

Reply to the review by Anonymous Referee #2 on “Measuring the 3-D wind vector with a weight-shift microlight aircraft”

We thank Anonymous Referee #2 for his / her valuable comments on this manuscript and the detailed feedback. In below text we hope to answer your questions and clarify the approach of our study. The comments by the reviewer are indicated with an asterix (*) and are cited in italics, followed by our reply. Where indicated, also see the reply to reviewer 1.

*** Page 1307.** *At the start of Section 2, the term "Joint Aviation Authorities" is used. According to their website <http://www.jaa.nl/introduction/introduction.html> this organization does not exist. The aforementioned website states, in part: “The Joint Aviation Authorities (JAA) was an associated body of the European Civil Aviation Conference (ECAC) representing the civil aviation regulatory authorities of a number of European States who had agreed to co-operate in developing and implementing common safety regulatory standards and procedures.” Reference to this organization should be changed to the successor organization, or the references should appear in the past tense. Note also that the purpose of this organization was not scientific, but safety/regulatory. This should be noted in the paper so that a reader who is unfamiliar with aviation will know the paradigms under which this organization (or its successor, as appropriate) operated/operates.*

We propose to change the reference in the manuscript, page 1307 line 13 to the successor organization: “According to the safety and regulatory standards of the European Civil Aviation Conference...”.

*** Page 1308.** *The paper states that all thrust is provided through a 73kW pusher engine-propeller combination. This must produce a large amount of as-yet un-quantified airflow distortion.*

The flow distortion originating from the propeller thrust is integrally considered in the presented approach. This is achieved using in-flight experiments for the characterisation and calibration (see also next paragraph ‘Page 1309’). More details will be included in the manuscript following the comments of reviewer 1 ‘Page 1314’ and ‘Page 1328, Eq. (7) and Fig. 8’.

*** Page 1309.** *The paper states: “The aircraft’s propeller, fuselage, and wing can be sources of flow distortion. Since the pressure probe is aligned on the longitudinal axis of fuselage and propeller, only little distortion from trike structural features is expected transverse to the pressure probe. Longitudinal and vertical distortions can be expected to carry continuously through the pressure probe location, since the probe is rigidly fixed to the trike.” Can the authors quantify what is meant by “only little distortion” and under what circumstances such little distortion exists?*

The trike body is symmetric on its port and starboard side, and the pressure probe, propeller and pilot are centred on its longitudinal axis (Figs. 1 and 3). In contrast the body is asymmetric on its upside and underside, and the propeller location is 0.8 m higher than the pressure probe. This suggests symmetric flows in transverse, and asymmetric flows in longitudinal and vertical directions. Our findings confirm that the symmetric flow transverse to the pressure probe requires less correction: leaving dynamic considerations aside (i.e. lift coefficient is zero), the magnitude of the sideslip angle correction (-0.004 rad) is one order of magnitude lower than the attack angle correction (0.039 rad, offsets in Table 4). At a true airspeed of 30 m s^{-1} this affects the wind measurement to approx. -0.1 m s^{-1} and 1.2 m s^{-1} , respectively. The transverse distortions increase and the vertical distortions decrease at a ratio of approx. 1:3, when considering interactions with propeller and wing (i.e. nonzero lift coefficient, slopes in Table 4).

We propose to amend page 1309 line 21 ff. of the manuscript: “Only little distortion from trike structural features is expected transverse to the pressure probe: the trike body is symmetric on its port and starboard side, and the pressure probe, propeller and pilot are centred on its longitudinal axis (Figs. 1 and 2). In contrast the body is asymmetric on its upside and underside, and the propeller location is 0.8m higher than the pressure probe. This suggests symmetric flows intransverse, and asymmetric flows in longitudinal and vertical directions. All of which are expected to carry continuously through the pressure probe location, since the probe is rigidly fixed to the trike.”,

as well as to insert after page 1331 line 22: “Compared to the upwash parameterization, sidewash was found to be modest ($\beta_{\text{upw,off}} = -0.004$ rad) and less sensitive regarding CL ($\beta_{\text{upw,slo}} = -0.010$ rad, Table 4). This is in line with the initial attempt to resolve the circulation around the wing and the trike movement explicitly (Fig. 6). The findings also confirm our initial hypothesis that flow transverse to the pressure probe requires less correction than in vertical direction (Sect. 2.1): leaving dynamic considerations aside (i.e. lift coefficient is zero), the magnitude of the sideslip angle correction is one order of magnitude lower than the attack angle correction (0.039 rad, offsets in Table 4). At a true airspeed of 30 m s^{-1} this affects the wind measurement to approximately -0.1 m s^{-1} and 1.2 m s^{-1} , respectively. The transverse distortions increase and the vertical distortions decrease at a ratio of approx. 1:3, when considering interactions with propeller and wing (i.e. non-zero lift coefficient, slopes in Table 4).”.

