Modeling and control of Airborne Wind Energy Systems using lifting line/surface aerodynamics

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1 ▸ Context and motivation

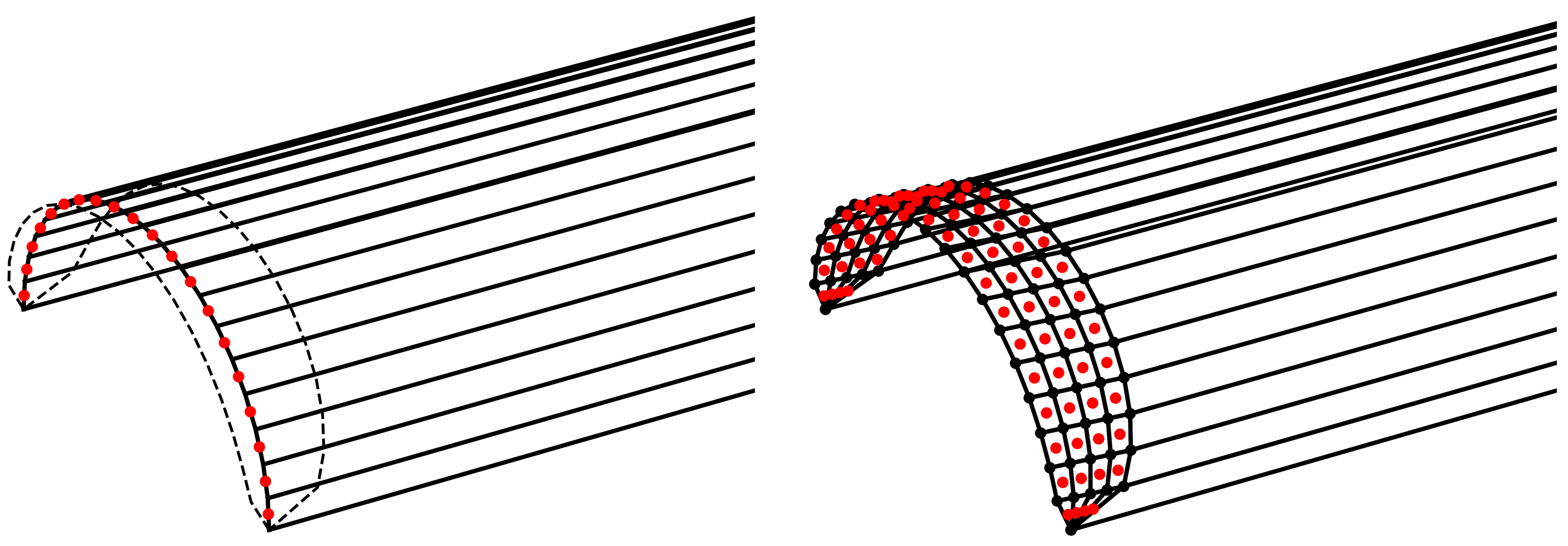
Airborne Wind Energy Systems have complex aerodynamic behaviors. Such devices also operate in perturbed flows (turbulent ABL, wakes, ...). They therefore need accurate aerodynamic models.

Lifting line and lifting surface:

- Good representation of wing aerodynamics
- Computationally cheap
- Allow to represent both fixed wings and soft wings
- Flow perturbations scales smaller than the wing span can be taken into account

2 ▸ Methodology

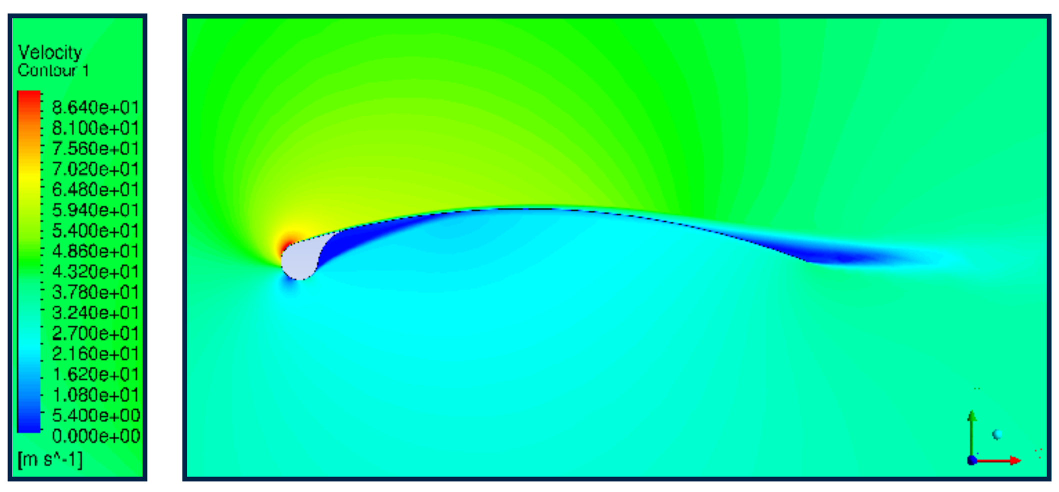
Lifting line/surface models are built using horseshoe vortices and vortex rings assemblies [1].



