Automatic Measurement and Characterization of the Dynamic Properties of Tethered Flexible Wings

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Project TETA (Test and Evaluation of Tethered Airfoils)

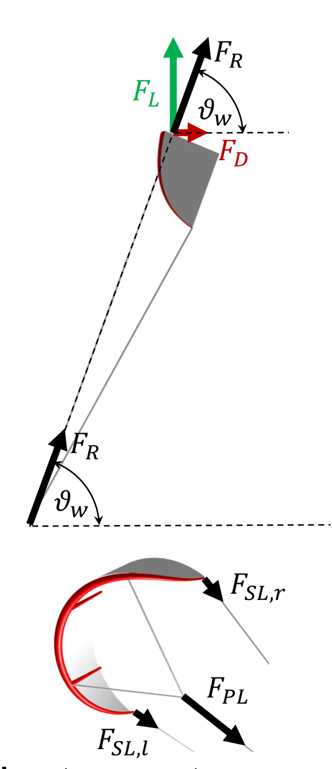
The project TETA was established by Jan Hummel as part of his doctoral thesis. A test bench was developed that allows accurate testing of different types of tethered airfoils. The test bench can be used stationary or by moving at a specific velocity to simulate different wind speeds as well as reducing influences by gusts.

Introduction

Since the turn of the millennium, the design and significance of highly flexible tethered airfoils has increased considerably. In particular, this has been attributed to the quantitative growth of global institutions involved in Airborne Wind Energy (AWE) as well as the rising popularity of kitesurfing.
While existing design methods have proven useful in achieving a high degree of maturity on product level, this has primarily been accomplished by the empirical variation of wing parameters. Measurements under reproducible conditions- including reproducible steering inputs- have not been carried out yet.

