AR3 Reply

Does the paper present novel concepts, ideas, tools, or data?

The wind estimation concept presented in this manuscript lacks novelty. Already, previous studies have explored the use of point mass models to infer the horizontal components of wind velocity. Moreover, what is presented as a stand-alone calibration process to characterize tilt as a function of air-relative velocity have already been performed Palomaki et al., as well as Gonzalez-Rocha et al.
Palomaki, R.T., Rose, N.T., van den Bossche, M., Sherman, T.J. and De Wekker, S.F., 2017. Wind estimation in the lower atmosphere using multirotor aircraft. Journal of Atmospheric and Oceanic Technology, 34(5), pp.1183-1191.
Donnell, G.W., Feight, J.A., Lannan, N. and Jacob, J.D., 2018. Wind characterization using onboard IMU of sUAS. In 2018 Atmospheric Flight Mechanics Conference (p. 2986).
González-Rocha, J., Woolsey, C.A., Sultan, C. and De Wekker, S.F., 2019. Sensing wind from quadrotor motion. Journal of Guidance, Control, and Dynamics, 42(4), pp.836-852.
Abichandani, P., Lobo, D., Ford, G., Bucci, D. and Kam, M., 2020. Wind measurement and simulation techniques in multi-rotor small unmanned aerial vehicles. IEEE Access, 8, pp.54910-54927.

We describe in detail the calibration procedure and the post-processing analysis, proving that our method could also handle atmospheric wind well (we could estimate the atmospheric wind that matches the meteorological re-analysis). Our calibration strategy maps all the possible flight speeds of the UAS. It guarantees a comparable amount of data points for each one of them.

Moreover, as Abichandani et.al 2020 mentions when talking about the tilt angle approach: “Another limitation to this approach is the requirement of wind tunnel tests to determine the drag force and tilt angle relationship. The relationship established is unique to that specific multi-rotor vehicle. A wind tunnel to perform tests may not be available to everyone, thereby limiting the usability of this technique.”. Our calibration approach can be performed in few hours and even easily repeated in order to gather further datapoints.

Studies like Neumann, Bartholmai 2015, Palomaki et.al. 2017, Donnell et.al. 2018, all build up their method like the one we call the direct method. So there is a direct relation between tilt angle and wind speed (squared or not). But none of them analyze the behavior of the Drag coefficient itself. Some studies even assume the drag coefficients to be constant over a specific range of velocities (maybe a valid assumption if the range of velocities is limited). In our case, we prove the Ca to be not constant over our range of speeds. We think mapping the behavior of the drag coefficient could be useful in developing better models and algorithms like the one proposed in Jia-Ying Wang, Bing Luo, Ming Zeng and Qing-Hao Meng,A Wind Estimation Method with an Unmanned Rotorcraft for Environmental Monitoring Tasks.

Are substantial conclusions reached?

The author’s claim to present a technique that does not require the use of a wind tunnel or mast towers. However, the validation experiments discussed in Section 4 were performed using a sonic anemometer, a standard practice for validation sUAS wind estimates (see references below).
Nolan, P.J., Pinto, J., González-Rocha, J., Jensen, A., Vezzi, C.N., Bailey, S.C., De Boer, G., Diehl, C., Laurence, R., Powers, C.W. and Foroutan, H., 2018. Coordinated unmanned aircraft system (UAS) and ground-based weather measurements to predict Lagrangian coherent structures (LCSs). Sensors, 18(12), p.4448.
Barbieri, L., Kral, S.T., Bailey, S.C., Frazier, A.E., Jacob, J.D., Reuder, J., Brus, D., Chilson, P.B., Crick, C., Detweiler, C. and Doddi, A., 2019. Intercomparison of small unmanned aircraft system (sUAS) measurements for atmospheric science during the LAPSE-RATE campaign. Sensors, 19(9), p.2179.

Every new measurement technique needs to be validated; a known, reliable and precise measurement technique should be used.
In this manuscript, we first describe our measurement technique (which works without using a sonic anemometer) and then we validate the measurement technique using a sonic anemometer.
Therefore, the measurement technique does not require any additional instruments apart from the copter, but, since the goal of this paper is also to validate this method, it has to be compared to a reliable measurement that works independently from the UAS measurement.

Are the scientific methods and assumptions valid and clearly outlined?
In addition to developing a model-based wind estimation technique, the authors propose simplifying the aerodynamic characteristics of sUAS by enclosing the airframe and electronic components using a Styrofoam sphere. The authors implicitly assume the airframe drag effects to be significant. However, data that support this assumption are have not been presented. On the other hand, a previous study by Powers et al. has shown multirotor sUAS drag effects to be dominated by the propeller and airflow interactions instead of airframe shape. Moreover, quadrotor experiments performed by González-Rocha et al. show the tilt variations as a function to sideslip angle to be within the noise of the measurement at different ground speeds.
Powers, C., Mellinger, D., Kushleyev, A., Kothmann, B. and Kumar, V., 2013. Influence of aerodynamics and proximity effects in quadrotor flight. In Experimental robotics (pp. 289-302). Springer, Heidelberg.
González-Rocha, J., Woolsey, C.A., Sultan, C. and De Wekker, S.F., 2019. Sensing wind from quadrotor motion. Journal of Guidance, Control, and Dynamics, 42(4), pp.836-852.