Lifting line method   Lifting surface method

The induced velocity is evaluated for each vortex segment using the Biot-Savart law.

The implemented lifting line is a numerical extension of the Prandtl lifting line method[2]. It can be implemented in a non linear way to allow the use of polar curves[3]. Kite airfoil polar curves (lift, drag and moment coefficients) are obtained from experiments or are generated using RANS. The effect of unsteady aerodynamics can also be implemented.



RANS of a Leading Edge Inflatable (LEI) kite airfoil at 10° angle of attack: norm of the velocity field.

The lifting surface best represents low aspect ratio wings (such as kites). The method also captures the chordwise load distribution.

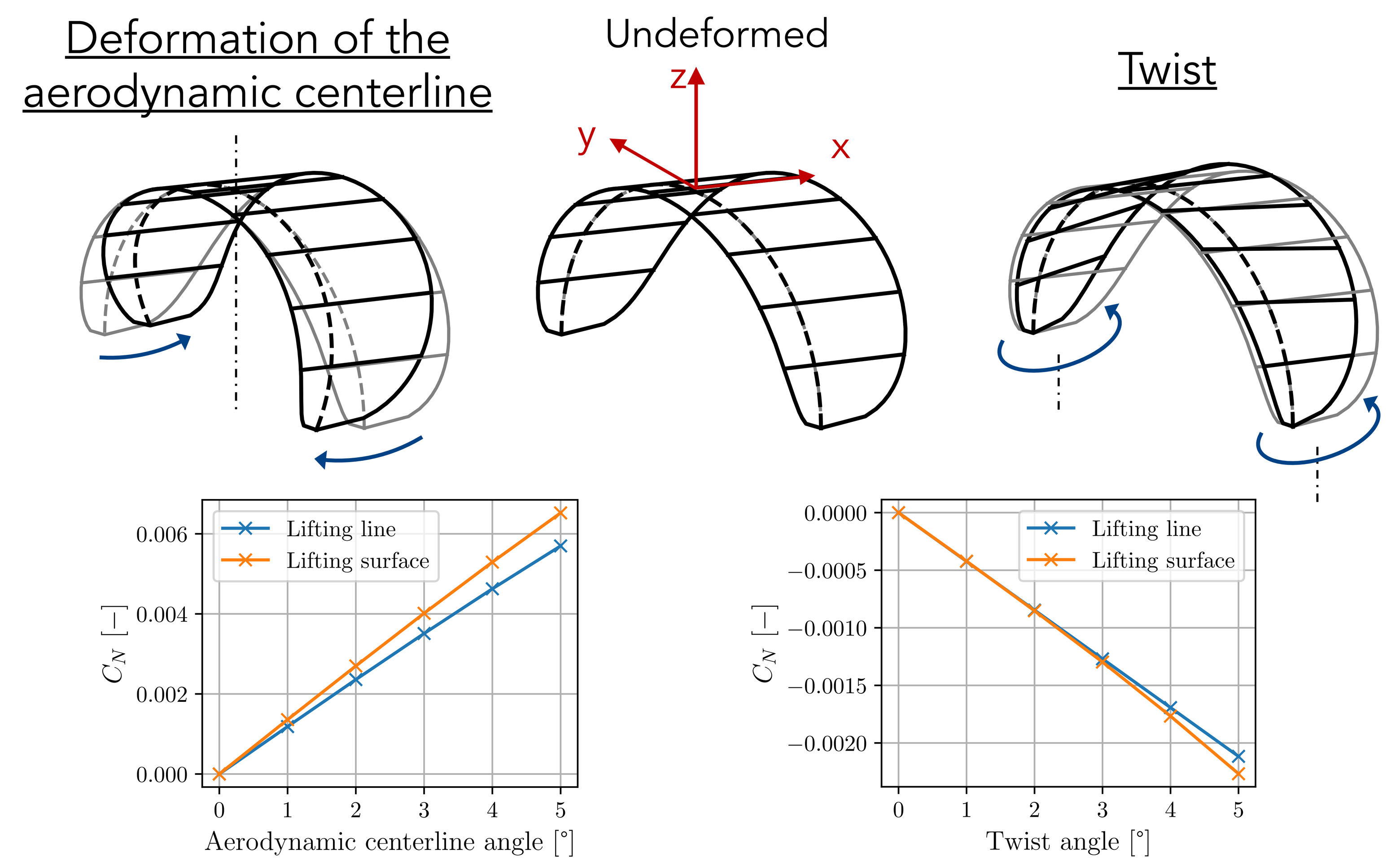
Polar curves cannot be used but geometrical complexities can be taken into account (such as large deformations, camber effects, etc.).