*** Page 1310, Eq. (3).** *This equation is a very simplified aerodynamic model of the upwash ahead of a wing with an elliptical lift distribution. An elliptical lift distribution is highly idealized, and real wings will only approximate this ideal model. The variable “n” is incorrectly represented as “the separation distance from the wing’s centre of pressure to the position of the pressure probe, normalized by the effective wing chord”. The correct interpretation/application of Equation 3 is for a pressure probe which is directly ahead of the wing. “n” should not be interpreted as a point-to-point distance. The applicability of this model to the aircraft in question is doubtful. The pressure probe is largely below – and not ahead of – the wing. As seen in Figure 3, the probe mounting is offset from the propeller’s centreline, and thus, different airflow entrainment would – in all likelihood – exist for various power settings. The aircraft body itself is not symmetrical – neither the shell shape, nor*

especially after considering the shape of the landing gear and occupant. (...) Also, the orientation angle (and the distance) between the centre of pressure and the pressure probe constantly change during flight, as the pilot rotates the wing to control the aircraft. No mathematical accommodation is made for this fact.

The equation in question is widely used to correct airborne wind measurements for wing induced upwash (e.g., Crawford et al., 1996, Garman et al., 2008, Kalogiros & Wang, 2002). In our study we use this model to introduce a functional relation between lift and upwash generation in Eqs. (1) – (3). This includes the normalized separation distance “n” in the definition of Crawford et al., 1996 (whose probe location is ahead and above the wing). We show that the model as such can not be applied to the wind measurement from WSMA (Fig. 7). Among others the varying orientation and distance between the wing and the five-hole pressure probe (5HP) is a potential reason: the 5HP is effectively 2.1 - 2.5 m below and 1.1 - 1.2 m ahead of the wingtip. The reply “Page 1328, Eq. (7) and Fig. 8” to reviewer 1 explains how this, besides other peculiar behaviours of the WSMA (including the influence of propeller slipstream) is accommodated in the derived correction. Moreover the derived correction solely draws on the functional relation between lift and upwash generation, and “n” is not further used.

We propose to amend page 1311 line 6 of the manuscript: “Based on the functional relation between lift and upwash generation a treatment for the wind measurement from WSMA is derived in Sect. 4.1.”.

** Of essential utility would be a mathematical model of the airflow distortion caused by the aircraft body, landing gear and propeller when different angles of attack and sideslip (relative to the aircraft body) are present, as well as for thrust changes. In the absence of an algebraic aerodynamic approximation, insight could be gleaned by utilizing one of several commonly available flow modelling programs (e.g. FLUENT).*

At the outset of this study the Institute of Aerodynamics and Flow Technology at the German Aerospace Centre was consulted, whether a correction of the WSMA wind measurement could be inferred from CFD. The assessment was that, with great effort, CFD could be used to describe the mean aerodynamic properties of the WSMA. The main focus of the wind correction however comprises from the sources of variability of the WSMA. Consequently a detailed experimental study was rated more appropriate. In consultation with the test centre of the German Ultralight Aircraft Association the presented set of flight manoeuvres was compiled, which enable the isolation of individual parameters.

We propose to insert after page 1307 line 1 of the manuscript: “At the outset of this study the use of computational fluid dynamics was envisaged. The assessment was that, with great effort, such model could describe the mean aerodynamic properties of the WSMA. The challenge of the wind measurement from WSMA however comprises from the sources of variability. Consequently preference was given to a detailed experimental study.”.

* **Page 1323.** *The 10-Hz aircraft data were block averaged to 1Hz. Why was this done? Surely the data can be analyzed in its entirety using modern computers. If the scatter is present without block averaging, isn't this a valid result?*

Only for the calibration steps D-G the 10 Hz aircraft data were block averaged to 1 Hz. These calibration steps are iterative optimizations. Here the block averaging facilitates convergence of the respective quality criteria.

