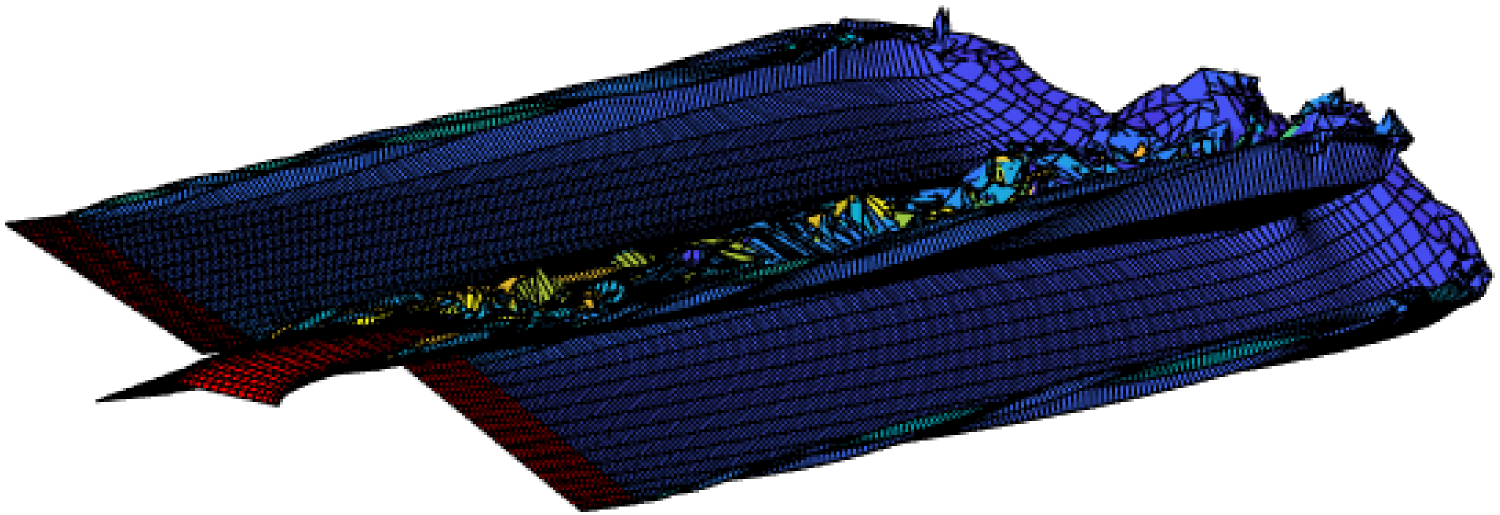
# Numerical and experimental analysis of tandem wings

**Thomas LAMBERT** – G. Dimitriadis – T. Andrianne
Liège University

N. Warbecq – P. Hendrick
Université Libre de Bruxelles

R. Nudds
Manchester University



# Introduction

- Studied since the very beginning of flight
- More or less abandoned during WW 2
- Renewed interest for micro and macro UAVs

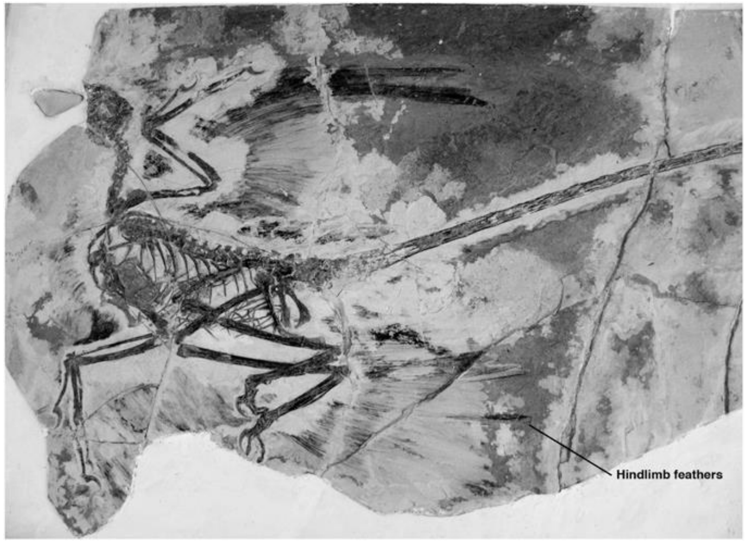

Proteus, Scaled Composites

Xianglong UAV

# Introduction – Microraptor

- Oldest specimen of winged dinosaur
- Likely the common ancestor of today's birds
- Feathers on hind limbs
- Glided from tree to tree
- **No clear consensus among biologist about its aft wings posture**

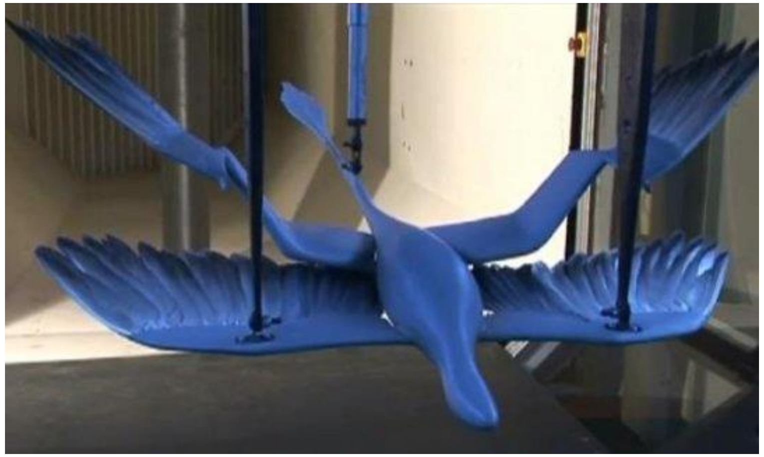
- Main goal: Understand the effect of wing attitude in tandem systems.
- Suggest the most probable positioning of wings for a four-winged animal, irrespectively of the wing size or profile.




