Imperial College London

Natural Environment Research Council

2024_6_Aero_KS: Improved aerodynamics and control of UAVs for precision Atmospheric Boundary Layer measurements

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Understanding and modelling the flow processes of the planetary boundary layer (PBL) is of critical importance to many fields of atmospheric science including air pollution, mesoscale meteorology, weather forecasting, and climate predictions (Garatt, Earth-Sci Rev 1994). To model such flow processes, one requires accurate measurements of the PBL flow properties, e.g., wind velocity, turbulent stresses, pressure, and humidity. Conventional measurement methods include the mounting of instruments on weather masts, weather balloons and research aircraft. However, these approaches suffer from severe limitations, in particular high cost, usage of unrealistic assumptions, and inability to "scan" a wide measurement area in a consistent way (Wildmann & Weltz, Atm Meas Techn 2022). The above limitations, coupled to the complexity of the PBL's flow processes, have contributed to the PBL flow physics remaining to this day largely opaque.

It has been recently proposed that the above can be addressed by mounting sensors on single or multiple multicopter UAVs, as the latter are low cost, can cover a grid of spatial points in a reproducible manner, and remain relatively insensitive to wind drift (Thielicke et al. Atm Meas Techn 2020). Essentially, the UAV takes the role of the "probe traversing system" of wind tunnels, when measuring laboratory-generated boundary layers.

However, this approach comes with its own challenges, as the operation of the UAV might cause contamination of the measurements. Together with our industrial partner, Menapia, we have identified two ways that this might occur: (i) The propellers of the UAV generate a downwash near the probe region; and (ii) the turbulent gusts of the PBL might perturb the "stable" hovering of the UAV. Both situations induce a measurement bias to the probes, via the rotation of the UAV propellers, or by the motion of the UAV itself.

The objective of this PhD will be to address the above challenges and to improve the accuracy of the PBL velocity and pressure datasets obtained by UAVs in atmospheric measurements. This will be achieved in two ways: First, an aerodynamic model for the propeller downwash will be developed, by extending the multiple impeller theory recently developed by Steiros et al. J Fluid Mech 2022. This will be used to remove the propeller-induced bias from the UAV probe measurements. The aerodynamic model will be validated by characterizing the velocity field of UAVs in the wind tunnels of the Aeronautics department, via state-of-the-art high-speed Particle Image Velocimetry (PIV) measurements. Second, the acquired PIV dataset will be leveraged to develop an improved data-driven control system for UAVs, providing superior performance (in terms of stability, efficiency and robustness to gusts), compared to conventional PID controllers. Finally, the above methodologies will be applied to real field measurements of the PBL, using Menapia's MetSprite UAV, in its field test site in Leeds.