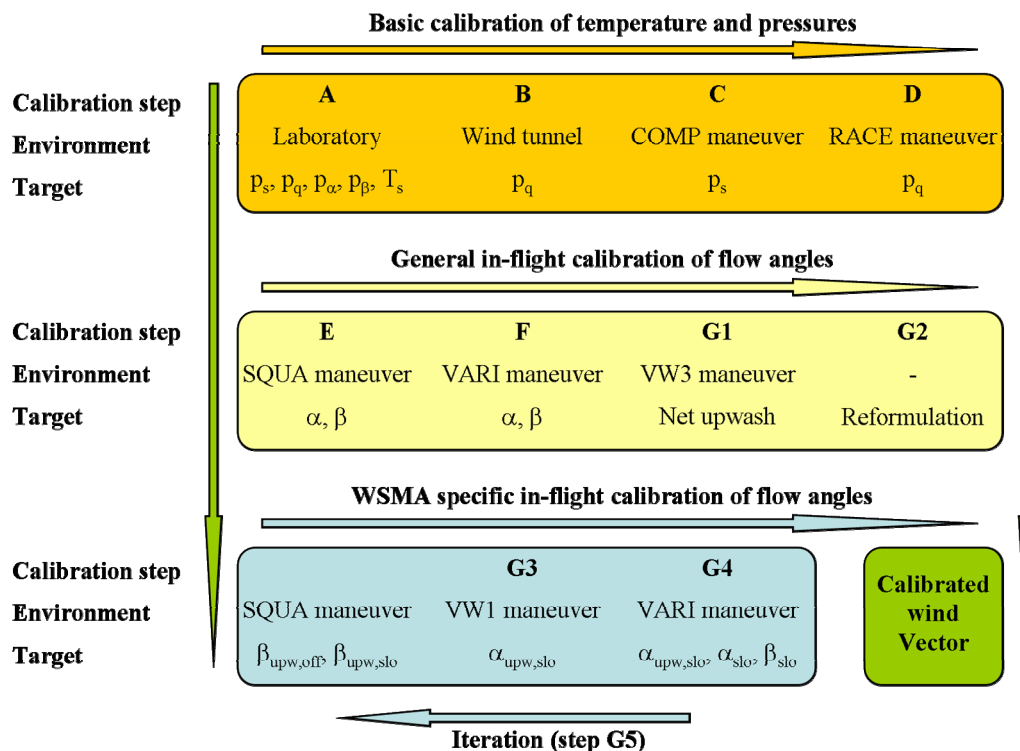
We propose to amend page 1323 line 1 f. of the manuscript: “To reduce scatter and facilitate convergence of the iterative process the 10 Hz aircraft data were block averaged to 1 Hz for steps D–G.”.

* **Pages 1323 - 1331.** *A flowchart would be helpful, and would assist the reader in visualizing the process. Also, were the calibrations obtained separately in each step (to an un-calibrated system), or were the calibrations applied in a cascade fashion – whereas each step resulted in an incrementally-refined system?*

The calibrations were applied in a cascade fashion: each step results in an incrementally-refined system.

We propose to amend page 1323 line 1 of the manuscript: “The actual calibration sequence was organized in seven steps (Fig. 5), resulting in an incrementally refined system.”.

We also propose to include a flowchart after Fig. 4 in the manuscript:



with the figure caption: “Flowchart of the calibration process. The calibration steps A–G are carried out in a sequence from left to right, top to bottom. Each step results in an incrementally refined system. The iterative step G5 (blue background)

comprises three flight manoeuvres. Within G5 the SQUA manoeuvre is not associated with an individual calibration step.”.

*** Appendices.** *The appendices are voluminous. Can the peer-reviewed and accessible publication (to which the appendices refer) be simply cited, instead of reproduced?*

Some journals allow the publication of additional materials in an online repository. This could be an adequate solution for Appendices A and B1, which however is not foreseen by AMT. In the forenamed appendices the reader is provided with important details of, and modifications to formulae, aggregated in consistent notation with the main paper. Also see the reply “General Comments” to reviewer 1. We propose to remove Appendix B2 “Uncertainty measures” from the manuscript.

References

- Crawford, T., Dobosy, R. & Dumas, E. (1996), ‘Aircraft wind measurement considering lift-induced upwash’, *Boundary Layer Meteorol.* **80**(1-2), 79–94.
- Garman, K. E., Wyss, P., Carlsen, M., Zimmerman, J. R., Stirn, B. H., Carney, T. Q., Santini, R. & Shepson, P. B. (2008), ‘The contribution of variability of lift-induced upwash to the uncertainty in vertical winds determined from an aircraft platform’, *Boundary Layer Meteorol.* **126**(3), 461–476.
- Kalogiros, J. A. & Wang, Q. (2002), ‘Aerodynamic effects on wind turbulence measurements with research aircraft’, *J. Atmos. Oceanic Technol.* **19**(10), 1567–1576.