is a combination of

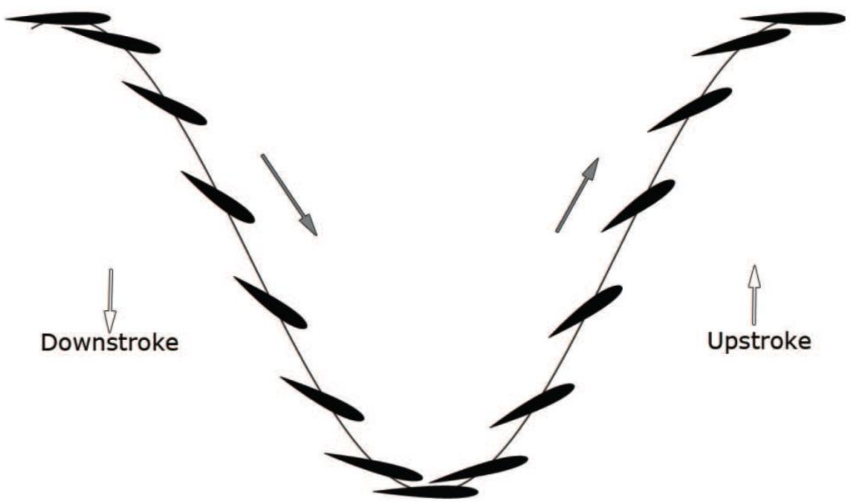
- **Unsteady aerodynamic loads**
- Inertial forces
- Added mass forces

The inertial and added mass forces must be subtracted

- Lead to larger errors in lift measurement

Only the wings are represented with UVLM

Flapping – Pitch leading



<u>Source</u>: N. Abdul Razak, *Experimental Investigation of the Aerodynamics and Aeroelasticity of Flapping, Plunging and Pitching Wings*. PhD thesis, University of Liege, 2012

- Pitch leads flap by 90°
- Flow always attached
- Best kinematics for UVLM analysis

Flapping – Pitch leading

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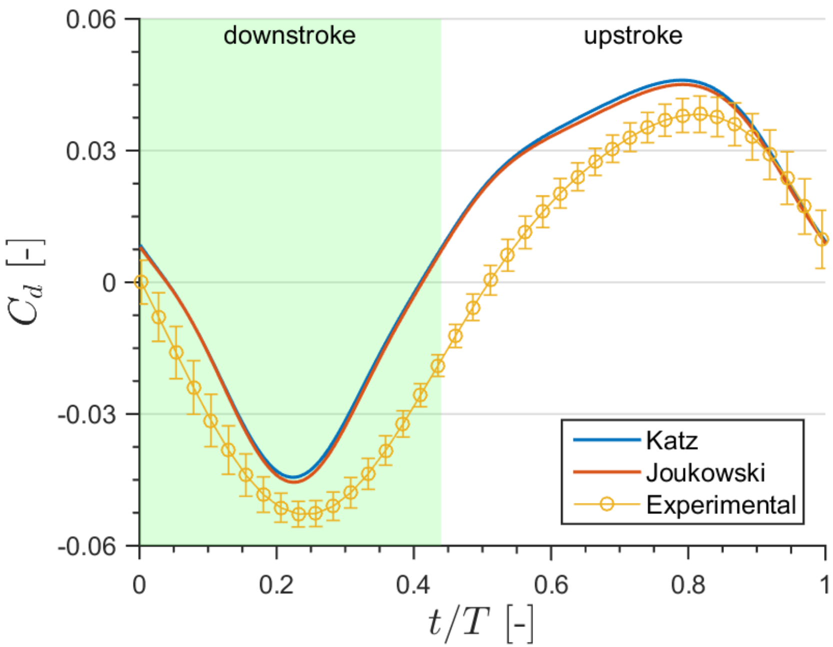
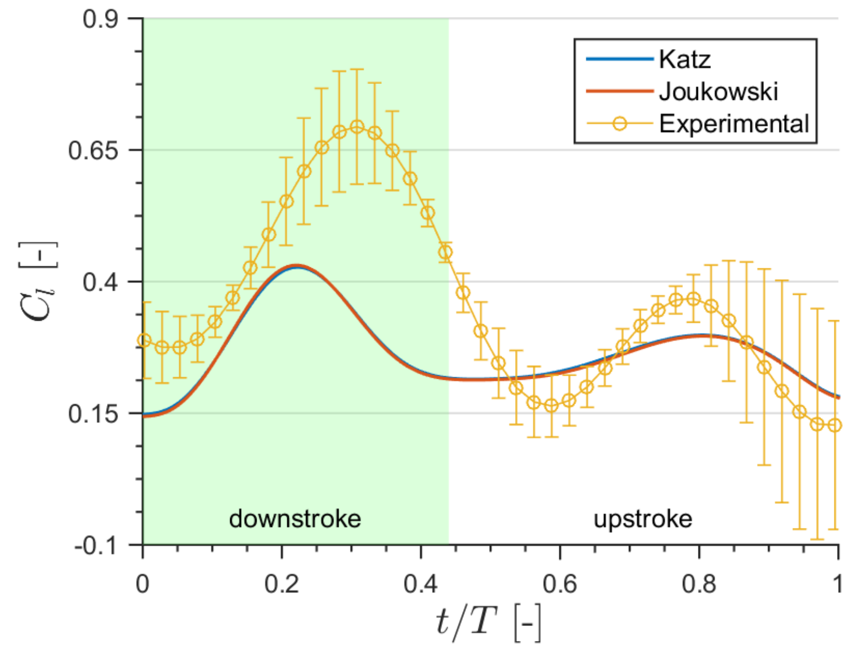
f=1.23 Hz, U=9.4 m/s





