Atmos. Meas. Tech. Discuss.,
doi:10.5194/amt-2020-126-AC3, 2020

Atmospheric Measurement Techniques Discussions

Interactive comment on "An Approach to Minimize Aircraft Motion Bias in Multi-Hole Probe Wind Measurements made by Small Unmanned Aerial Systems" *by* Loiy Al-Ghussain and Sean C. C. Bailey

Loiy Al-Ghussain and Sean C. C. Bailey

sean.bailey@uky.edu

Received and published: 2 October 2020

We would like to thank the reviewer for their time spent in review of this manuscript and providing their detailed comments and suggestions. We have prepared a revised manuscript which we believe addresses the concerns and comments raised in their review. In the revised manuscript, specific changes are indicated in blue text, with each of the reviewer's comments addressed below.

1. I wonder why there is no example dataset and example correction code available.

In my opinion, this must be the case.

The reason no data or code have been provided is simply due to the difficulty the authors had in selecting the most appropriate data level to provide.

The easiest approach would be to provide the corrected and uncorrected time series the authors used to produce the figures. However, this level of data would be only suitable for reproducing the figures in the text without allowing the interested party to test the correction themselves. Similarly, the correction described within the paper is contained within five lines of Matlab code centered on the fminsearch command and is of little value without the context of the conversion of raw data to wind measurements.

As the correction is embedded within the processing of the raw data to produce wind vector estimates, the alternative would be providing the original raw data used to produce the time series of wind vector. However, the required data files would consist of raw voltage data from the five-hole probe, pressure, temperature and humidity from the iMet sensor, and six-degree-of-freedom data from the IMU/GPS system. We would then have to provide the numerous subroutines we use to convert the raw voltages to relative velocity, align the data files in time, and extract the wind speed from the relative velocity, as well as provide the individual calibration files for each five-hole-probe and configuration files which are used as part of this process. As well as providing these files, the authors would have to produce sufficient documentation so that an inexperienced user could run the scripts which, ultimately, are custom written for the authors' sUAS measurement system and therefore provide little-to-no value to other sUAS operators who use different hardware.

Instead our goal was to provide a precise description of the correction procedures, with sufficient generality, so that other sUAS operators can implement these procedures within their own data analysis codes.

2. Line 26: Temperature? (e.g. Witte2017)

   Definitely an oversight! The authors have added temperature to the list.

3. Line 32: The difference between the three approaches is not clear: An onboard wind sensor measures air speed, and aircraft kinematics are used to determine ground speed. This seems to be the same as the second approach that you mention. Please briefly explain the differences, it might be helpful to add a reference for each approach (the first approach lacks a reference).

   The authors have revised the sentence as follows: "Wind velocity measurements typically can be partitioned into several approaches: directly by using the instrumentation employing an on-board wind sensor and subtract the aircraft kinematics (Suomi and Vihma, 2018; Cassano et al., 2016); indirectly using the attitude and position data recorded by the inertial measurement unit (IMU) and GPS, respectively (Suomi and Vihma, 2018) ; using both techniques (Rautenberg et al., 2018); or through calibration of the aircraft's kinematic and dynamic response to the wind (González-Rochaet al., 2020)."

4. Line 34: Typo "kinmatic".

   Corrected.

5. Line 36: Sensor-based wind measurements: Isn't everything that measures wind sensor-based? An IMU can be used to determine wind, but it is also a sensor (typically it consists of even 3x3 sensors). Which sensors do you mean?

   The authors have revised the sentence as follows: "Broadly speaking, wind measurements taken by sensors like sonic anemometers, single- and multi-hole pressure probes, and hot-wires tend to have higher temporal (and hence spatial) response."