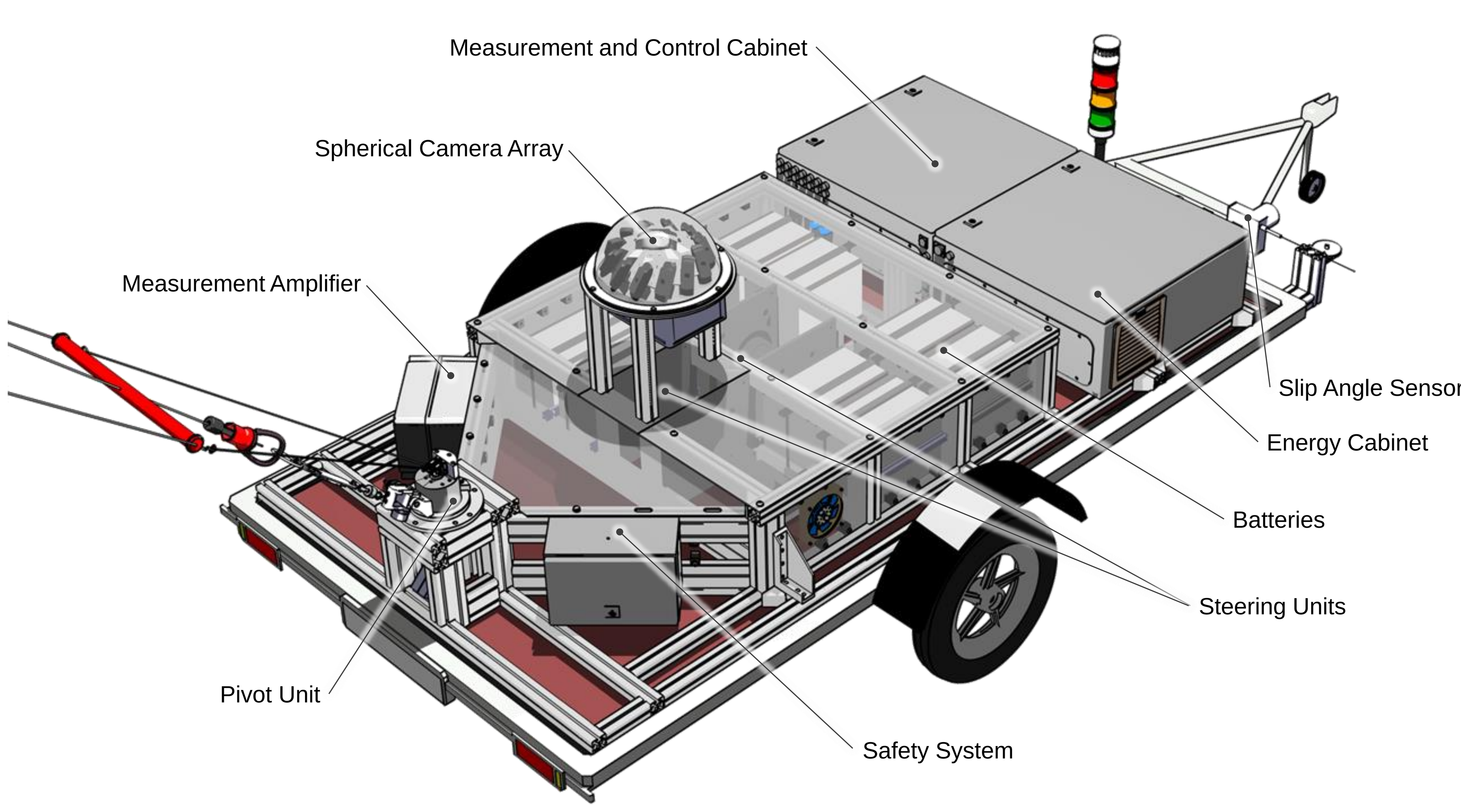
Measured Properties

- airfoil properties are defined as dynamic, which are determined against variable control inputs or kite positions
- the following properties are measured by the test bench:
  - aerodynamic efficiency (lift/drag ratio) $E = \frac{F_L}{F_D} = \frac{C_L}{C_D}$
  - aerodynamic coefficients $C_R = \frac{2F_R}{\rho A v_a^2}$, $C_L = \frac{2\sin\vartheta_w F_R}{\rho A v_a^2}$, $C_D = \frac{2\cos\vartheta_w F_R}{\rho A v_a^2}$
  - force ratio $f = \frac{F_{SL,l}+F_{SL,r}}{F_{PL}}$
- In the future, it should be possible to measure additional properties like turn rate