3 ▸ Soft Wing Deformation

Two deformation modes are identified to be responsible for control of a kite in yaw[4]:

- Twist of the airfoil profiles along the span
- Deformation of the aerodynamic centerline

The steering capabilities of the two modes are studied. Both deformations are applied linearly along the span (no deformation at the center of the wing and maximal deformation at the tips).

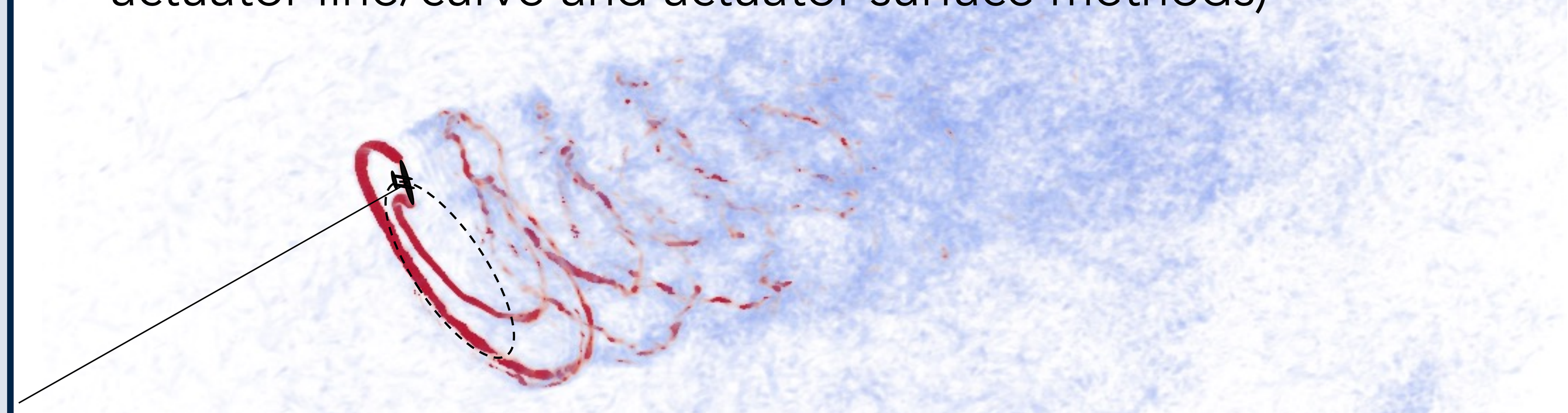


Yawing moment coefficient due to the two deformation modes

The variation of the moment coefficient with the angle is obtained for each mode considered independently.

4 ▸ Perspectives

- Further understanding of the steering behavior in relation to the deformation modes
- Coupling of the aerodynamic models (lifting line, lifting surface) with AWES dynamics and control
- Study of AWES aerodynamics and control in flows with perturbations (encounter of wake vortices, of gusts) and in turbulent flows (ABL)
- Implementation of the methods in a LES framework (using actuator line/curve and actuator surface methods)



LES of a fixed wing AWES in a flow at U_∞ = 10 m/s with 6% TI

5 ▸ References and aknowledgments

[1] J. Katz and A. Plotkin. Low speed aerodynamics. Cambridge University Press, 2001.
[2] R. Leloup, Roncin K., G. Bles, J. Leroux, C. Jochum, and Y. Parlier. Estimation of the lift-to-drag ratio using the lifting line method: application to a leading edge inflatable kite. Airborne Wind Energy, 2013.
[3] J.D. Anderson. Fundamentals of aerodynamics. McGrawHill, 5th edition, 2011.
[4] J. Breukels.: An Engineering Methodology for Kite Design. Ph.D. Thesis, Delft University of Technology, 2011.

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