

Response to Reviewer Comments

Aerodynamic evaluation of wind speed sensor placement on UAVs for meteorological applications

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Atmospheric Measurement Techniques: EGUSPHERE-2026-977

The authors of the submitted manuscript titled ‘*Aerodynamic evaluation of wind speed sensor placement on UAVs for meteorological applications*’ would like to extend our sincere gratitude to the reviewer from the ‘*Atmospheric Measurement Techniques*’ journal for taking time to consider our submission, assess our work and provide detailed, invaluable comments/ reviews/ suggestions. We have carried out additional in-depth numerical and experimental analyses to address each query of the reviewer, and compiled the findings and responses in this document. We would like to note that:

1. Throughout this document, the questions/comments from the reviewer are provided in blue colour, and the authors’ responses are provided in black colour.
2. Figures, tables, and discussions are presented for each of the points raised by the reviewer, as applicable.
3. The revised manuscript would be provided as per EGU sphere guidelines, post the closure of the online forum including the discussion on this response document.

Reviewer #1

Recommendation: Accept with Minor Revision

1. This paper addresses a practically important and under-explored problem in UAV-based atmospheric measurement: the identification of aerodynamically quiet regions around VTOL drone systems within which wind-speed sensors can be reliably mounted without contamination from rotor-induced flow. The topic is timely given the rapid proliferation of UAV platforms for boundary-layer meteorology and the acknowledged gap in publicly available, systematic guidance for sensor placement on commercial multi-rotor configurations. The authors make a genuine and well-executed contribution to filling this gap, and I recommend acceptance subject to a minor revision described at the end of this review.
2. The methodological choice to use a free-vortex wake model (FVM) rather than high-fidelity computational fluid dynamics is well-motivated and carefully justified. The authors correctly identify that CFD, while accurate, is computationally prohibitive for the kind of broad parametric sweep — across rotor configurations, flight conditions, and disk loading values — that is needed to produce practically generalizable guidance. The FVM occupies an appropriate middle ground: it captures the blade-tip vortex dynamics and rotor-rotor wake interactions that are critical to quiet-zone identification, while remaining tractable enough to explore the full parameter space the study requires. The decision to exclude viscous effects and vortex breakdown is acknowledged, and the authors correctly note that this limits model accuracy below the rotor disk plane, where wake turbulence dominates. Since the region below the rotor is in any case unsuitable for sensor placement on practical multi-rotor platforms — due to fuselage obstruction — this limitation does not undermine the paper’s central conclusions.
3. The validation strategy is sound. The FVM was previously validated against thrust and power data for the APC single-rotor in Narayanan and Govindarajan (2024), and the present work meaningfully extends this by validating predicted induced velocity distributions against in-house TriSonica ultrasonic anemometer measurements. The agreement above the rotor plane — precisely the region of interest for sensor placement — is good, with deviations of approximately 0.5% of tip speed, well within the 1% threshold used to define quiet zones. The authors also present the discrepancies that emerge below the rotor plane and provide a physically coherent explanation for them. The additional validation cases presented in Appendix B, spanning the full-scale Harrington coaxial rotor in hover, the APC propeller across RPM ranges, and the Carpenter–Fridovich unsteady pitch-rate experiment, collectively build a convincing case that the FVM implementation is reliable across a broad range of operating conditions and rotor scales.
4. The choice of disk loading as the scaling parameter for cross-vehicle generalisation is well-argued, and the appendix justifying it over the conventional blade-loading coefficient for electrically-driven variable-RPM UAVs is a thoughtful addition that will be useful to readers from the meteorological community who may be less familiar with rotorcraft aerodynamics. The demonstration in Figure A1 that three rotors spanning dramatically different physical scales produce nearly coincident normalised induced velocity profiles at the same disk loading provides strong empirical support for the approach.
5. The results themselves are clearly presented and physically well-interpreted. The finding that hover represents the most restrictive flight condition for single-rotor quiet-zone extent — and is therefore the appropriate design case — is both intuitive and important. The characterization of axial descent as practically eliminating viable sensor locations, and of forward descent as introducing asymmetric wake skew that confines quiet zones to the

upstream side, provides nuance that has not previously been captured in a systematic, scalable form. For multi-rotor configurations, the identification of the geometric centre as consistently preferable to positions above individual rotor hubs is a practically actionable result, particularly given that the difference in minimum quiet-zone height between the geometric centre plane and the most favourable inter-rotor plane is modest enough that structural and stability constraints are likely to dominate the final placement decision anyway. The paper’s engagement with the existing literature is thorough: Wilson et al. (2022), Jin et al. (2024), Ghirardelli et al. (2023, 2025), and Thielicke et al. (2021) are accurately represented, and the paper correctly identifies the key limitation of prior studies — namely, their restriction to specific platforms without a generalised, scalable framework — as the gap the present work addresses.

