AR1 Reply

Line 19-23: *There are few papers that compares conventional meteorological instruments with the UAS-based weather instruments. Please add some references …*

Thanks for the suggestions. We added some sentences in the introduction, and found another paper comparing UAS with radiosondes.

Line 31: *Edit to say: "The effect of the incoming wind on the UAS attitude provides the basis for …" …*

Done.

Line 39: *Instead of feasible say something like "more affordable/accessible/simple". …*

Changed with more accessible.

Line 40: *Add the following: "… repeated for different multi-copters under the same conditions".*

Done.

Table 1: *Make first letter upper case …*

Done.

Line 67: *Please provide the version of ArduCopter used.*

Done.

Line 70: *Since the styrofoam is crucial component in this study, it would be worth describing it more in depth. …*

Added a short description of the sizes of the dome and the way we secure it on the copter body.

Line 73-75: *Table 1 is not referenced …*

Done at the beginning of section 2.1.

Line 105: *However, yaw is important for estimating the wind direction. …*

We added a sentence to clarify that the yaw is ignored at this point only because we are looking for the tilt angle. It will be used later for the direction.

Line 114: *Replace used with applied.*

Done.

Equations 10-12: *I understand what you did here. However, many readers will be confused by the appearance of the wind components u and v. To avoid confusion you can define* ***V*** *=* ***V****wind –* ***V****uas =* ***V****eq = {u,v,w} knowing that* ***V****uas = 0 because of hovering conditions.*

We agree that the u and v notation is not clear due to the fact that later on they are addressed as the wind speed components. However, equations 6 and 7 from Gonzalez-Rocha et al.2017 describe the behavior of the UAS flying in still air. If atmospheric wind is present some other terms appear because of the composition of the two velocity vectors. We decided to start from this set of equations because they are simpler and it is quite intuitive to switch from a no-wind condition flight and hovering.

We have reformulated the equation in order to remove the u and v variables by using the notation x_dot for u and x_dotdot for the acceleration in x direction. We adapted accordingly the following assumptions and definitions.

Line 152-154: *I think this statement has to be declared as an author's opinion and the approach taken by them, please do so. In my opinion, I believe A(Tilt) can resolve forces on the solid body alone (styrofoam sphere) while the external components (mainly the rotors) need other different approaches, like a different model to describe them, and then combine the results.*

The variable Ca(Tilt) accounts for everything we can not assume to be constant at different velocities. Our shape being a sphere, A(Tilt) would be a constant value if it would only resolve the forces on the sphere. We do not want to model the rotors in order to keep this approach accessible for every type of copter without running a model each time.

Wang et al. Is an interesting paper. Their method seems to overcome the wind estimation methods by tilt angle only. However, they similarly measure three drag coefficients as we do (flying backward and forward) in an indoor environment. There are some problems, though: they assume these coefficients to be referred to the body axes. However, this approximation is valid only when the Tilt angle (the wind speed) is low.

When the tilt angle gets bigger, the difference between the inertial and body reference frame becomes non-negligible. Then measuring this type of drag coefficients would probably be possible only with a wind tunnel equipped with a scale and holding the copter *untilted* for multiple wind tunnel speeds.
But let's assume we could somehow measure the three drag coefficients referred to the body axes. They still might not be constant in a range of wind speeds we would operate the copter afterward. Indeed the authors show results only for a simulation and experiment with 1 ms-1 wind speed (this also allows them to assume a linear relation between aerodynamic forces and relative velocity). We think Step 11 of their algorithm could benefit from a model like the one we present for the Ca in our manuscript.

Rajan and D’Andrea developed two different models for the forces and moments generated by a single rotor in forward flights. This model in its simplest form is a function of 9 geometric parameters of the blades and three flights parameters (RPM, V, and tilt). It is already a great effort to find the 9 parameters, then the RPM of our system is not available in our dataset. Moreover the velocity that each one of the rotors of our system experience might not be the same (some of them might be in the lee of the sphere).

Line 165: *Replace “will maintain its position as computed by” with “holds its position assisted by”.*

Done.

Line 174-178: *For non-zero wind conditions, an idea that you can try in the future is to let the drone drift by the wind for a period of time …*

We have read some papers that perform this method. Still, as far as we see, there are two significant problems: we can not control the UAS path and can not systematically test a lot of ground speeds. Thus the calibration would be limited to the wind speeds present during that specific daty. However, leaving the multicopter in altitude mode is effectively the only way one could get the body axes' drag coefficients without using a wind tunnel (Wang et al. Coefficients).

Line 188-189: *Please also mention authorizations and permissions to fly drones in the area, if any. It is good example to show the reader the efforts made to fly drones legally.*

Added a couple of sentences about the permission we have from the airfield itself.

