Fluid-Structure Interaction Analysis of a Rigid-Framed Delta Kite for Airborne Wind Energy

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Introduction

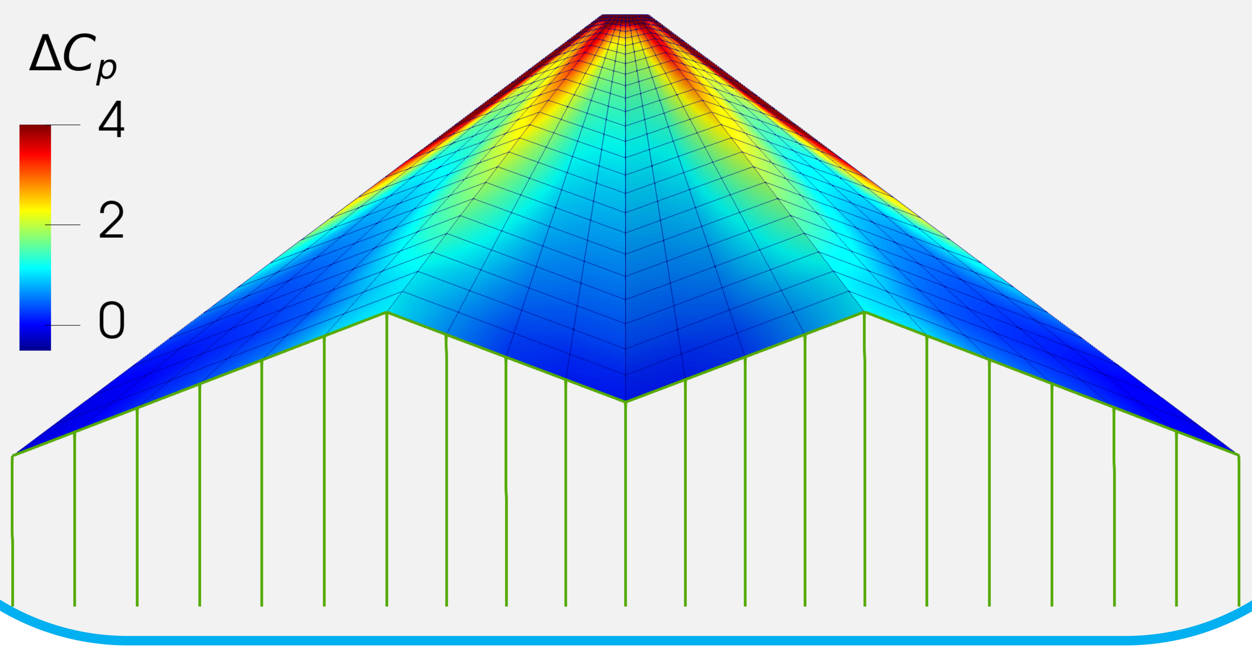
The coupling between aerodynamics and structure plays a major role in membrane and semi-rigid (hybrid) wings applied to airborne wind energy systems. Besides the inherent flexibility of these structures, the aerodynamic pressure presents significant variations induced by large changes in the aerodynamic velocity vector (angle of attack, sideslip angle and airspeed) during crosswind operation [1]. Owing to its relevance in AWE, fluid-structure interaction (FSI) of leading-edge inflatable [2] and ram-air [3] kites was extensively studied. The rigid-framed delta (RFD) kite used by the AWE group of UC3M was aerodynamically characterized through experiments [1] and simulations [4], but its aeroelasticity had not been studied yet. This work presents an FSI analysis of the delta kite where an in-house aerodynamic tool (UnPaM) [5] is coupled with a commercial finite element software (Abaqus). In the following, the FSI solver and the aeroelastic results are shown.