We acknowledge the comments and encouraging remarks of the reviewer from Points 1–5, and would like to thank the reviewer for the detailed analysis of the manuscript, and for providing positive feedback on different aspects of the work.

6. The one minor revision I would suggest concerns the multi-rotor FVM predictions. While the single-rotor FVM results are validated against in-house experimental data, the multi-rotor quiet-zone predictions rest on the computational model alone. This may be okay at first sight since they have tested against the single rotor configuration. Wilson et al. (2022), which the authors already cite, provides experimental PIV and field measurements of rotor-induced velocities above a quadcopter in hover and reports a quiet-zone separation distance of approximately 5.3 rotor diameters — a figure that invites at least qualitative comparison with the present FVM predictions. I would encourage the authors either to include a brief discussion of how their multi-rotor results compare with Wilson et al. (2022), even acknowledging the differences in disturbance metric and platform, or, to briefly explain why such a comparison is not straightforward. This would further strengthen reader confidence in the multi-rotor results without requiring any additional computations or experiments.

We fully understand the concern about multi-rotor free-vortex method (FVM) validation. As per the reviewer comments, an attempt at the validation of induced velocity characteristics predicted by the FVM model against the experimental investigation of Wilson et al. (2022) was conducted.

The rotor system considered for validation is a quad-X configuration from the reference paper (3rd row, Fig. 2). The rotors are 3-bladed, and measure 0.0762 m (3 inches) in diameter. No explicit definition of the twist and chord geometry (either in the reference or from the manufacturer) exists, to model the rotor geometry in FVM; consequently, the chord distribution was measured manually from a digital image, and replicated for the FVM study. Similarly, the rotor was assumed to be “ideally twisted” rotor (which is a hyperbolic span-wise twist distribution). The measured chord and twist distributions, and other geometric details of the quad-X configuration utilised for the FVM validation are presented in Fig. 1.

The original experiments in the paper were conducted in a water tunnel, whereas the FVM validation utilises the equivalent flow conditions in air, obtained by maintaining the same Reynolds Number ($Re = 38,100$) and advance ratio ($\mu = 0.1393$). Accordingly, the rotor angular speed was set to $\Omega = 1,413$ rad/s (225 Hz), and the freestream velocity at 7.5 m/s. For the aforementioned geometry and flow parameters, the streamwise variation of the vertical velocity component presented in the reference paper for $Y/D \approx 0.35$ from the rotor disk plane (Fig. 4 in the reference paper) was compared with the results obtained from the FVM model for all the three measurement planes, namely the hub, mid, and the tip planes (see Fig. 1).

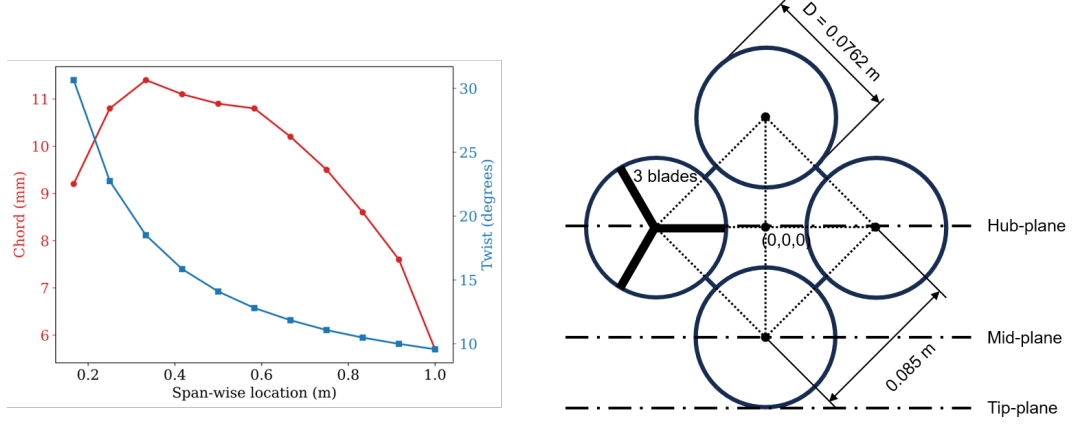


Figure 1: Rotor geometry details for the quad-X configuration presented in [Wilson et al. \(2022\)](#)

The obtained velocity profiles are presented in Fig. 2, where the solid curves correspond to FVM, and dashed curves represent the results from the reference paper and the Masters thesis upon which it is based [Brenner \(2021\)](#). The induced velocity (y -axis) is normalised with the freestream velocity, and the streamwise direction (x -axis) is normalised with the rotor diameter (D). Additionally, the dimension values of the original experiments are presented in the secondary y -axis. It can be observed from Fig. 2 that the peak velocity at the hub-plane is under-predicted by FVM ($0.5 V_\infty$ against $1.25 V_\infty$ from the reference results), and so is the peak at the tip-plane. Nevertheless, the location of the minima and maxima are predicted with reasonable accuracy at the various stream-wise locations for each of the measurement planes. While the normalised induced velocity trends and order of magnitude are captured by FVM in Fig. 2, lending some confidence in the predictions, visible disagreement in the prediction of exact values exists.