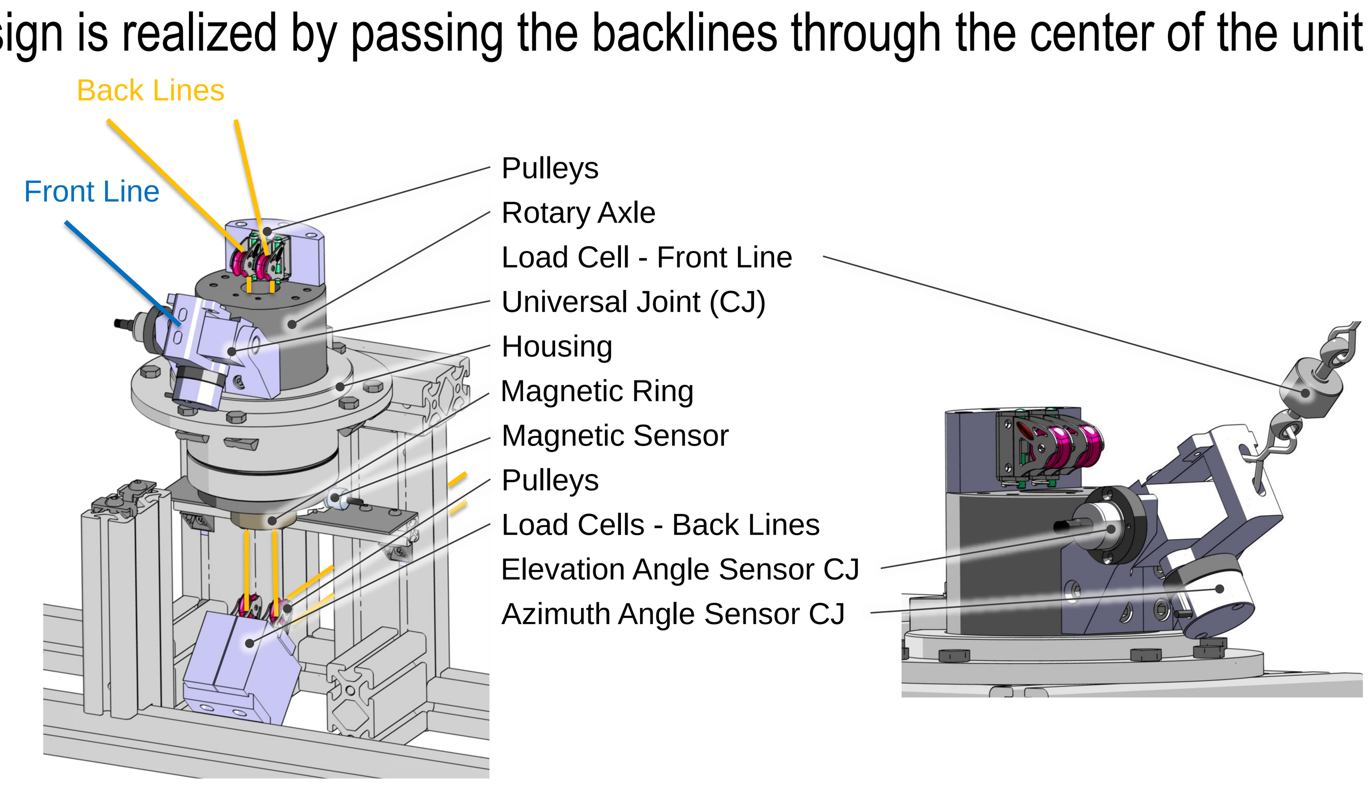
Design of the Test Bench

Based on the desired properties, the methodical test bench design was carried out.



Pivot Unit

- the Pivot Unit is designed for minimum inertia, which allows a smooth untwisting of the lines
- this design is realized by passing the backlines through the center of the unit

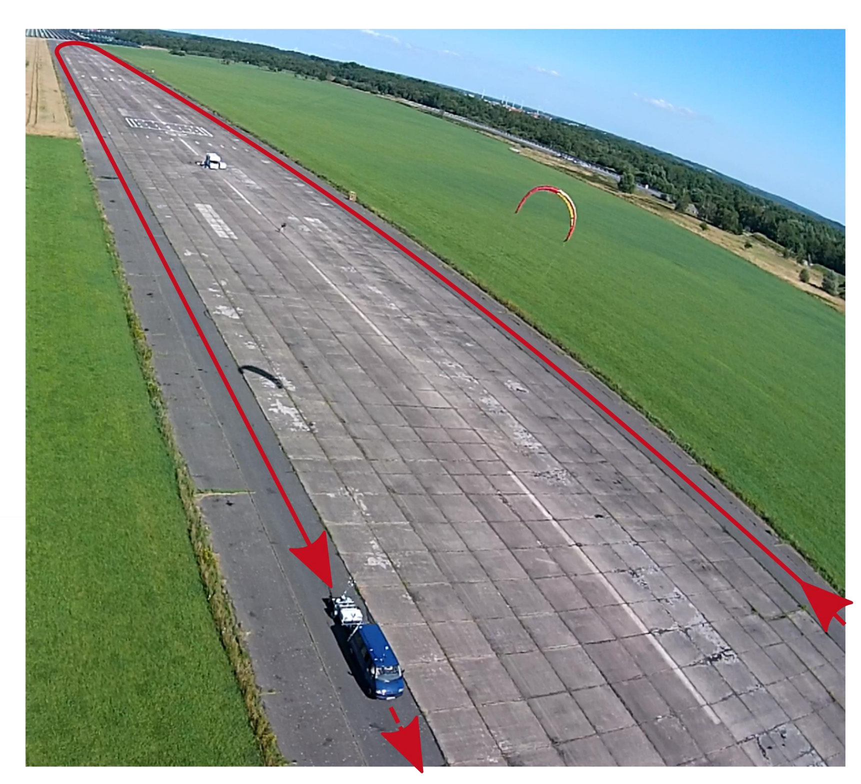


Central Control Unit

- the Central Control Unit is located inside of the measurement and control cabinet
- It is realized by a National Instruments sbRIO 9632 containing:
  - a Central Processing Unit (CPU)
  - a Field Programmable Gate Array (FPGA)
- the sensors are connected to the sbRIO by a self-made interface circuit board

Measuring Procedure

- It is essential to generate a constant airflow at the kite
- this could be achieved by towing the test bench on a former runway under calm wind conditions
- it is crucial to measure the entire kite system under realistic conditions, and initiate repeatable, automated maneuvers
- selected dynamic properties are successfully determined by using the "Linear Power" maneuver:
  - the ratio between front lines and control lines is varied fully automatically (this allows the measuring of the kite property depending on the length ratio between front and control lines)
  - at the same time, the pilot can still perform control inputs to keep the kite in positon

