Inertia-supported pumping cycles based on a roto-kite

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INTRODUCTION
Rotary kites show, like tethered multiple-kite systems, a great potential over single-kite systems due to the reduced main tether drag [1]. Fig.1 depicts both variants. Over tethered multiple-kites, rotary kites have the advantage of simpler dynamics and minimal secondary tether drag. On the downside, they have a higher induction factor and they scale badly due to the small power-to-mass ratio.

The research question of this poster entails the numerical computation of an optimal pumping cycle for a small-scale AWE system based on a rotary kite. The optimal cycle is compared to a classical pumping cycle based on Loyd’s insights [2], in order to evaluate its theoretical and practical implications.

SYSTEM MODEL
The roto-kite is modeled in natural coordinates, and the SO(3) Lie group is parametrized by the Direct Cosine Matrix. These choices lead to simple symbolic, cheap function evaluations and reduce the non-linearity of the dynamics [3]. After index reduction, the dynamics are given in the form of an index-1 DAE. Baumgarte stabilization is performed on all invariants present in the model.

The aerodynamic model is based on thin airfoil theory with lifting-line theory for elliptical wings. Rotational and side-slip stability derivatives, and airfoil-airmass interaction are not accounted for. Tether elasticity and sagging are not modeled.

The system is controlled by cyclic pitch control and the tether jerk is assumed to be controlled directly.

PERIODIC OPTIMAL CONTROL
Optimal power cycles are found by solving the periodic optimal control problem (POCP):

\[
\minimize_{x(t), \dot{x}(t), u(t), z(t), \theta, T} - \frac{1}{T} \int_0^T u(t)^T R u(t) dt
\]

subject to

\[
F(x(t), \dot{x}(t), u(t), z(t), \theta, T) = 0,
\]

\[
x(0) - x(T) = 0,
\]

\[
h(x(t), \dot{x}(t), u(t), z(t), \theta, T) \geq 0.
\]

The classical ‘Loyd’ cycle is obtained by additionally limiting the reel-out speed to a third of the average wind speed.

RESULTS
Solving the POCP leads to very short cycles, and an optimal pumping cycle that differs greatly from the classical Loyd cycle. The results are summarized in Fig. 2 and Table 1.

CONCLUSION
The theoretical feasibility of a pumping cycle with a roto-kite has been shown. Supported by inertia, a small-scale system shows the theoretical potential to approximate Loyd’s power limit. The quasi-sinusoidal, high-frequency reel-out profile could e.g. be realized by connecting the tether at the ground station to the rotor of a vertical-axis generator. Future research should entail investigating the influence of tether elasticity and the airfoil-airmass interaction.

REFERENCES & ACKNOWLEDGEMENTS

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