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Measuring the turbulent wind vector with a weight-shift Microlight Aircraft

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The Small Environmental Research Aircraft (SERA) D-MIFUs initial fields of application are aerosol / cloud and radiation transfer research. Therefore a comparatively slow (True Airspeed, TAS $\sim$25 ms^{-1}) but highly mobile microlight aircraft was envisaged. To broaden the application area of D-MIFU we explore whether the microlight can also be used for Eddy Covariance (EC) flux measurement.

To obtain useful data sets for airborne EC a reliable turbulent Wind Vector (WV) measurement is a key requirement. Here we present methodology and results to calibrate and express performance and uncertainty of microlight based WV measurement. Specific attention is given to the influence of the flexible-wing weight-shift geometry on the WV measurement.

For the WV measurement we equipped D-MIFU with a 70 cm long noseboom supporting a classical 5 hole probe and a fast 50 μm diameter thermocouple. An Inertial Navigation System (INS) supplies high accuracy ground speeds (σ=0.05 ms^{-1}) and attitude angles (σ=0.03°, 0.1° respectively for heading). Data are stored with 10 Hz yielding a horizontal resolution of 2.5 m. The INS also allows to analyze aircraft dynamics such as 3d rotation rates and acceleration of the nacelle body. Further estimates for 3d acceleration of airfoil and noseboom are obtained at 100 Hz.

The noseboom calibration coefficients under laboratory conditions were obtained by wind tunnel- and thermal bath measurements. To transfer these characteristics for in-flight conditions we carried out a series of flights with D-MIFU above the Boundary Layer under calm conditions. On basis of level flights at different power settings we were able to determine dynamic pressure-, sideslip- and attack angle offsets. Additionally forced maneuvers, such as e.g. phugoids, have been performed. By means of multivariate analysis these data are used to assess and minimize the impact of microlight nacelle and airfoil rapidly varying motions (RVM) on the WV components. In the final step of the calibration we employ a Markov Chain Monte Carlo based Bayesian optimization. Recording the posterior parameter distribution this optimizing procedure allows an integrated assessment of WV uncertainty as induced by the instrumental setup. To test whether the airborne measured WV is in agreement with ground based measurements we additionally performed flights at tall tower sites equipped with ultrasonic anemometers as well as a Sodar facility.

The impact of the in-flight correction on the WV components is found to be in the order of 1 ms^{-1} in the horizontal and 0.1 ms^{-1} in the vertical. From racetrack comparisons we obtain a maximum final wind error of 0.9 ms^{-1} for horizontal and 0.2 ms^{-1} for vertical WV components before RVM correction. At that the vertical WV measurement is found to be independent from TAS. Ground truth comparisons show mean horizontal and vertical wind deviations of 0.2 ms^{-1}, 0.1 ms^{-1} respectively for 10 minute averages. Deviations are independent of aircraft heading, sideslip angle respectively.

From these findings we conclude that a thoroughly setup microlight aircraft is capable of measuring the WV components with an accuracy sufficient for EC applications.