Fluid-structure interaction (FSI) solver

Aerodynamics (UnPaM) [5]

- In-house potential-flow tool
- Steady vortex lattice method (VLM)
- Inputs: Airspeed, angle of attack, sideslip angle and deformed mesh
- Outputs: Aerodynamic pressure (panel forces)

Pressure distribution and flat wake



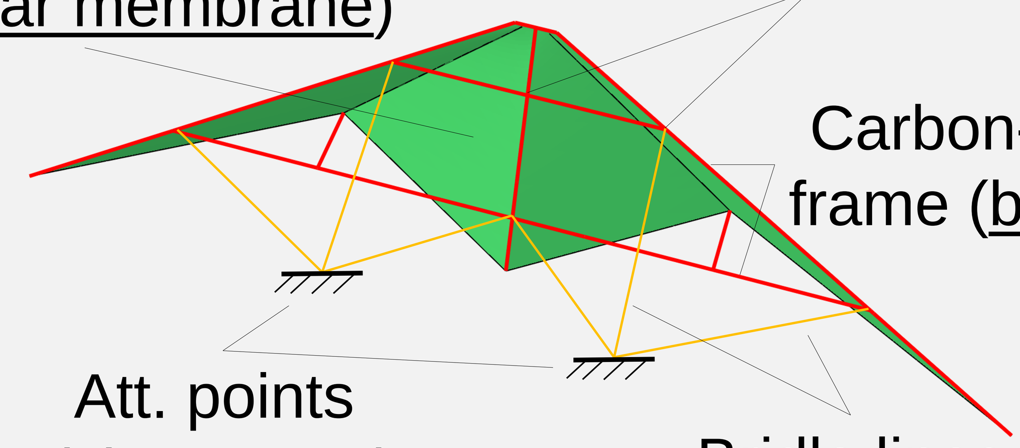
Orchestrator (MATLAB)

1 Displacements
3 Forces
2 Forces
4 Displacements

Structure (Abaqus)

- Finite element analysis software
- Dynamic implicit solver (time integration to reach a steady state)
- Inputs: Aerodynamic pressure
- Outputs: Nodal displacements