Alexander et al., 2010

# Introduction – Microraptor

- Previous estimations based on empirical models for birds and biologically possible postures
- No real consensus on the methodology and results
- Wind tunnel tests conducted by biologists
  - Suggest that dihedral has no effect



Dyke et al., 2013

# Overview

- Introduction
- Experimental model
- Numerical analysis
  - UVLM
  - Numerical model
- Results
  - Horizontal and vertical positioning
  - Angle of attack
  - Dihedral angles
- Conclusion
- Future work

# Models

Experimental model – Wind tunnel

Numerical model - UVLM

# Experimental model

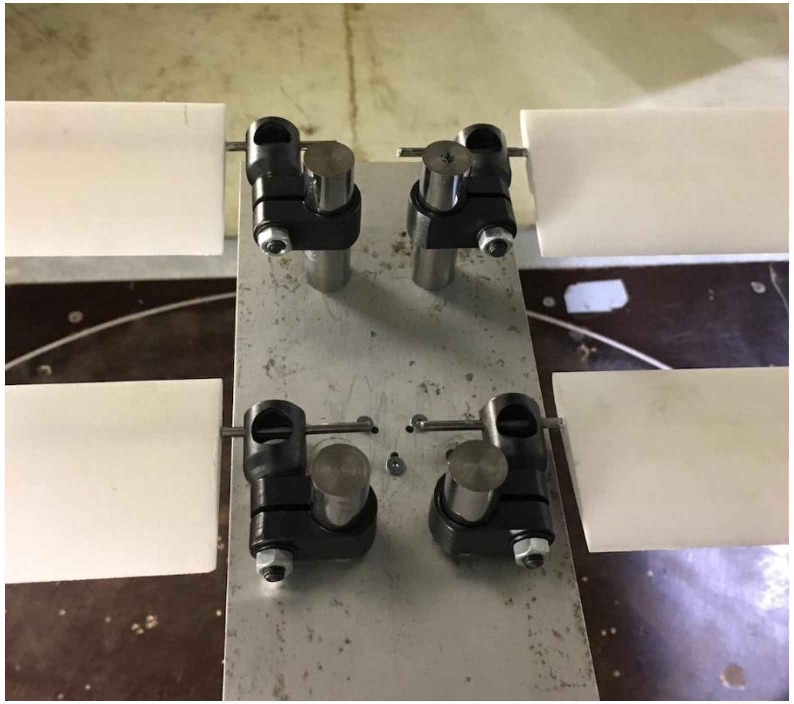
- Based on actual Microraptor dimensions : ~ 0.5 m total span
- 4 wings + large body

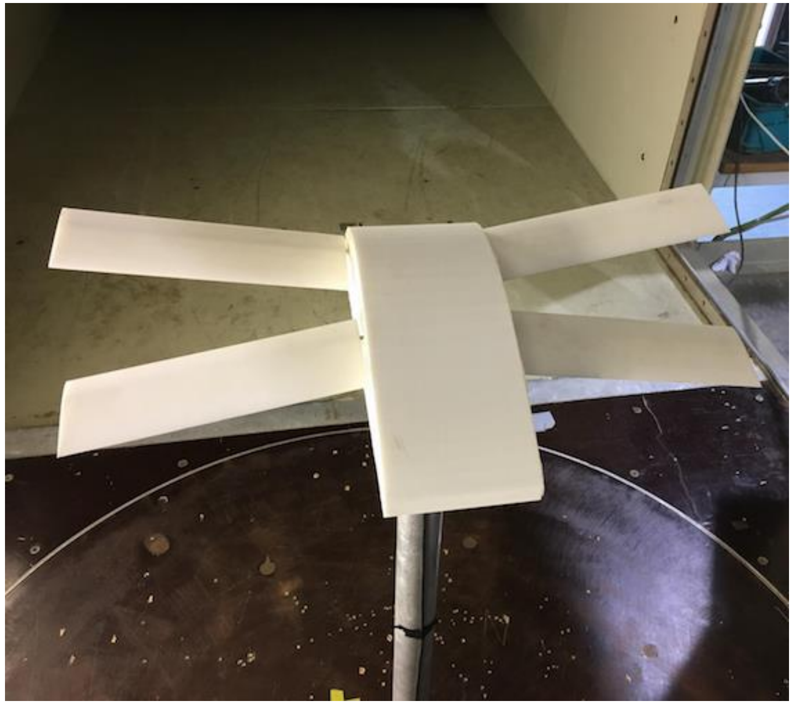
| Wing | |
|---|---|
| Profile | NACA 0012 |
| Span | 0.20 m |
| Chord | 0.0625 m |

| Body | |
|---|---|
| Profile | Nearly bluff |
| Span | 0.10 m |
| Chord | 0.256 m |

