Towards sensible heat flux measurements with fast-response fine-wire platinum resistance thermometers on small multicopter uncrewed aerial systems.

Norman Wildmann[1] and Laszlo Györy[1]

[1]Deutsches Zentrum für Luft- und Raumfahrt e.V., Institut für Physik der Atmosphäre, Oberpfaffenhofen, Germany

Correspondence: Norman Wildmann (norman.wildmann@dlr.de)

1 Review response

1.1 Review General comments

1. *This manuscript is well written and provides a topic that is relevant to the AMT readership. Fast response temperature measurements using UAS are typically achieved using fixed-wing aircraft. It is valuable to see more studies that demonstrate the ability to use rotary-wing UAS for this purpose. The authors are well qualified and the experimental techniques are suitable to demonstrate the objectives of the study: that sensible heat flux measurements can be achieved with the assistance of rotary-wing UAS. I did find it difficult at points to follow some of the data processing steps, but this can be rectified in a revision. I feel that the paper would benefit from a major revision.*

   We thank the reviewer for the objective review and good points of criticism and suggestions for improvement. We will add more detail on the processing (also in response to the second review) in order to improve the understanding and readability.

2. *The paper would benefit by having more background on eddy covariance measurements.*

   We agree that we presumed a good background knowledge of the eddy-covariance method, which is maybe not appropriate for the whole readership of the article. We add two sentences in the introduction to introduce the method and also include further references:

   "A common technique for turbulence flux measurements from stationary measurements in the ABL is the eddy-covariance method (Baldocchi et al., 2001). The eddy-covariance method directly measures the net exchange of gases, heat, and momentum between an ecosystem and the atmosphere by statistically correlating rapid fluctuations in vertical wind speed with concurrent fluctuations in the scalar of interest (e.g., gas concentration or, as in this study, temperature). [...] In order to derive accurate fluxes of sensible and latent heat in the ABL, corrections are necessary which are described in detail in Baldocchi et al. (2001) and Mauder and Foken (2011)."

3. *The paper references papers from previous work by the authors, which is appropriate, but the reader should not need to read those papers to follow the flow of the proposed study. More information from the previous studies (as related to the present work) should be provided as a summary.*

We did not explain previous work in much detail and agree that we should improve on this. We add one chapter in the revised manuscript in Section 2 describing the UAS system and previous results of calibration and spatial measurements. We also include a paragraph specifically about the vertical velocity estimation in Sect. 3:

1.1.1 The SWUF-3D UAS

The SWUF-3D UAS are commercially available racing drone frames of type Holybro QAV250. They are powered by a Pixhawk 4 Mini autopilot. Depending on the batteries which are used for the specific operation, the QAV250 can reach flight times up to 25 minutes. In this study, only batteries with a lower capacitiy were available, so that maximum flight times were 15 minutes and therefore, the hover periods were set to a maximum of 12 minutes. Further characteristics of the UAS are described in Wetz et al. (2021). In a fleet configuration, a multitude of drones can fly pre-defined routes synchronously and automatically. Up to twenty drones were operated during the FESSTVaL campaign (Hohenegger et al., 2023). At the research wind park WiValdi, ten drones were operated simultaneously in multiple campaigns before Wildmann and Kistner (2024, 2025). Through field tests (Wetz et al., 2021) and wind tunnel calibration (Kistner et al., 2024), the accuracy of wind speed measurement was found to be well below 0.5 m s^{-1} and mostly below 0.3 m s^{-1}. The fleet of drones was deployed in the past to investigate spatial correlation and coherence in the ABL (Wetz et al., 2023) as well as wind speed deficit, turbulence and distinct vortices in wind turbine wakes (Wetz and Wildmann, 2023; Wildmann and Kistner, 2024, 2025).

1.1.2 Vertical velocity esimate

Attempting to calculate fluxes with the eddy covariance method requires synchronous measurements of temperature with vertical flow velocity w. As described in Wildmann and Wetz (2022), vertical velocity can be estimated from thrust and lift of the UAS. The force acting on the drone in z-direction F_z in the body frame of the drone is a combination of gravitational force (mg rotated into body frame with roll φ and pitch θ angle), vertical accelerational forces $m\ddot{z}$, thrust T and lift force F_L which depends on the drag force F_x:

$$F_z = -mg\cos(\theta)\cos(\varphi) + m\ddot{z} + T + F_L(F_x) \tag{1}$$

Vertical velocity is derived based on a calibrated curve using the equations

$$w_b = \begin{cases} c_{z\uparrow}F_z^{b_{z\uparrow}} & F_z \geq 0 \\ c_{z\downarrow}F_z^{b_{z\downarrow}} & F_z < 0 \end{cases} . \tag{2}$$

Since the study in 2022, new rotors and new batteries were installed on the SWUF-3D UAS, which changes the thrust and lift behaviour. Parameters were adjusted accordingly. It also showed that it is beneficial to first rotate the forces into the geodetic coordinate system and do the vertical velocity calibration in this frame of reference, so that:

$$w = \begin{cases} c_{z\uparrow} F_z^{g_{z\uparrow}} & F_z \geq 0 \\ c_{z\downarrow} F_z^{g_{z\downarrow}} & F_z < 0 \end{cases} \quad . \tag{3}$$

4. *This is related to the previous point but more information on the actual UAS would be useful.*
   See our response above.

5. *The authors should provide more information on the sensitivity of the wind vane mode to wind speed.*
   The weather vane mode is working if a roll angle larger than 1° can be inflicted, which is the case for wind speeds larger than $\approx 2\ \mathrm{m\ s^{-1}}$ in spanwise direction. The wind algorithm for the SWUF-3D takes spanwise wind into consideration if the UAS is not perfectly aligned. In Kistner et al. (2024) it is described how much the uncertainties increase for sideslip angles up to 30°.

6. *Are the FWPRT sensors available commercially? How prone are they to damage? Is this a limiting factor?*
   The FWPRT sensors as in the SWUF-T sensor are not commercially available, but are self-designed and manufactured. Within the housing, the fine wire is not very susceptible to damage. However, hard landings or objects that will hit the wire directly can certainly damage the sensor, however that is also the case for other sensors.

7. *Maybe I missed it, but it is not clear to me how the vertical wind data (from the towers?) are paired with the temperature measurements from the copters?*
   This may be a misunderstanding. The vertical wind data is also measured by the drones according to Wildmann and Wetz (2022). We add a section in the revised manuscript to further describe the vertical wind estimation (see above).

8. *I did not see information on the sampling rate of the sonic anemometer.*
   The sonic anemometers have a sampling frequency of 10 Hz. In the revised manuscript they are downsampled to a rate of 5 Hz to match the UAS. This information will be explicitly given in the revised manuscript.

9. *Which instrument was used to measure humidity on the UAS?.*
   For humidity, the HYT.R411 is used (HYT271 in previous versions). This is a capacitive humidity sensor.

10. *To me it seems that demonstration of the FWPRT measurements against the tower and the onboard solid state thermometer would be sufficient for a study. The inclusion of measurements of flux adds extra layers of complication, which are not necessarily adequately resolved in the paper.*
    It is right that temperature sensing itself is a challenging task and we want to put the focus on this. On the other hand it is

important for us demonstrate the purpose of turbulence and flux measurements very clearly, because the high temporal resolution is particularly important for these applications. We hope that the responses that are provided to the second reviewer will adequately resolve the complications, or at least transparently explain the state of the art and limitations at the current state of development.

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