Response to Reviewer 1

April 4, 2025

Major Concern:

"Overall, the article is well written, figures are high quality and the mathematical formulations and the technical information are presented accordingly. However, I have one major concern for the publication of this paper. For me is very difficult to follow the reasoning about the EKF implementation/design, specially the sensors used and the observation model of both the V3 and V9 kites flight tests.

In my opinion, the paper should be optimized for increased clarity and conciseness. The authors should make an effort to facilitate the reader the matching between caps 4 and 5."

Response: We thank the reviewer for highlighting the need for greater clarity in the explanation of the EKF design and its relationship to the sensor configurations used in the V3 and V9 kite flight tests.

To address this concern, we have revised Sections 3 to 5 to explicitly distinguish between required and optional measurements across different EKF configurations. In particular:

- In Section 3 (Sensor Setup), we clarify more concisely the most reliable measurements, which include position and velocity (from GPS), tether force (from a load cell), and reel-out speed (from the tether reel-out encoder), which are sufficient to estimate the kite motion. We also specify that when the KCU is modeled, a measurement of acceleration is additionally required to account for its inertial effects.
- In Section 4 (Filter Design), we state more clearly the required measurements for the EKF, and the need for additional acceleration measurement if the KCU is modeled.
- In Section 5, we improved the explanation of the different EKF setups and explicitly reference Section 3 when introducing the baseline configuration. This reinforces the logic behind the sensor combinations used in the evaluation of V3 and V9 datasets.

Together, these changes clarify the reasoning behind the EKF design and improve the consistency of terminology across sections. We hope these improvements resolve the reviewer's concern and make the EKF framework easier to follow.

Minor Comment 1:

"Line 115-120, further discussion about direct measurement of in-situ aerodynamic angles of attack and sideslip is welcomed (Oehler and Schmehl, 2019). Using booms for isolating aerodynamic sensors from aircraft's perturbations is a well-known practice in the aerospace industry during development phases"

Response: We thank the reviewer for this helpful suggestion. We have expanded the corresponding paragraph in the sensor setup section to include the resolution of the sensor. In response to the reviewer's comment, we now mention the use of boom-mounted sensors on the leading edge of the kite during development phases, which is indeed a common approach in the aerospace industry. While effective for isolating sensors from the perturbations caused by the wing, this solution is generally unsuitable for commercial airborne wind energy systems due to its fragility. The revised paragraph also includes references to Oehler and Schmehl (2019) and Borobia-Moreno et al. (2021) to support these points.

Minor Comment 2:

"Line 143 $\rightarrow$ Fig2. could be improved by showing a detailed view/scheme of the implementation of the load cell sensing the tension of the tether without interfering with the reel in-out system."

Response: We appreciate the reviewer's suggestion. However, we prefer not to include a detailed schematic of the load cell implementation due to its proprietary nature. A schematic of a similar system can be found in Hummel (2018), which illustrates the principle used. We trust the updated description in the manuscript clarifies the sensing approach while respecting confidentiality constraints.

Minor Comment 3:

"Further detail about how airborne data is logged/transmitted to the ground and synchronized with the ground-measured data is also welcomed."

Response: We appreciate the reviewer's interest in the data acquisition and synchronization procedures. However, the airborne and ground-based sensor data used in this study were pre-processed and provided by Kitepower, and the specifics of the logging, transmission, and synchronization infrastructure were not available to the authors. As such, we are unable to provide further technical detail on this aspect. We would also like to note that the focus of this work is on the development and evaluation of the EKF estimation framework, which operates on already time-aligned datasets. As a result, the underlying transmission architecture does not impact the methodology or the conclusions of this study.

Minor Comment 4:

"Line 396, 405-410 → In my opinion, the output of the Px4 position and velocity estimations should not be used as measurements for the EKF as errors are not guaranteed to be zero mean and gaussian. Instead, raw GPS position and velocity from PixHawk Gps should be used, plus a measurement error model to guarantee that the measurement noise described in eq.24a and 24b is Gaussian white noise. (R.Borobia et al. 2018). This change will eliminate the dynamics of the PixHawk onboard estimator increasing the stability of the filter."

Response: We fully agree with the reviewer that using raw GPS measurements would be preferable to ensure that the assumptions on the measurement noise in the observation model (Eq. 24a and 24b) hold. Unfortunately, in the dataset analysed, only the output of the Pixhawk's internal EKF (GPS+IMU fused) was logged, and the raw GPS data were not recorded.

We attempted to reflect this limitation in the manuscript (lines 396–397), but we recognise that the implication for the filter's noise characteristics and stability may not have been sufficiently emphasised. To address this, we have clarified the text accordingly to highlight the impact of using pre-filtered measurements.

Minor Comment 5:

"Line 411 → In Fig9. The measured Euler angles are the estimated ones by Px4?"

Response: Yes, the Euler angles shown in Fig. 9 are the estimates provided by the PX4 onboard EKF, based on the Pixhawk's IMU data. A clarification is added to the text to make this point explicit and avoid future readers to question the same.

Minor Comment 6:

"Line 419 → Calculation of Yaw angle assuming alignment of the kite body axis with aerodynamic velocity vector assumes no side-slip during the flight. However, direct measurement of side-slip angle showed non zero values for a inflatable kite (R.Borobia et al. 2021)"

Response: We agree with the reviewer that the assumption of zero side-slip does not strictly hold, particularly during manoeuvres. Our intention was not to neglect sideslip effects, but rather to illustrate the general tendency of the kite to align with the local inflow. To clarify this point, we have extended the discussion by including measured sideslip angle statistics from the V9 dataset, which show a standard deviation of approximately 2.5° and peak values up to 5° during turns.

Minor Comment 7:

"520 -530 → The underpredicted side-force could be related to assuming zero-side slip angle? "

Response:

We thank the reviewer for the observation. To clarify, the side-force is estimated by the EKF, but it is not modelled as a function of the side-slip angle (see section 4). The dynamic model employed is a 3-DOF point-mass formulation, where yaw dynamics are not considered. The kite orientation (pitch and roll) is inferred from the bridle segment orientation in the quasi-static tether model, rather than modelled as a full 6-DOF body. The assumption of alignment with the apparent wind is used only in post-processing to estimate the yaw angle for qualitative analysis and is not part of the EKF or the dynamic model. Therefore, the underprediction of the side-force is not attributable to a zero side-slip assumption.