- Negligible difference between Katz and Joukowski
- Underprediction of thrust
- Same behavior than experimental

- Same prediction for both methods
- Not a good fit of experimental data

Flapping – Pitch leading

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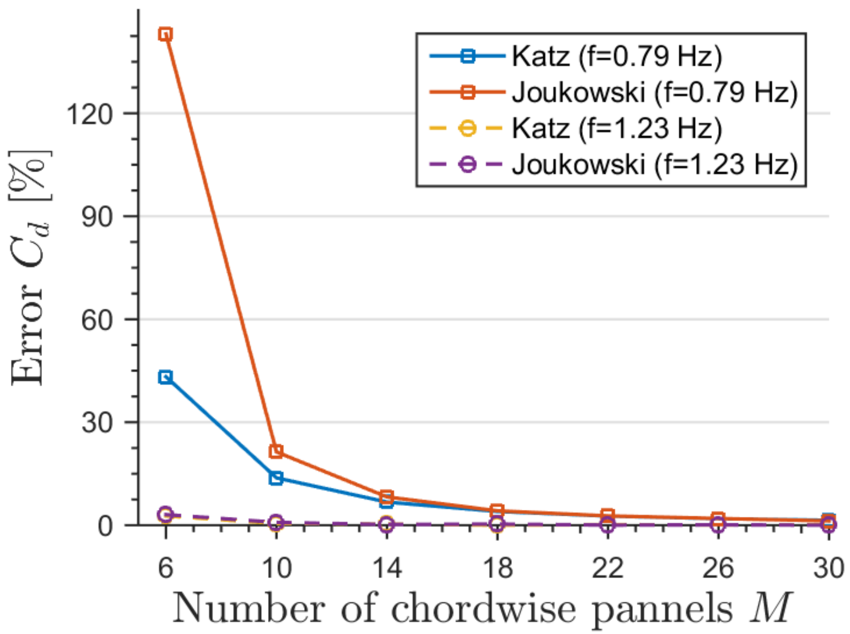
f=1.23 Hz, U=9.4 m/s