# Experimental model

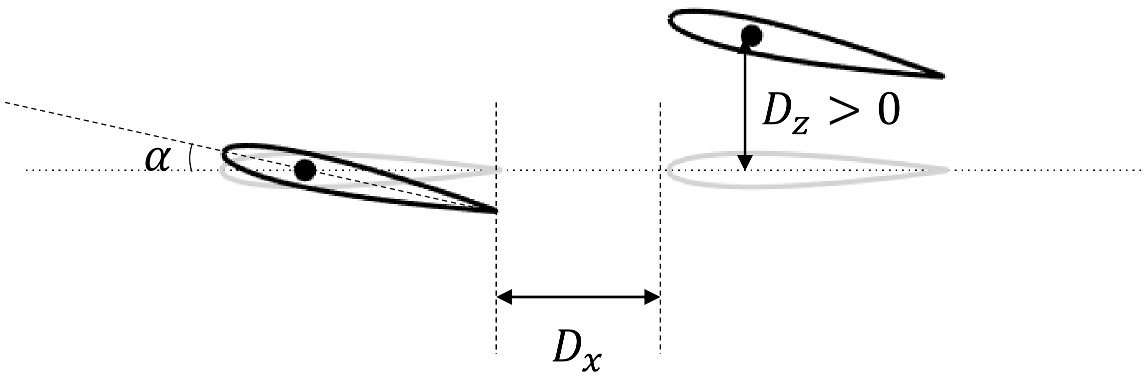
- Clamping mechanism with one single bolt to fix all DOFs
  - Easy to move and test a very wide range of configurations
  - Fiddly: when bolt is loosened, all DOFs may move





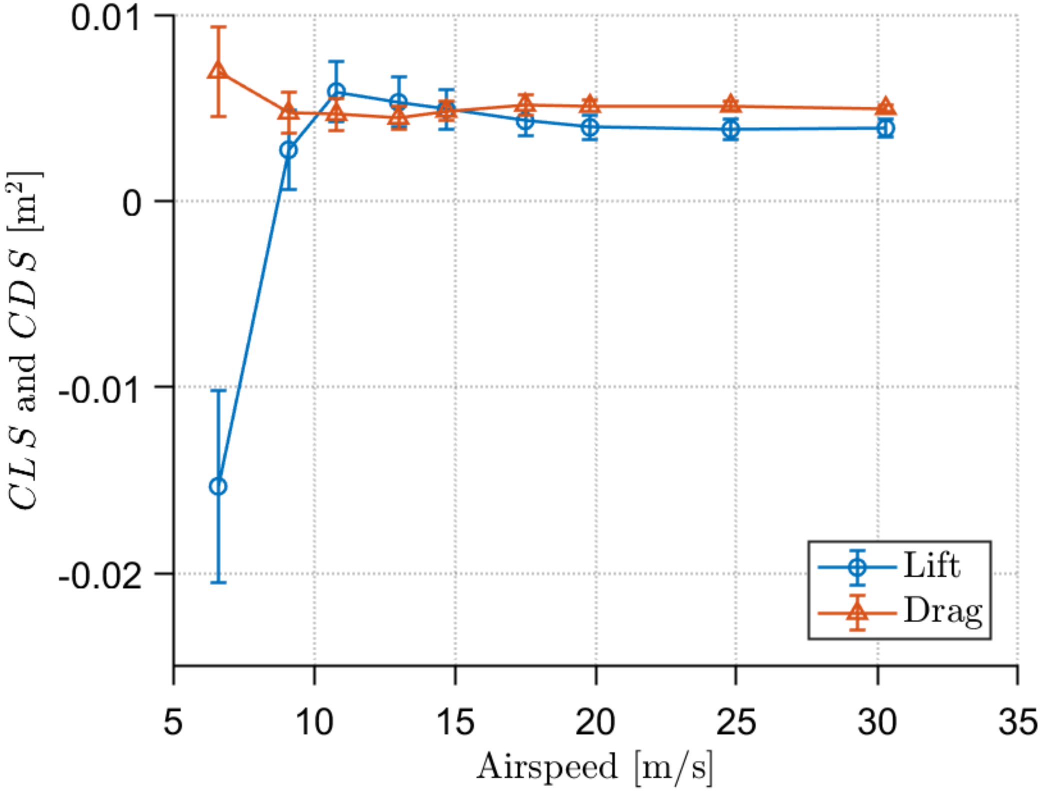
# Parameters

- Horizontal ($D_x$) and vertical ($D_z$) separation
- Angle of attack ($\alpha$)
- Dihedral angle ($\theta$)



