Multiple Wake Discrete Vortex Model for 2D LEI Tube Kite Airfoil

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Introduction

During pumping cycles, TU Delft airborne wind energy system (Leading edge inflatable (LEI) tube kite) is operated over a range of angle of attacks (aoa) in which the following flow separation phenomena are possible to occur:

- a suction-surface trailing-edge flow separation - and this separation location moves forward as aoa increases,
- a leading-edge flow separation - at high aoa,
- pressure-surface leading-edge flow separation, even at low aoa due to the lack of lower surface.

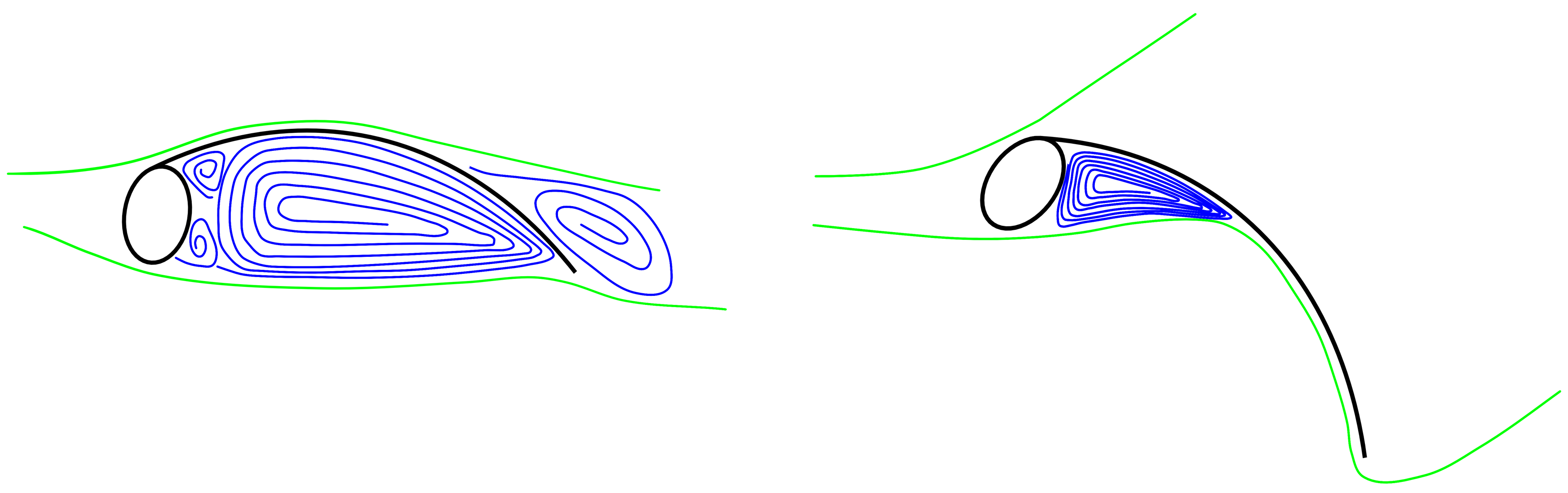

Figure: 2D LEI kite - Flow separation at moderate and high angle of attack

The applicability of vortex methods to model such complex flow phenomenon is justified by the ability of available vortex models (multi-wake) that successfully capture flow separation characteristics and time-dependent wake dynamics.

Flow separation modeling details

For high Reynolds number flows, the viscous effects are restricted to thin shear layers. Here, the idea is to represent the shear layer emanating from flow separation location by vortices (discrete or continuous vortex distribution) of appropriate strength and placing it in a position such that it mimics flow separation. The circulation strength of separated vortex can be found by line integral around a closed curve of the velocity field.

$$\Gamma \equiv \oint_C V.ds$$

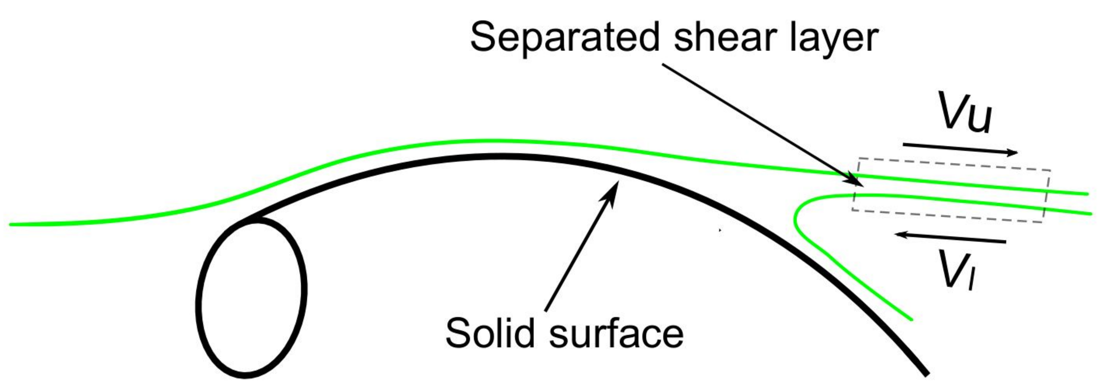

Figure: Separated shear layer

The rate of circulation shed is given

$$\frac{d\Gamma_S}{dt} \cong (V_u - V_l)\frac{V_u + V_l}{2}$$

This equation is experimentally verified (Fage & Johanson, 1927) and used by numerous authors to model flow separation. The latest position of the separated vortex is given by the product of average of velocities above and below the shear layer and time step. This varies depending on the vortex singularity element used to model shear layer.

