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Swinging Motion of a Flexible Membrane Kite with Suspended Control Unit During Turning Manoeuvres

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Most airborne wind energy systems use a single tether to connect the kite with the ground station. Some concepts use an additional bridle line system to distribute the force from the kite to the tether. Typically, flexible membrane kite systems use such a configuration and are steered by a control unit fixed to the bottom of the bridle. The inertia of the control unit affects the turning mechanism of the kite. Outside the reel-out phase, also tether sag affects the attitude of the kite substantially. In this study, we evaluate how well these effects are captured with two different models.

The pitch and roll of the kite are evaluated along an actual figure of eight flown by the development system of Kitepower B.V. using an extended discretized tether model. When under tension, the bridle fixes more or less the shape of the leading edge of the kite canopy. Consequently, the bridle can be modelled as an additional rigid link in a discretized tether model.

The tether-bridle shape is evaluated using two types of tether models. First, a time-invariant model is used to calculate the tether-bridle shape at individual snapshots in time. This model finds an instantaneous solution by assuming that the airborne components together rotate as a rigid body. The change over sequential snapshots illustrates the motion of the tether-bridle. Next, the full tether-bridle motion is simulated using a dynamic model by imposing the motion of the canopy inferred from the flight data.

The results of both the time-invariant models with single and 30 tether elements and the 30-element dynamic model agree well with the measured pitch and roll of the kite along the figure of eight. The roll of the aerodynamic force of the kite provides the centripetal force and thus enables the kite to turn. Most of the roll of the aerodynamic force into the turn results from the roll of the kite. Since a multi-point-mass model accurately captures the roll of the kite, the turning mechanism can be incorporated with a physical model. In contrast, a single point mass model needs to rely on empirical relationships for turning the kite.

The 30-element time-invariant model is also used to evaluate the pitch of the kite along ten pumping cycles. During the reel-in, the pitch varies substantially as the kite is flying towards the zenith. Nevertheless, the results show a good match with the measurements. Consequently, the model is compatible with an aerodynamic model of the kite with a dependency on the angle of attack, which strongly depends on the pitch.

To conclude, performance models with a dedicated point mass for the control unit are general applicable and model the state of the kite more faithfully than single-point-mass models. In the case of a two-point-mass model, the extra computational effort is small. As such, these models can be a powerful tool for the performance modelling of flexible kite systems.