Finite element model

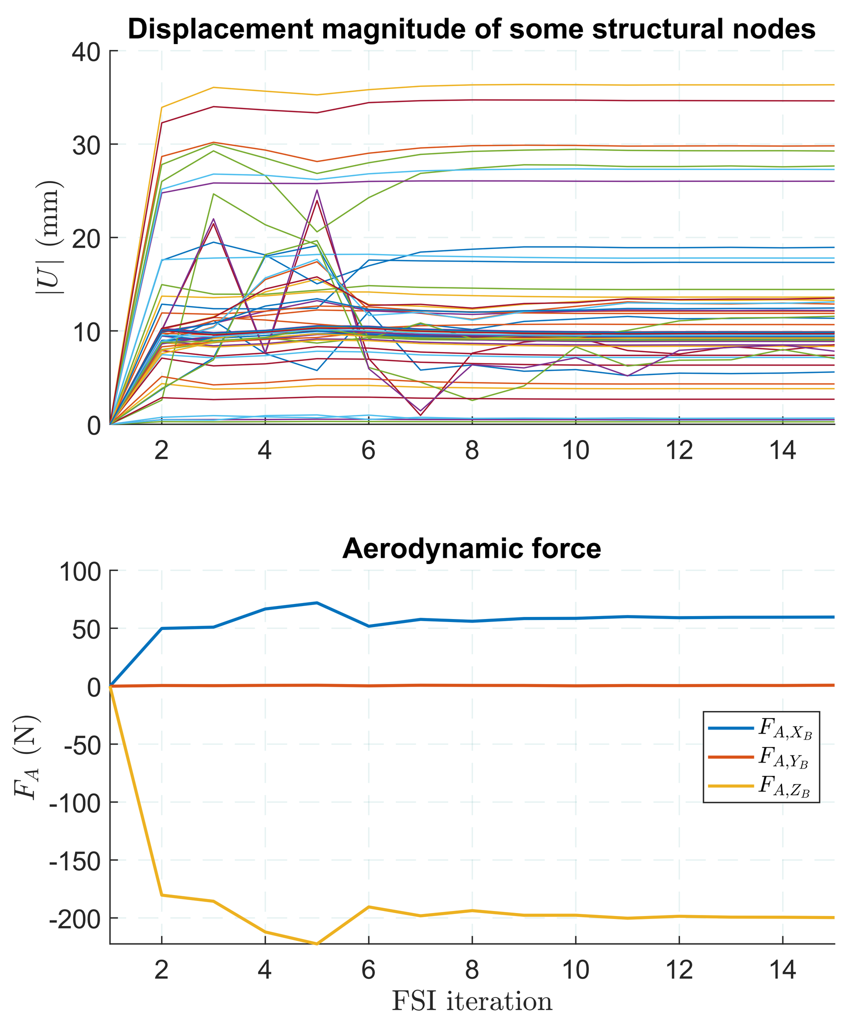


FSI analysis of the RFD kite

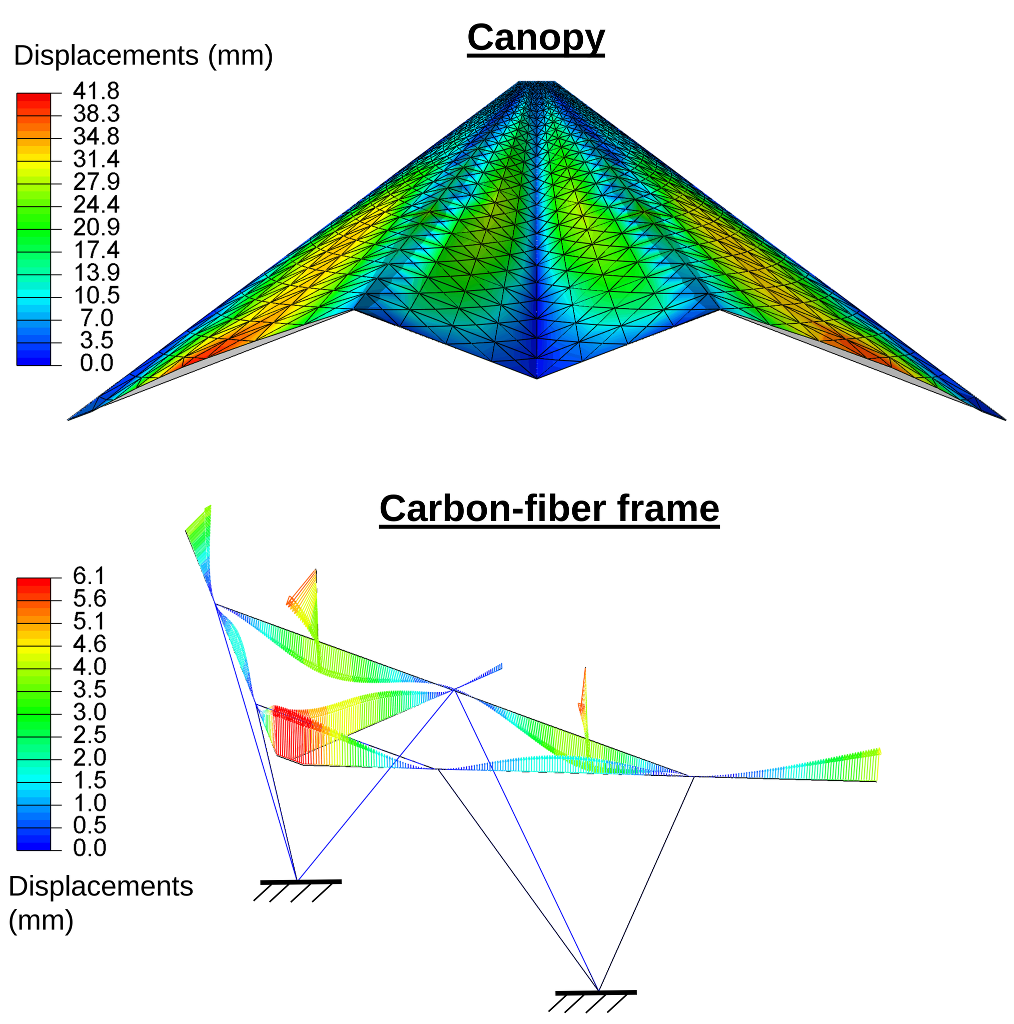
Description: **Panel (a)** shows the evolution of some variables during the FSI iteration finally reaching convergence. **Panel (b)** displays the deformed shape of the canopy and carbon-fiber frame. **Panel (c)** shows the aerodynamic polar (C_D vs C_L) and the lift-to-drag ratio as a function of α for the nominal and deformed kites, and a colormap of C_L/C_D as a function of V_A and α.

Conclusions: The aerodynamic pressure inflates the canopy increasing its curvature (higher $C_L(\alpha)$). The deformed kite has a higher C_L/C_D than the nominal kite at low angles of attack and finds the max. at lower α (~25º). Both V_A and α highly influence the aerodynamic coefficients, unlike in the nominal case (only α). The clamped BC (att. points) is a limitation of the model that will be revisited in future works.