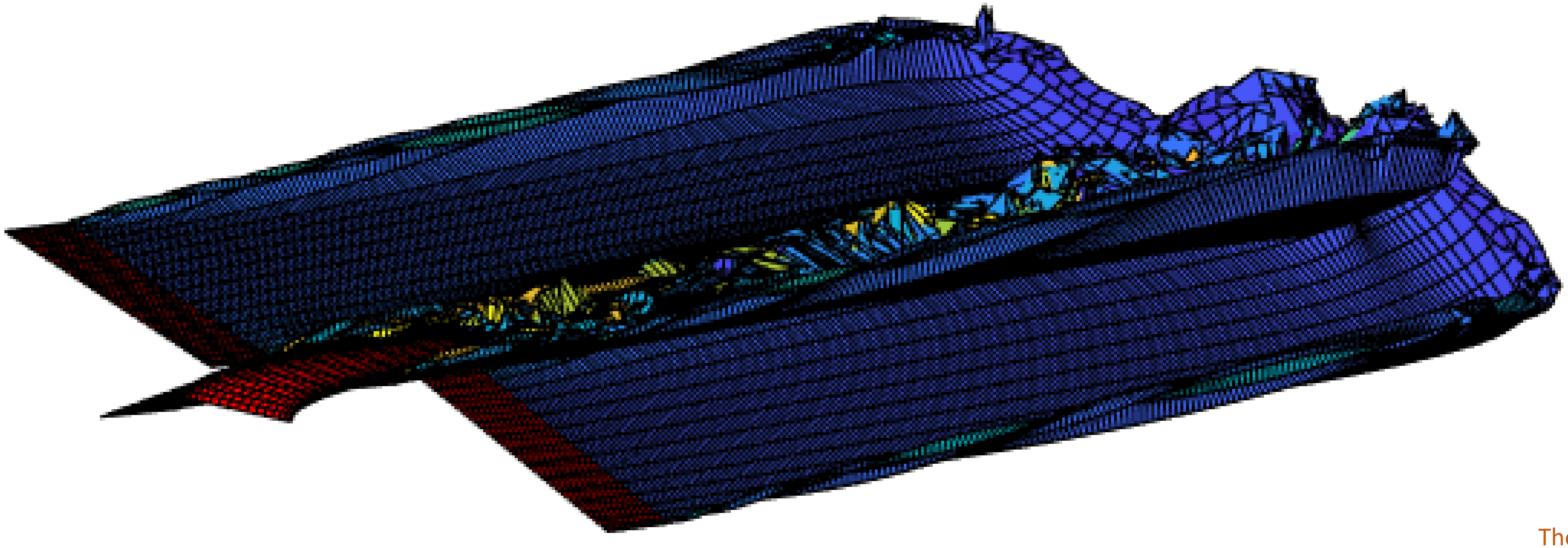

# Wind tunnel

- Large subsonic wind tunnel @ ULiège
- Section of 2x1.5 m
- Reynolds sensitivity analysis
  - Final measurements realized at 20 m/s
  - Re $\approx$ 80 000



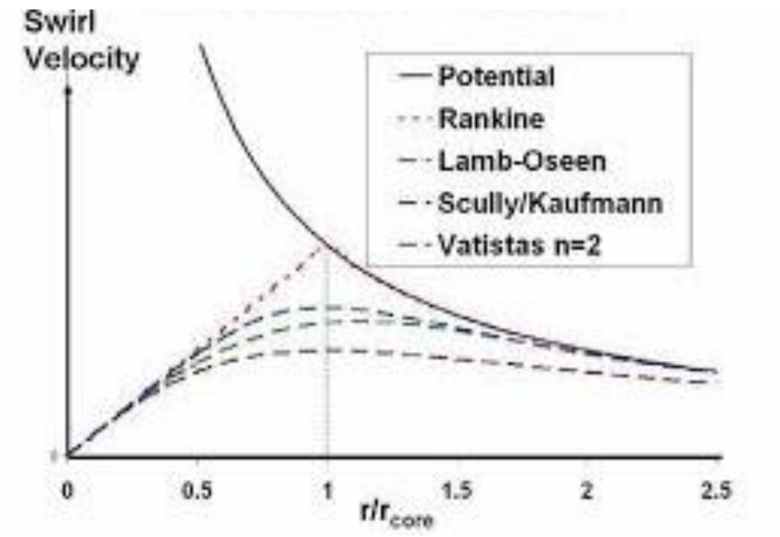
# Numerical analysis – UVLM

- Unsteady Vortex Lattice Method
  - Potential flow theory
  - Thin airfoil theory
  - Free-wake model
- In-house code used for flapping wings analysis



