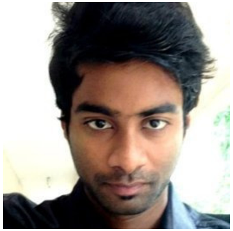

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Multiple-Wake Vortex Method for Leading Edge Inflatable Tube Kites used in Airborne Wind Energy Systems

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In this study we propose a robust vortex model for time-dependent vortex shedding at separation locations and trailing edge. The model, which is able to capture flow separation and reattachment phenomena, aims at improving a previously developed a multiple-wake vortex lattice model [1], which could not describe flow reattachment phenomena on suction and pressure surfaces.

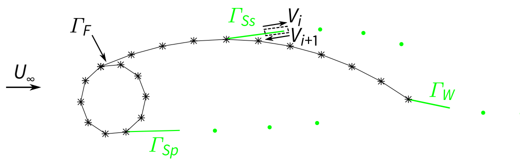
Starting from potential theory the two-dimensional Leading Edge Inflatable (LEI) kite airfoil is discretized by several straight panels with point vortices at quarter chord point of each panel. A constant-strength vortex panel is shed at each separation location and is convected in the next time step as vortex blob without change in its strength for further time steps. The circulation is defined as a closed line integral of the tangential velocity component around the fluid element.

$$\Gamma \equiv \oint_C V \cdot ds$$

Considering a closed line integral around the separation panel, as described in Katz [2], applying the above equation, we get

$$\frac{d\Gamma_S}{dt} = \frac{D}{Dt}\oint Vds = \frac{d}{dt}(V_i ds - V_{i+1} ds) \cong \frac{1}{2}(V_i{}^2 - V_{i+1}{}^2),$$

and Γ_{Ss}, Γ_{Sp} are separated wake strengths defined using above formulation on suction and pressure sides respectively.



2D LEI kite airfoil discretized into straight panels with vorticity placed at quarter chord point.

Together, the N_p bound vortex strengths Γ_{Sp}, as well as Γ_{Ss} and Γ_W, give $N_p + 3$ unknowns. The boundary conditions are no flow penetration through the surface (applied at three-quarter chord point on each panel) and the vorticity shed during the time step at separation locations, along with Kelvin-Helmholtz theorem, form $N_p +$ 3 boundary conditions. Circulations obtained from iterative solution scheme are post processed using time-dependent Bernoulli's equation for momentary pressure distribution.

References:

[1] R. Leuthold: Multiple-wake vortex lattice method for membrane-wing kites. MSc Thesis, TU Delft, The Netherlands, December 2015. http://resolver.tudelft.nl/uuid:4c2f34c2-d465-491a-aa64-d991978fedf4

[2] J. Katz: A discrete vortex method for the non-steady separated flow over an airfoil. Journal of Fluid Mechanics, 1981, vol. 102, pp. 315-328.