- Katz converges faster
- Convergence reached for the same M

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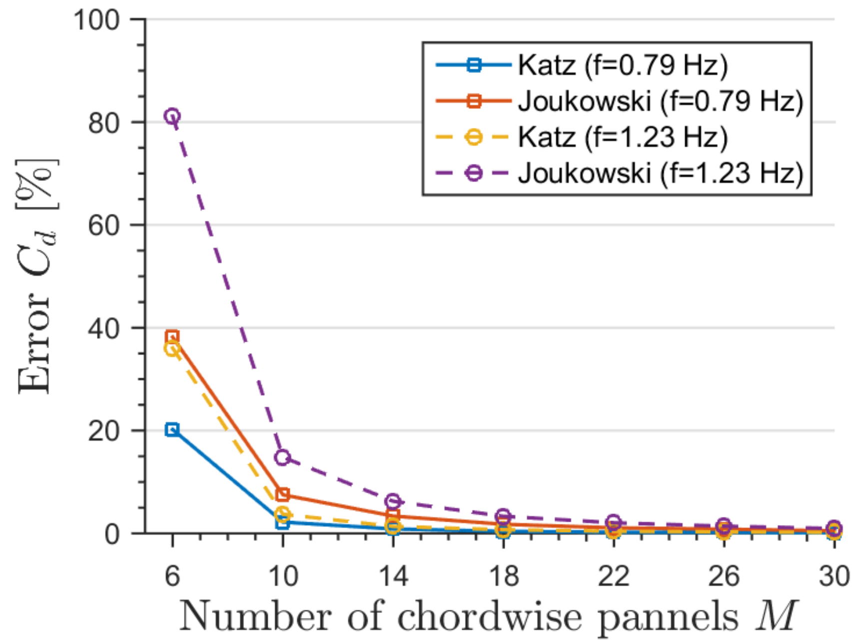
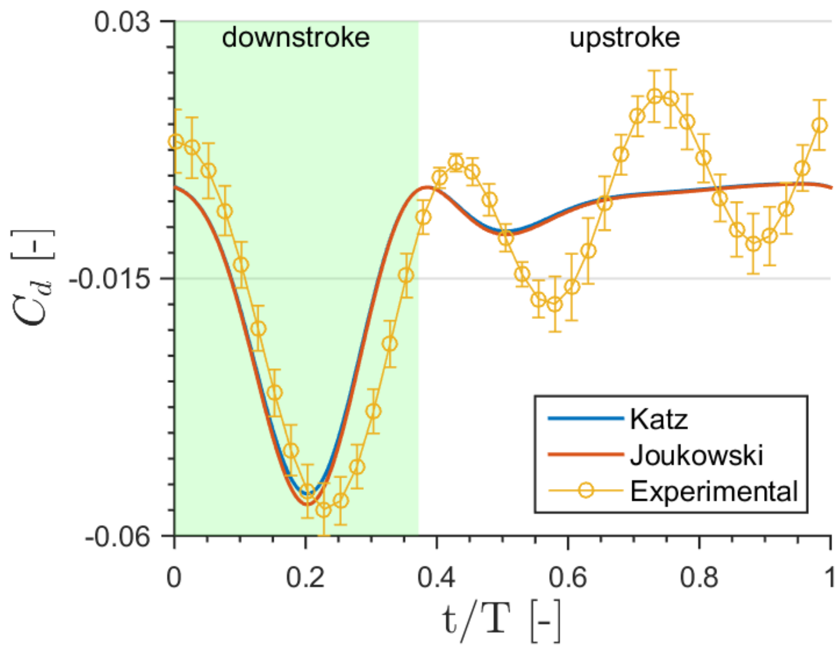
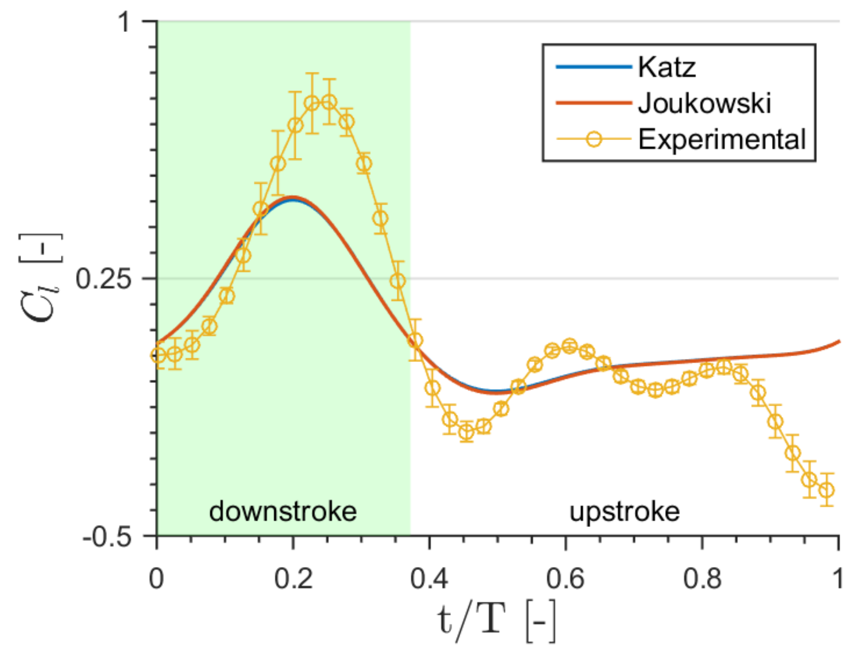