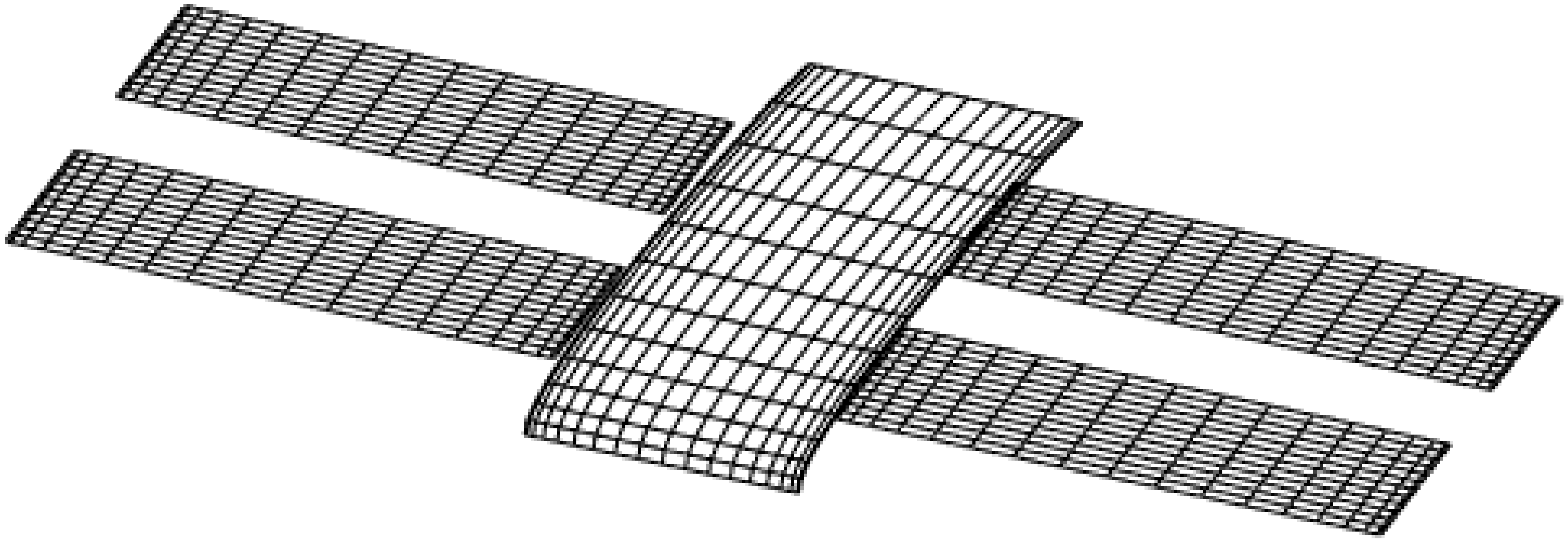
# Numerical analysis – Free wake model

- Usually induced velocity computed using Biot-Savart law
- Singularity when point of evaluation lies too close to the vortex segment
- Solution: Introducing a vortex core that reduces induced velocity
  - Common practice when wake interactions are expected
  - Add viscous dissipation in the vortex core
  - **Vatistas** second order



# Numerical analysis – Model

- Model the entire system (4 wings + body)
- Same dimensions as experimental model
- Same number of panels on wings and body
  - 18 spanwise, 12 chordwise
  - Smaller panels at tips and for the body at leading edge as well