We recently managed to compare the tilt angle output of our two DJI systems mounting the dome on one while leaving the frame exposed on the other. We added some weights on the second one in order to simulate the weight of the dome so that the comparison is meaningful. The results are reported in Figure 12a of the new version of the manuscript and the description of the experiment is described in section 5.1

However we think that what stated about the symmetry and the more regular shape provided by the encasing is anyway valid. We do not want to argue what found by Neumann, Bartholmai 2015 and Gonzálex-Rocha 2019, but rather, considering their results, the spherical cover could only grant more uniformity in the system response at different sideslip angles. We performed another test to prove this, and the result is shown in Figure 12b. Again the description of the test is in Sect 5.1.
Bot not only that, the sphere grants the same cross sectional area (body area) when the copter is tilting. Donnell 2018 while discussing about the accuracy of the tilt angle method applied to the different system he is comparing says: "With respect to the indirect methods the Solo performs the best. The Solo is a more advanced vehicle with a newer generation Pixhawk flight controller. The airframe of the Iris is larger and contains more planer surfaces with sharp edges whereas the Solo has contour features and smooth edges. The Iris's motor and body layout are symmetric only about its roll axis, excluding small features such as antenna and mini USB port on the port side of the vehicle. The Solo's airframe body is symmetric about its roll and pitch axis, excluding the undercarriage where on the forward end is a flat with a hole to mount a payload such as a camera. The combination of these factors directly influences the behavior and orientation of the vehicle while it maintains position with an incoming wind velocity". It seems then reasonable to enclose all the sharp edges and electronics cables inside a more uniform and smooth surface.

Are the results sufficient to support the interpretations and conclusions?
The authors need to perform experiments to compare the inflow angle of nominal and spherical sUAS configurations over a range of ground speeds and sideslip angles.

See section 5.1 and Fig 12.

Is the description of experiments and calculations sufficiently complete and precise to allow their reproduction by fellow scientists (traceability of results)?
Yes, the description of experiments and calculations are in general complete. However, there are formulae that need to be improved for correctness.

We updated the formulae as specified in the following comments.

Do the authors give proper credit to related work and clearly indicate their own new/original contribution?
Tilt models to estimate wind velocity have been proposed before. It was difficult to understand how the work presented in this manuscript improves upon previous models.

The calibration procedure has been explained extensively, and tested by proving that it can handle and even identify the magnitude of possible atmospheric wind. A model for the extended drag coefficient is presented and compared to the more common velocity vs tilt model highlighting advantages and disadvantages.

Does the title clearly reflect the contents of the paper?

No, the wind estimation algorithm being presented is not a stand-alone technique. The implementation of this algorithm requires calibration experiments next to a conventional wind sensor.

We use a sonic anemometer in the moment we want to <u>validate</u> our calibration procedure.

Does the abstract provide a concise and complete summary?
The abstract does not provide a concise and complete summary of the work presented. It was difficult to appreciate what the authors

The abstract has been partially modified in order to try to give the reader a better summary of the manuscript.

Is the overall presentation well structured and clear?
The presentation of the manuscript is well structured. However, there are sections of the manuscript that need to be improved for clarity and conciseness.

The manuscript has now been modified taking into account all the three reviewers comments. Some unclear sentences have been rephrased and some equations modified.

Is the language fluent and precise?
The authors can significantly improve the language to be more precise.

See previous comment

Are mathematical formulae, symbols, abbreviations, and units correctly defined and used?
The formulae need to be revised. For example, in Eqs. (1) and (2) the rotation matrices need to be defined.
Additionally, the transformation presented in Eq (1) need to be transposed for correctness. Moreover, the tilt angle in Eq (3) can be estimated using the product rule.

We included the extended expression for the three rotation matrices.

Should any parts of the paper (text, formulae, figures, tables) be clarified, reduced, combined, or eliminated?
The abstract language needs to be clarified. As it stands, it is not evident that the authors are proposing a method based on flight transects for characterizing a wind estimation tilt model instead of hovering inside of a wind tunnel or next to a sonic anemometer.

The abstract has been partially modified in order to try to give the reader a better summary of the manuscript.

Are the number and quality of references appropriate?
The manuscript does not present a comprehensive survey of model-based estimation techniques.

The introduction has been extended and a short section on on-board sensors has been added in order to make the survey of wind measurement techniques more complete.

Is the amount and quality of supplementary material appropriate?
Yes.