Solver

Minor modifications to a usual steady-state potential flow solver,(J. Katz & A. Plotkin, Low Speed Aerodyanamics), resulted in a time dependent solver which can treat unsteady flows. Since equation defining rate of circulation shed is non-linear, an iterative solution technique is applied at each time, till the convergence of shed circulation strength. Circulations obtained from iterative solution scheme are post processed using time-dependent Bernoulli equation for momentary pressure distribution. After post processing, solver advances in time and wake is convected with local flow velocity using first order Euler scheme.

Wake shedding behind impulsively started 2D LEI tube kite

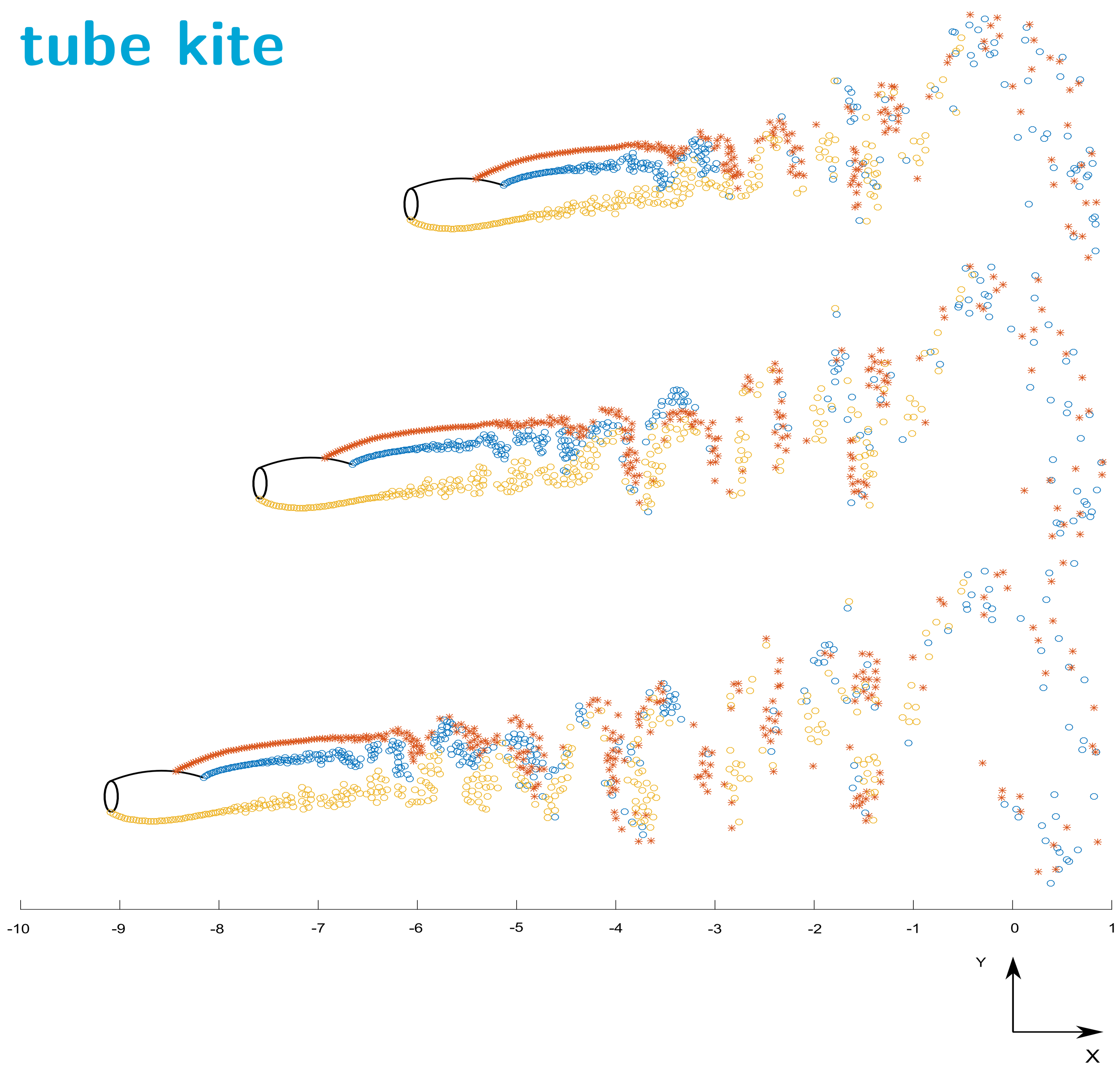

Figure: Reduced frequency = 0.03, aoa = -5^0, 2D LEI Kite airfoil with LE radius = $\frac{C}{15}$ and Canopy radius = $3C$, where C is the chord of the airfoil.

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