Line 195: *Replace “situation” with “conditions”.*

Done.

Line 236: *Replace “A” with “The”, and “end up in obtaining” with “produce”.*

Done.

Line 236-240: *In theory, these “sloped lines” should ideally be just points. You can prove this in simulations within ideal environments. However, your data looks spread out because the drone is tilting back and forth correcting its GS and even fighting turbulence in its way (like its own propeller wash. The lower the GS, the more spread it looks because speed is getting close to the minimum velocity resolution of the GNSS and that introduces errors. …*

The GS is maintained with a good accuracy by the autopilot as it can be seen in Figure 5. Here the idea is just that by definition every tested velocity defines a line in Figure 6b and the slope of the line depends on the GS. The lower the GS the steeper the line. So with comparable tilt variance we get a very high Ca variance at low speeds while a limited variance at high speeds. It is difficult to see a physical meaning.

Section 3.2: *Have you considered doing circular flights? …*

This is a really nice suggestion. Performing circular flights is possible with ArduPilot and also one could control where the copter should face during these flights (in order to see if any difference is present in terms of incoming wind direction). The only problem is that the force system modeling is a bit more involved since also centripetal force has to be considered and an eventual atmospheric wind also has to be taken into account. We have already performed some of these flights with a different system and we will have a look at the data soon. Probably there will be a dedicated section about this topic in a future manuscript of a colleague of mine.

Line 283: *Replace "will offset the horizontal wind" with "will produce an offset in the horizontal wind estimates".*

Done.

Line 287-288: *Again this statement has to be declared as an author's opinion and the approach taken by them, please do so. Unless you found literature that also supports this, please cite them.*

Modified the sentence. We did not find any source in the literature, the idea is that by looking at the data they clearly do not show a linear behavior, so a non linear function was preferred.

Line 292: *Replace "by" with "described in".*

Done.

Line 293: *I am assuming that you are computing the density of dry air since you only mention pressure and temperature variables. If you have humidity data, it is possible to also include the water vapor density for improved accuracy.*

Yes it is dry air. For the dataset described in the paper we did not have humidity measurements yet. Now the system has an array of sensors and we get pressure temperature and humidity data from the multi-copter itself. We will use also the humidity data in the future.

Section 5.2: *The discussion and analysis of the spectra results are quite consistent and valid. However, there are other factors that are relevant and deserves some discussion too. The propeller wash can very well be within the frequency range of the plateau, injecting energy into the surrounding air. Its effect should be greater when the wind is low since the prop wash does not move away. But this is hard to see in Figure 9 because it shows an "average" of all the flights and wind velocities. GNSS is also another factor, if the position estimation drifts away, the drone will try to follow the wrong position estimate and tilt towards it. The drone is basically rocking back and forth, and this is reflected as increased energy in that range of spectra.*

It is interesting to note that the energy then decreases to levels close to the sonic anemometer spectra , to me this means that the drone's high frequency wind estimates has not reached the noise floor yet and be as sensitive as the sonic anemometer. Unless there is some kind of arifact in the algorithm. I suggest the authors to explore more on this and come back with conclusions.

We have checked the spectra for each single hovering section during the validation flights. The plateau is more or less visible in all of them. It is challenging to understand if the rotor downwash plays a role here and up to which wind speeds. Even during the same hovering mission, the wind changed quite significantly (see Figure 10c where it changes from 4 to 9 ms-1).

While in PosHold mode, the UAS uses its EKF to maintain its position (GNSS is used as input to the EKF together with other sensors). We have checked the output of the autopilot EKF in terms of position. Over the whole hovering time during the calibration flights the standard deviation of the distance to waypoint is around 8 cm. From the autopilot we can not see any sign of position estimation drifts.

Section 5.4: *Did you check if the compass measurements are with respect to the true north? However 15 deg seems high. ArduPilot offers advance magnetometer calibrations and it compensates for induced magnetic fields of the electronics. Consider this for the next experiments.*

We did not perform a calibration with a current compensation, however the bias was in the range of other studies. We are planning for the future to use a differential GPS configuration in order to improve the wind direction estimation.

Line 404: *replace "usually" with "general". The word "varying" can be omitted.*

Done.

Line 408: *correct the sentence "since it may not be constant".*

Done.

Line 414: *"undesired instead of "spoiled" would sound better.*

Done.

Line 427: *consider replacing "since it is specific for the mass that the system had" with "since the mass is unchanged during the calibration flights".*

Done.

Line 455-456: *Rephrase "uniforms the aerodynamic forces with respect to the incoming wind's direction" to "helps producing uniform aerodynamic forces with respect to the incoming wind from any direction.*

Done.