6. Line 38: Witte2017 writes "Typically, these measurements employ wind velocity probes with a temporal response that is little better than that of sonic anemome-

ters", and "Increasingly, UAVs are utilizing five-hole pressure probes [32,33,40], which can resolve to 40 Hz while flying at approximately 20 m/s.". Today's 3D sonic anemometers can have a data output rate of 100 Hz (e.g. Gill R3-100). So, I am not sure if this is true anymore.

   Although such high frequency sonic anemometers do exist, to our knowledge, these anemometers do not exist in a package size sufficiently lightweight to be used on a fixed-wing sUAS. Hot-wire anemometry is also an option, but is not yet in common usage for sUAS measurements and, to our knowledge, multi-sensor hot-wire anemometry capable of resolving the velocity vector has not yet been utilized on sUAS. The authors have removed this sentence as the justification for using multi-hole probes was provided in the sentence following the one described above, and no further justification for their use relative to sonic anemometers is required.

7. Line 142: A change in direction (what direction? Flight direction? Yaw angle?) will result in an acceleration due to a curvature of the flight path. So, what kind of acceleration (rate of change of velocity) do you mean? Flight velocity changes? Vertical acceleration?

   We meant the flight direction while the acceleration represents the rate of change in velocity. The authors have revised the sentence to address the reviewer's question as follows: "The assumptions used here are relatively straightforward. The first being that any biasing of $U(t)$ by U_s will result in $U(t)$ having dependence on the direction of travel of the aircraft." and "This portion should not include any significant acceleration or deceleration of the aircraft's horizontal ground speed (e.g. as experienced during takeoff or landing) and should include multiple changes of direction of the aircraft."

8. 146: incomplete sentence

   Corrected.

9. Line 194: When you argue with periodicity, then why not show it in a FFT plot?

   The authors have added an FFT plot and corresponding discussion as the reviewer recommended.

10. Line 202: Does $DeltaQ$ have a unit?

    ΔQ is unitless, it is a correction factor for the dynamic pressure. In retrospect, the authors realized that the Δ is confusing in this context and have replaced ΔQ with ζ.

11. Why are figures 5+6 bitmaps and not vector graphs? Is there a way to omit the wrapping-around at 360°? Is there a better way to convince the readers that the correction improves the accuracy of the data? Because the true velocities are apparently unknown, I would again prefer spectral analyses, that show that the motion of the aircraft becomes less apparent in the corrected data. Color schemes in figures might be better if same colors are used for same objects (e.g. red = sUAS and black = reference). Please also check that colors correctly convert to a gray scale that is distinguishable in black and white print outs.

    The authors have replaced figures 5 and 6 with whiskers plots to better represent the effect of the bias removal.

12. Line 250-266: This seems to be a discussion of the specific weather conditions of that day on that site, I don't see how this adds to the message of the manuscript. Please explain.

    The authors intended to give an overview on the condition of the atmospheric boundary layer to put the fluctuations of the wind into context following correction. (e.g. fluctuations caused by different turbulence intensity at different altitudes corresponding to the boundary layer stability rather than due to uncorrected bias). However, based on the comments of both reviewers who saw little value in

these profiles, we have removed the potential temperature profiles in the revised manuscript.

13. Line 267: "Corrections work": do they improve the data? How do you prove this?

    We revised this statement to state that the corrections reduce fluctuations about the mean profile under different conditions for different aircraft. Our justification for concluding that the corrections are working is provided in the final paragraph of the conclusions. Specifically: "Measurements flown near a ground-based reference system revealed significant reduction in measured oscillations of both wind magnitude and direction, which corresponded to the aircraft flight pattern. Additional verification was conducted by comparing profiles of wind speed and direction measured by two different aircraft at two different times. The estimated biases were within $\pm 1°$ for each aircraft, and successful minimization of aircraft-induced oscillations in the measured profiles was observed for both aircraft. These results confirm that the biases are most likely due to physical misalignment of the aircraft and probe axes, as well as demonstrating that the same correction procedures can be applied to multiple aircraft."

14. Line 279: is there a word missing in the first sentence?

    Corrected.