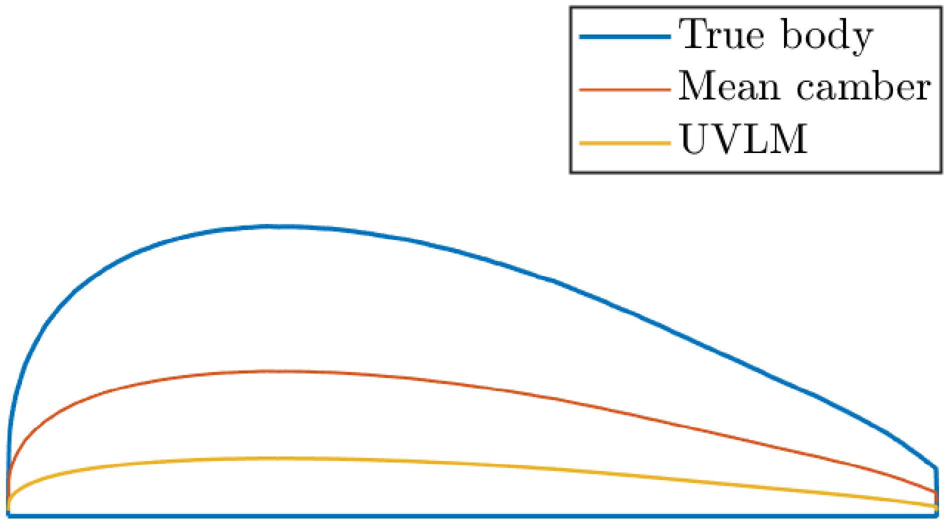


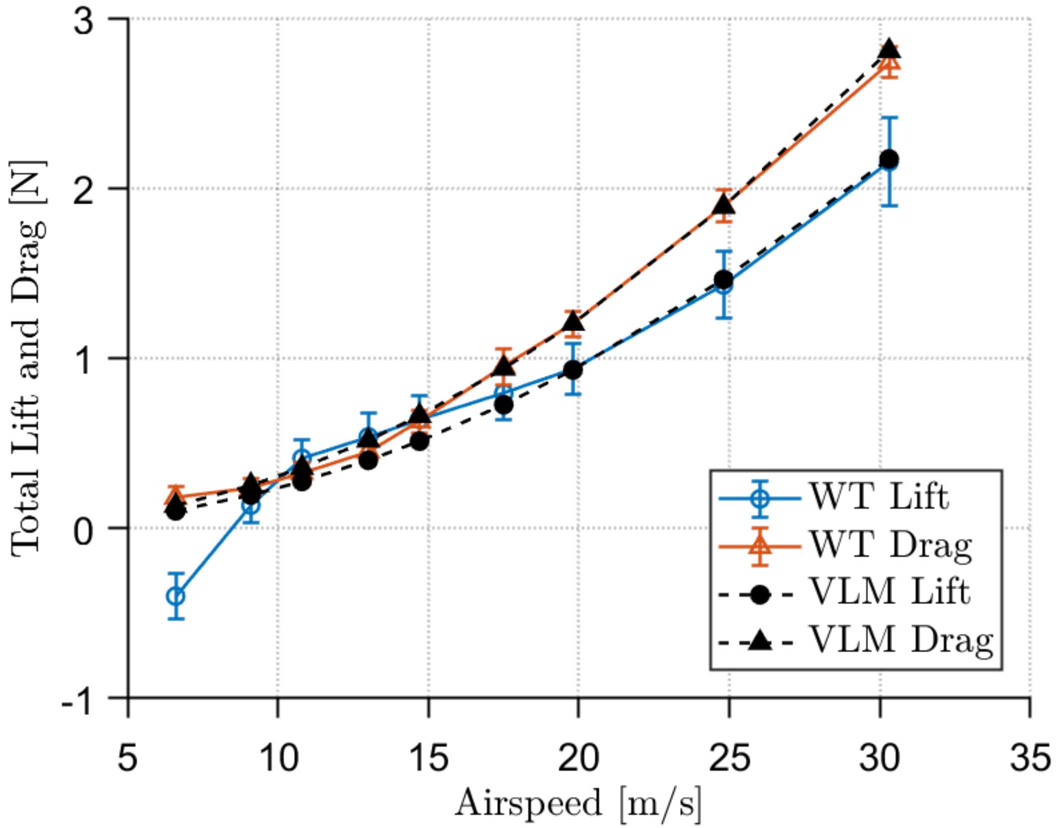
# Numerical analysis – Body model

- Body's impact too important to remove from total loads
  - Body must be included in numerical model
  - Results are presented for the entire system

- Experimental body is nearly bluff
  - Modeled in the UVLM as a highly cambered plate
  - The camber was adjusted in order to give the same lift as measured in the wind tunnel
  - UVLM induced drag predictions were correct but an offset was added to represent viscous drag