This disagreement between FVM and experiment could be attributed to either the assumptions of FVM, or the lack of clarity in the presentation of the experimental data.

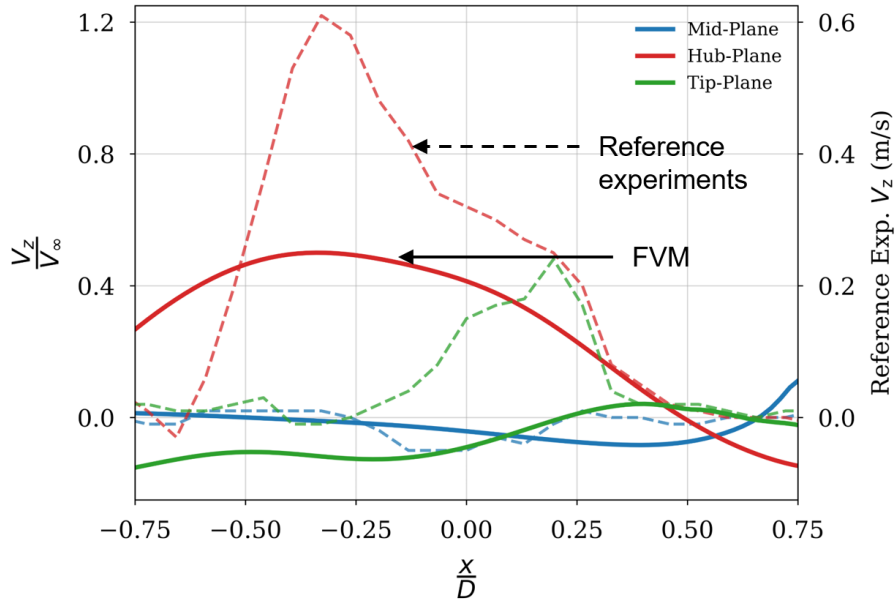


Figure 2: Validation of the FVM model for velocity field predictions of the quad-X configuration from the reference paper.

For instance, FVM simulates only isolated rotors, and do not model fuselage and other structural members (out of scope of the present study), whereas complete quad-rotor system is investigated in the reference experiment. The values presented in FVM are time-averaged over 10-rotor revolutions after the initial transients have settled. However, details of averaging techniques used to obtain the induced velocity, particle image velocimetry (PIV) measurement uncertainty and accuracy, physical limitations in resolving the locations of the measurement planes, the associated blockage effects, influence of ambient conditions, and rotor blade geometry (such as airfoil sections, span-wise chord, and twist distributions) are unclear in the reference paper. These quantities influence the induced velocity distribution significantly, and remain essential for effective modelling into FVM. Especially, since the reference velocities are not more than 0.6 m/s, without clarity on background flow and the associated measurement uncertainties, it becomes considerably hard to replicate the results and quantify disagreements in prediction with FVM. To obtain test cases with more complete information, we also performed a detailed analysis of the literature on wind-speed measurements using UAV-mounted sensors (Thielicke et al. (2021); Wilson et al. (2022); Jin et al. (2024); Ghirardelli et al. (2023, 2025)); however, we observed a similar lack of clarity on the governing parameters such as those listed above.

We note that a comprehensive, reproducible set of reference data is still not easily extractable from the literature, and hence, we are unable to perform a stringent comparison between numerics and experiments for multi-rotor systems. Regardless, we were able to model the rotor system provided in (Wilson et al. (2022)), for which the induced velocity results are presented in Fig. 2. Due to the discussed limitations in the literature and the FVM model, we acknowledge the observed disagreements in the comparison, and we will present the validation results in the revised manuscript as “potential” or “likely”, rather than those obtained after strong verification.

Potential addition to the manuscript: We will include the multi-rotor validation plot (Fig. 2) along with the rotor geometry details (Fig. 1). We will also provide a concise explanation of the results, highlighting the parameters and model limitations.

7. In summary, this is a well-written, carefully reasoned, and practically valuable paper. The assumptions are appropriate and clearly stated, the methodology is well-suited to the problem, the results are physically consistent and usefully general, and the literature context is handled with accuracy. I recommend publication following the minor revision noted above.

We thank the reviewer again for the valuable comments and suggestions.

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