Wind Energ. Sci. Discuss.,
https://doi.org/10.5194/wes-2018-56-AC1, 2018

WIND ENERGY SCIENCE DISCUSSIONS

Interactive comment on "Automatic Measurement and Characterization of the Dynamic Properties of Tethered Membrane Wings" *by* Jan Hummel et al.

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Received and published: 17 September 2018

Thank you for your detailed review. I will answer your questions in the same order:

2.1 terms in introduction part

I will explain the kite-specific terms within the paper, briefly.

i.e. "ribs (connecting topskin and bottomskin)"

"chambered design (chambers are separated by ribs, topskin and bottomskin)"

Additionally, we can add a figure, as shown below (Fig.1)

Caption: “left: Leading Edge Inflatable (LEI) tube kites (single-skin kite); right: ram air wing”
Alternatively, the terms are also explained in more detail in the following publications:

Ram air wing:

Dunker, Storm (2014): Ram-air Wing Design Considerations for Airborne Wind Energy. In: Uwe Ahrens, Moritz Diehl und Roland Schmehl (Hg.): Airborne wind energy: Springer-Verlag (Green energy and technology), S. 517–546. http://dx.doi.org/10.1007/978-3-642-39965-7_31.

p.518 Fig. 31.1

LEI kite

Bosch, Allert; Schmehl, Roland; Tiso, Paolo; Rixen, Daniel (2014): Nonlinear Aeroelasticity, Flight Dynamics and Control of a Flexible Membrane Traction Kite. In: Uwe Ahrens, Moritz Diehl und Roland Schmehl (Hg.): Airborne wind energy: Springer-Verlag (Green energy and technology), S. 307–323. http://dx.doi.org/10.1007/978-3-642-39965-7_17.

p.312 Fig. 17.3

What do you think is the most suitable solution?

2.2 control of the control bar

The steering lines of the test bench are connected to the ends of the control bar, passed through the rotary axle and redirected by pulleys. At the other side, they are connected to rope pulleys that are operated by motors (p.8 lines 14-15, Fig. 6).

The sliding of the control bar along the power line is shown in Fig. 3. In the center of a common kitesurfing control bar, there is a hole through which the powerline is guided.

2.3 load cell precision

We can insert the absolute error in section 3.2. and delete chapter 3.3.1

2.4 wind speed error

Actually, we are measuring the wind speed on top of the towing vehicle, while driving. However, for calculating the kite properties, the resulting wind speed at kite level is needed. The resulting error caused by differences in height can be estimated by the wind power law (eq. 13).

An overestimated coefficient of friction will result in an overestimated static wind speed on kite level, which in turn will result in an overestimation of the resulting error $\delta v_{w,real}$

Here is an example:

We have to adjust the traveling speed of the towing vehicle depending on the measured wind speed on the towing vehicle which in turn has to be the target testing speed (i.e. $v_w(z_{REF}) = 11m/s$). As can be seen in eq. 14, the relative portion of the traveling speed depends on the natural wind speed at the height of $z_{REF} = 3m$. The traveling speed of the towing vehicle is minimized if the vector of the static wind speed is directed against the towing direction. Assuming a maximum line length of 24 meters ($z = 24m$) as well as a maximum natural wind speed of 3m/s at a height of 3 meters ($v_{tw}(z_{REF}) = 3m/s$) with eq. 13. a static wind speed on kite level ($z = 24m$) of $v_{tw,plaw}(z) = 5m/s$ results.

By a target speed $v_w(z_{REF})$ of $11m/s$, a traveling speed of $v_p = 8m/s$ results (eq. 14).

The wind speed on kite level is composed of the traveling speed ($v_p(z_{REF})$) as well as the wind speed calculated with the wind power law (eq. 15). Since the traveling speed of the wind window is constant ($v_p(z_{REF} = 3m) = v_p(z_{REF} = 24m)$), the true wind speed on kite level is calculated to $v_{w,real}(z = 24m) = 13m/s$ if $v_w(z_{REF}) = 11m/s$.

Regarding this worst-case scenario the relative error can be assumed as $\delta v_{w,real} <= +20\%$.

2.5 elevation angle

The resultant error from the three angle sensors and the accuracy of the weather station was calculated analogously to the elevation angle (Sec.3.3.3) with $\epsilon\varphi_w = 2.14°$. However, this angle is not used for the calculation of the dynamic properties and was therefore not mentioned in this paper.

2.6 data processing system

The camera system works as an independent sensor system and also provides the elevation angle as well as the azimuth angle. In addition, the orientation is measured to improve future control algorithms. For the calculation of the dynamic coefficients it has not yet been used.

2.7 synchronization of the measurements

all presented sensors are operated via the “master-slave” principle. Within the deterministic loop mentioned in Sec. 4.1 a measured value is retrieved once per iteration (50Hz), except for the weather station, which has a frequency of 1Hz. The measuring amplifiers of the load cells could theoretically reach a frequency of 150Hz and the angle sensors of approx. 100Hz.

2.8 results presentation

The minimal timespan in postprocessing was set to 4 seconds.

Your question was: “the maneuvers affected by gusts are not part of the valid results?”

This is not completely right, only maneuvers with a length less than the mentioned 4 seconds were excluded. This means if the pilot was able to control the kite until the end of the maneuver, also maneuvers which were strongly influenced by gusts were taken into account.

2.9 presentation of the tested kites

Yes, this curve represents the average of all maneuvers for each kite (including different test runs on the same day). The confidence interval results from the deviation of the different maneuvers.

2.10 discussion on the elevation angle offset

Since the curves of day 1 and day 2 only differ by an offset for the aerodynamic efficiency, a representation was omitted to improve the clarity. Of course, this offset must be further investigated if it cannot be compensated by the measures mentioned below (p.17 line 32 f.).

For the force ratio, each test run is shown individually as an example. An offset was not observed. Regarding your suggestion of calibration: We carried out this kind of calibration. The offset is very unlikely caused by the angle sensors. As mentioned, the offset is most likely caused by changes in geometry which are difficult to control. This is why we will also test the reference wing/ kite in future.

We test this reference kite each test day. The curves of different days should fit each other. If this is not the case, the setup changes compared to the test days before must be investigated systematically. Furthermore, the offset can be compensated in postprocessing, so that the kites can be still compared against each other. As mentioned before, it can also be determined from other measurements that curves for a kite fit very well against each other at the same day. The assumption that this offset is caused in changes of geometry, e.g. due to the changed tire pressure or loading of the towing vehicle, is therefore very likely.

2.11 Results of lift coefficient

No, we do not neglect the wind power law. Here the error of the wind speed, discussed before is important. If we have perfect wind conditions, which means zero wind speed ($v_{tw}(z_{REF}) = 0m/s$), the wind speed resulting from the wind power law is zero, too, which in turn means the resulting windspeed on kite level is the same as on the ground. If the natural wind is not equal to zero (which is always the case), the relative error is below +20%.

2.12 force ratio

The angles of the steering lines are not taken into account because of the line length.

2.13 Conclusions

This is correct, the wording is not favorable. We will change it to:

‘With existing approaches the reproducible measurement of flight dynamic properties of tethered flexible wings was not feasible.”

Interactive comment on Wind Energ. Sci. Discuss., https://doi.org/10.5194/wes-2018-56, 2018.


Struts
Canopy
Leading Edge
Trailing Edge
Topskin
Bottomskin
Ribs
JUICE
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Fig. 1.