# Numerical analysis – Body model



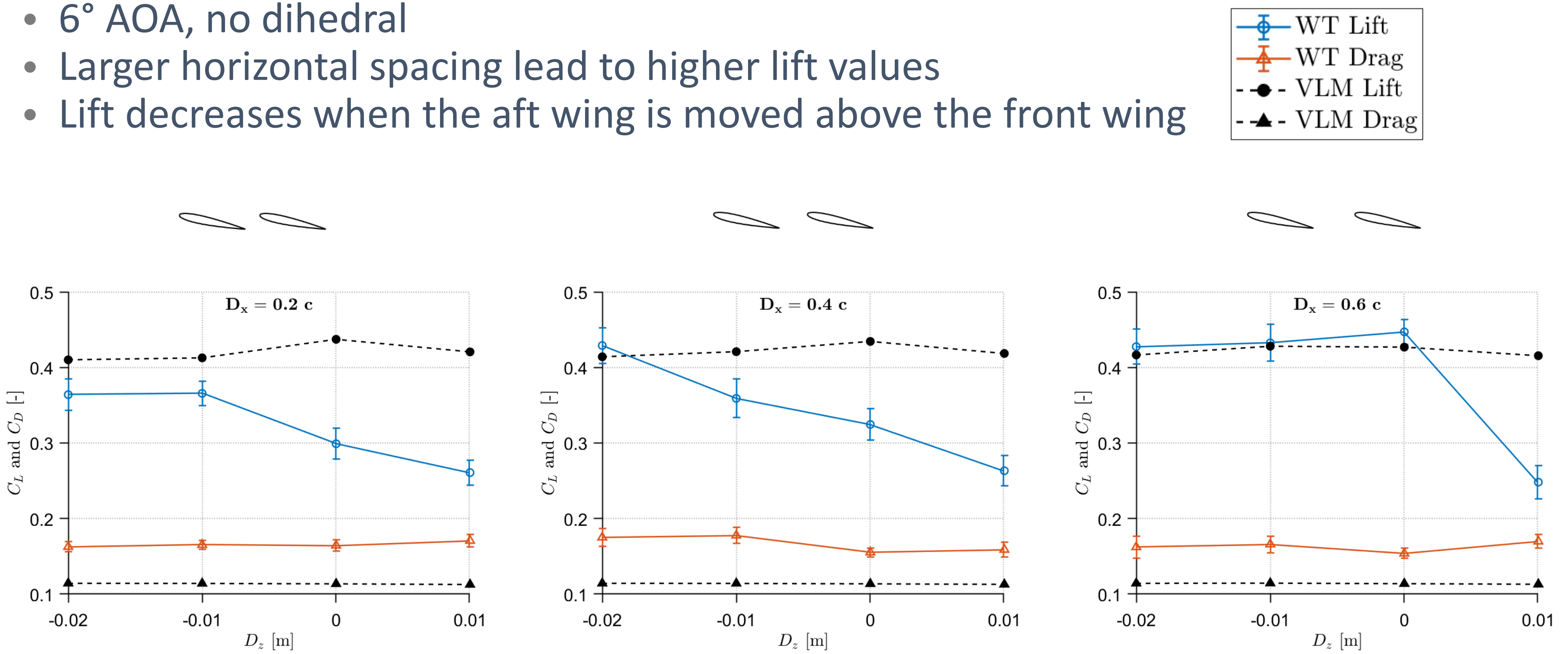



# Results

Horizontal and vertical positioning
Angle of attack
Dihedral angles

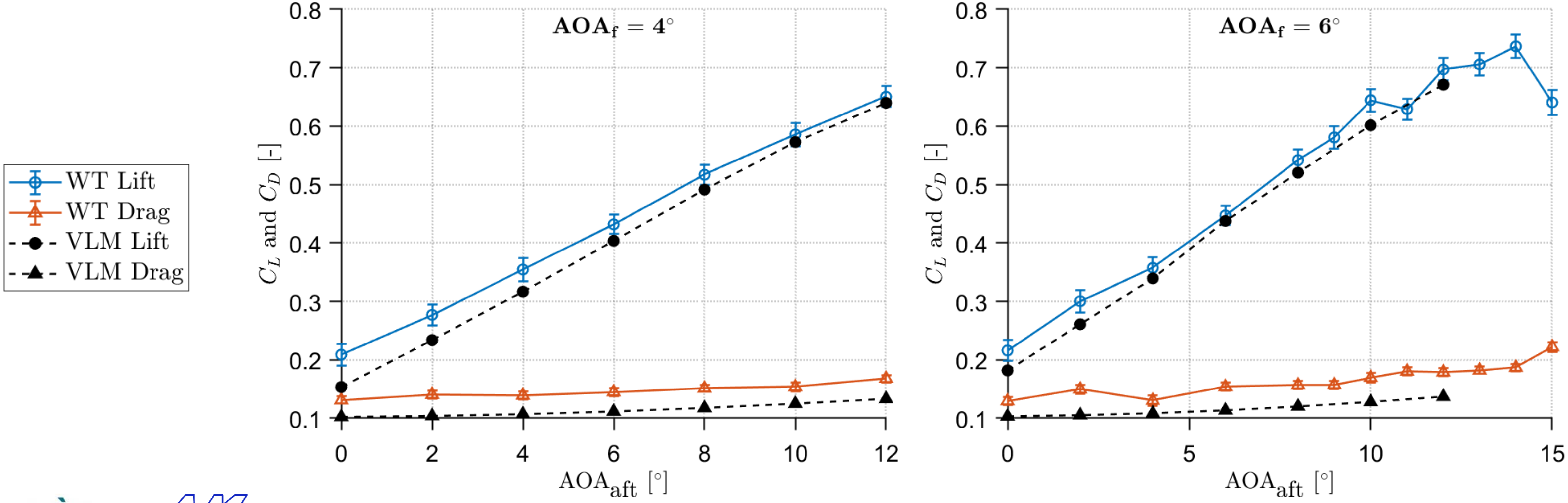
# Results – Horizontal and vertical position

- 6° AOA, no dihedral
- Larger horizontal spacing lead to higher lift values
- Lift decreases when the aft wing is moved above the front wing