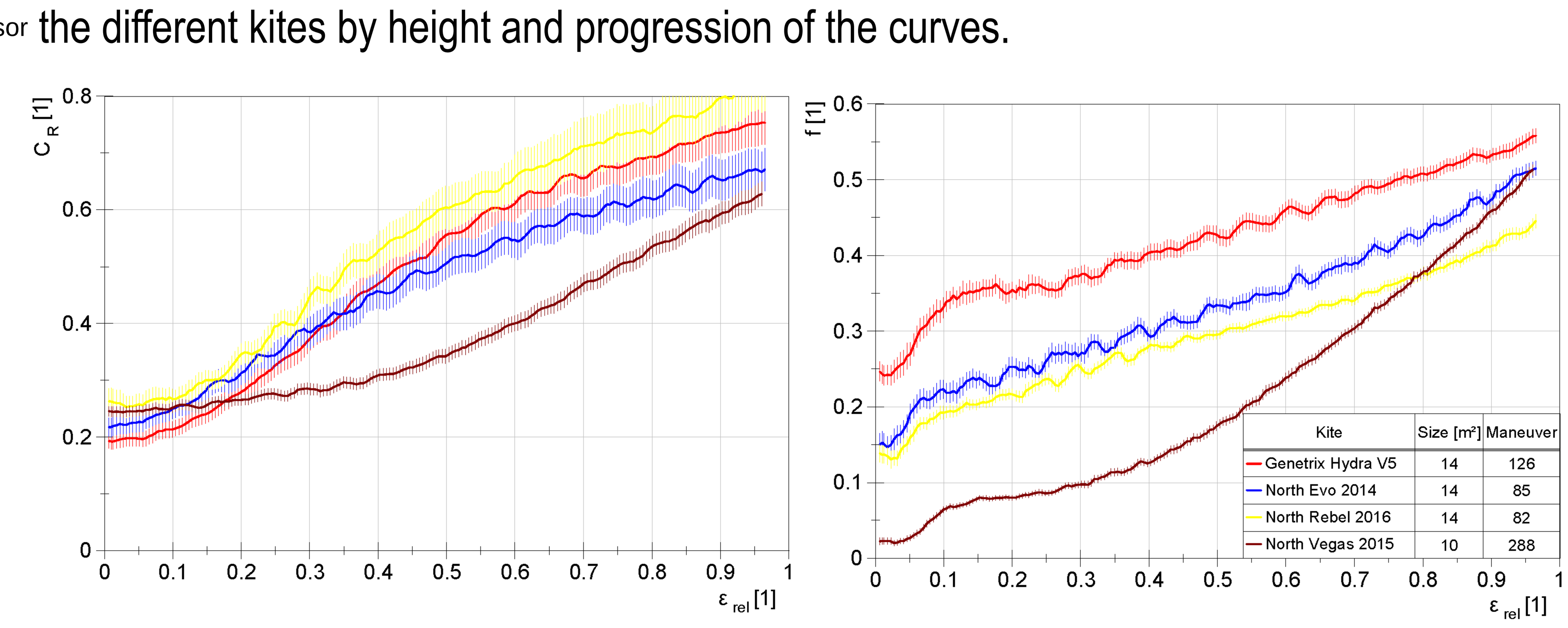


Test run at the former airfield Pütnitz

"Linear Power" maneuver

Exemplary Measuring Results

The figures demonstrate exemplary measurement results. It is possible to characterize the different kites by height and progression of the curves.



aerodynamic coefficient C_R (left) and force ratio between back and front lines f (right) against power ratio ε_{rel} including error of the mean (P=95%)

Conclusions

The findings described in this thesis enable an objective measurement of specific dynamic wing properties of highly flexible tethered airfoils. The measurement results are essential for the development and characterization of these airfoils as well as for the validation and improvement of simulation models.
Furthermore, it was demonstrated that the method is suitable for comparing basic airfoil design concepts, based on the in-depth measurements of the kite properties. In addition, subjective evaluation criteria used for the characterization of surf kites were objectively confirmed.
The thesis makes a decisive contribution to the evaluation of follow-up designs and simulation models of highly flexible tethered airfoils.