- Katz converges faster

Flapping – Pure flapping

Attached case: NACA 2412



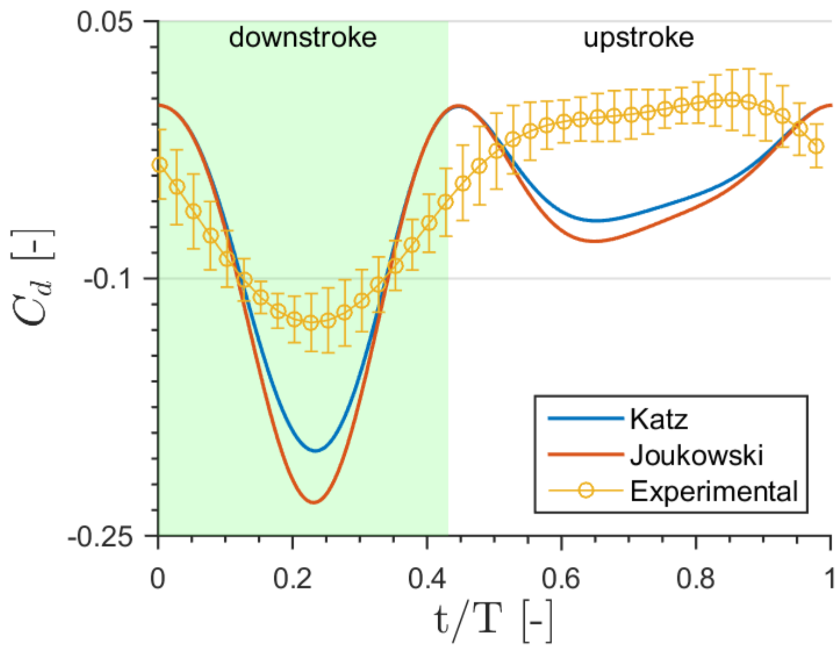


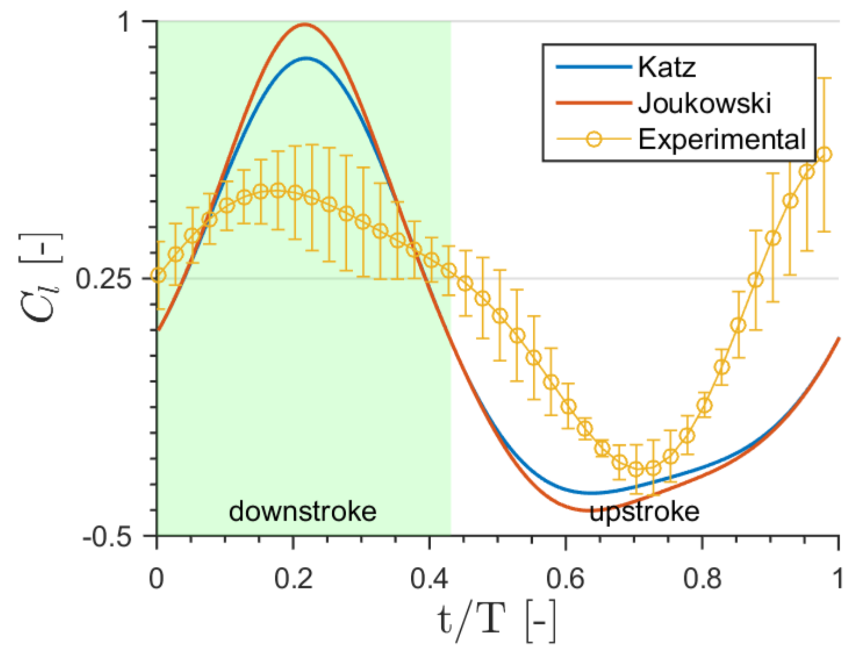
- Joukowski predicts a little bit more thrust
- Good fit of the data during downstroke
- Problem with experimental data for upstroke

- Not a good fit of experimental

Flapping – Pure flapping

Detached case: NACA 2412





- Both methods completely wrong (stall)
- Joukowski even "more wrong"

- Both methods completely wrong (stall)

Conclusion

Validity

- Joukowski and Katz give the **same solution** in most of the cases
  - Joukowski slightly better for high a.o.a.
  - Joukowski "more wrong" in stall

Convergence

- Joukowski better only for **uncambered airfoils** in pitch or plunge
- Katz converges faster in **all the other cases**

Thank you

Thank you for your attention