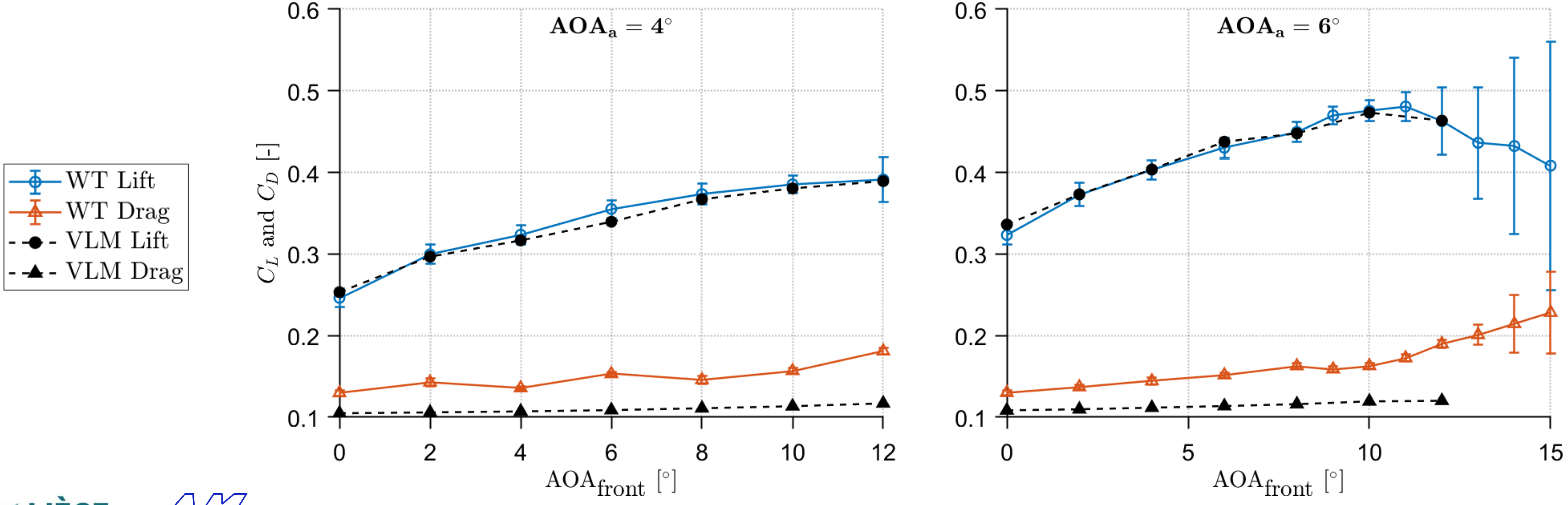
# Results – AOA aft

- Dx = 0.6 c , Dz = 0 c, no dihedral
- AOA front fixed, only AOA aft changed
- System stalls at high AOA, thanks to downwash induced by front wings



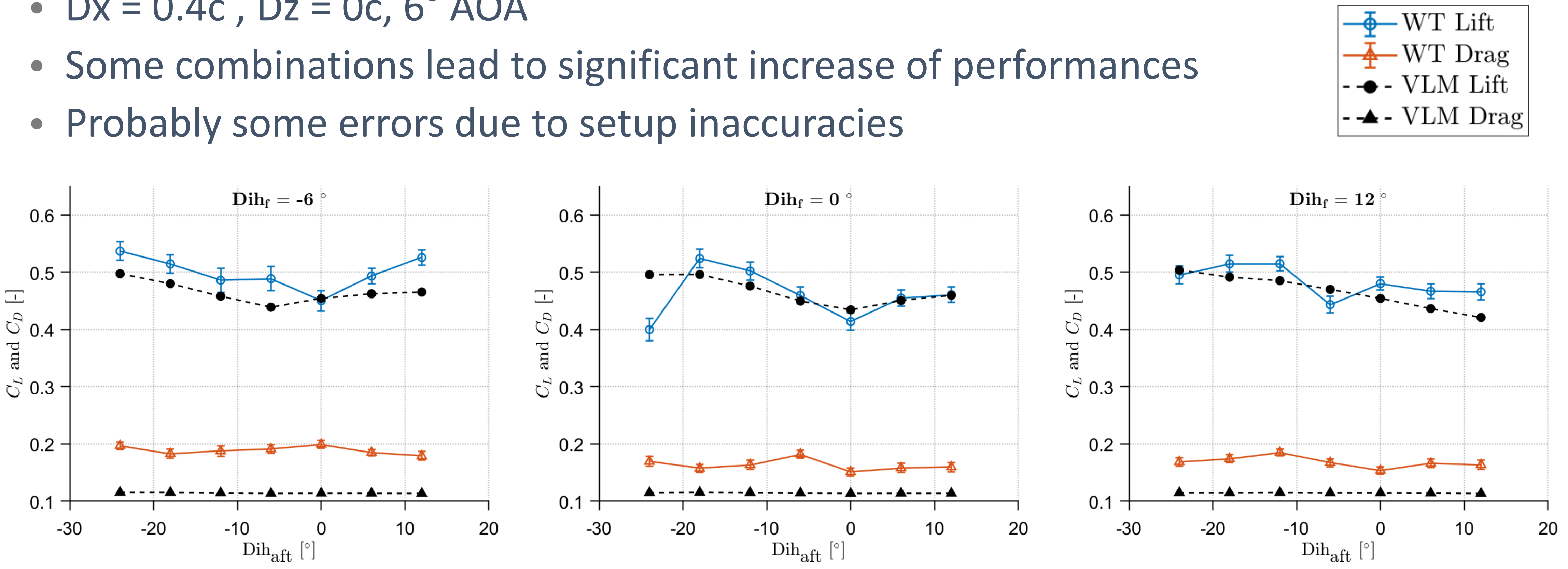
# Results – AOA front

- Dx = 0.6c , Dz = 0c, no dihedral
- Increase in AOA front less beneficial then in AOA aft
  - Higher AOA at the front increases the downwash on the aft wing



# Results – Dihedral

- Dx = 0.4c , Dz = 0c, 6° AOA
- Some combinations lead to significant increase of performances
- Probably some errors due to setup inaccuracies



# Conclusion

Conclusion

Future work and perspectives

# Conclusions

- Horizontal and vertical spacing have a significant effect on the lift
  - Best lift is obtained when the horizontal distance is high and the aft wing is below the front wing
- Variations of the AOA are more efficient if applied on the aft wings
  - For best lift the aft wing AOA should be higher than that of the front wing
- Dihedral seems to play an important role in the lift force generated by the system
  - Best lift is obtained when the difference between the two dihedral angles is high
  - For the Microraptor, the best lift would be obtained with dihedral at the front and anhedral at the rear
- UVLM predictions are generally good

# Future work

- Compare tandem wing results to an equivalent single wing
- Use of flow visualization techniques
  - Better understanding of flow interference phenomena
- Repeat analysis with:
  - Cambered wings
  - Biologically accurate wings (goose)
- More accurate representation of an actual Microraptor

# Thank you

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