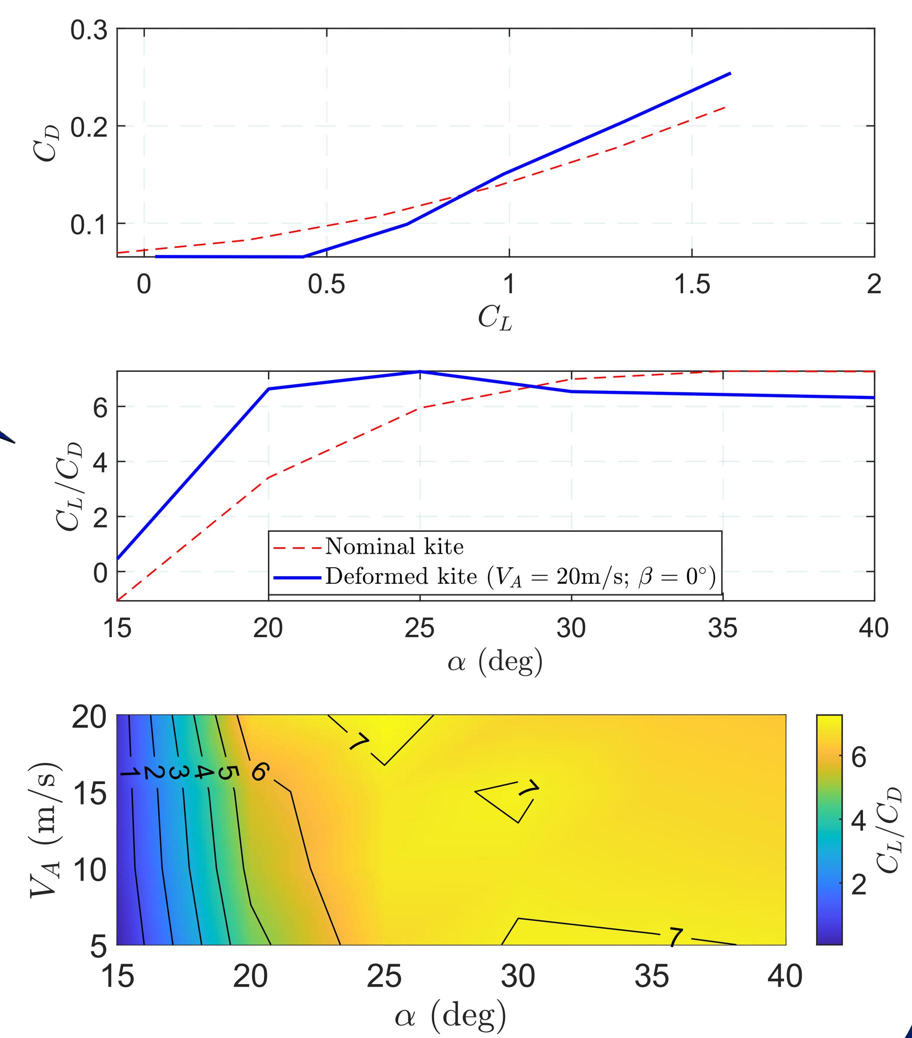
(a) FSI iteration



(b) Deformed shape ($V_A = 15$m/s; $\alpha = 35°$; $\beta = 0°$)



(c) Aerodynamic coefficients



References: **[1]** Borobia-Moreno, R., et al.: Identification of kite aerodynamic characteristics using the estimation before modeling technique. Wind Energy 24 (6), 596-608 (2021); **[2]** Cayon, O., et al.: Fast Aero-Structural Model of a Leading-Edge Inflatable Kite. Energies 16 (7), (2023); **[3]** Thedens, P. and Schmehl, R.: An Aero-Structural Model for Ram-Air Kite Simulations. Energies 16 (6), (2023); **[4]** Castro-Fernández I., et al.: Three-Dimensional Unsteady Aerodynamic Analysis of a Rigid-Framed Delta Kite Applied to Airborne Wind Energy. Energies 14 (23), (2021); **[5]** Cavallaro, R., et al.: Amphibious PrandtlPlane: Preliminary Design Aspects Including Propellers Integration and Ground Effect.56th AIAA/ASCE/AHS/ASC Str. Dyn., and Mat. Conf. (2015).

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