Evaluation of Probe-Induced Flow Distortion of Campbell CSAT3 Sonic Anemometers by Numerical Simulation

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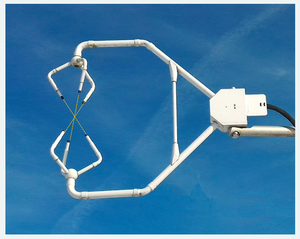
Introduction

The Campbell CSAT3 sonic anemometer is one of the most trusted instruments for eddy-covariance measurements. However, conflicting estimates for the probe-induced flow distortion error of this instrument have recently been reported, and these **error estimates range between 3% and 14%** for the measurement of vertical velocity fluctuations. This large discrepancy between the different studies can probably be attributed to their different experimental approaches. In order to **overcome the limitations of both field intercomparison experiments and wind tunnel experiments**, we propose a new approach that relies on virtual measurements in a **large-eddy simulation** environment.

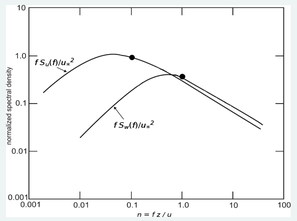
Questions

- How large are the measurement errors due to flow distortion?
- Are the vertical velocity and horizontal velocity equally affected?
- Does the error change with varying azimuth and angle-of-attack?
- How does the frequency of fluctuations affect the flow-distortion error?



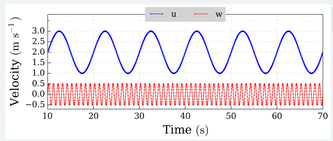
Large-Eddy Simulation in OpenFOAM®

- Assumption: no influence of measurement height
- Periodic boundary conditions in vertical (*z*) and spanwise (*y*) directions
- Inflow/outflow in the streamwise (*x*) direction
- Simulated time: 70 s (including 10 s spin-up time)
- Domain: 1 m x 1 m x 1 m, unstructured grid
- Mesh resolution: **vicinity of transducer: 1 mm**, farfield: 12.5 mm

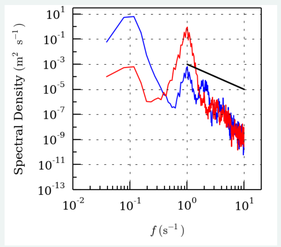


Case	Frequency (Hz)		Azimuth Angle (°)	Angle of Attack (°)
	u	w		
A	0.1	0.1	0, 30, 60, 90	0 (mean)
B	0.1	1	0, 30, 60, 90	0 (mean)
C	Const.	Const.	0, 30, 60, 90	0, 5, 25

Sinusoidal inflow based on model spectra (modified after Kaimal et al. 1972)

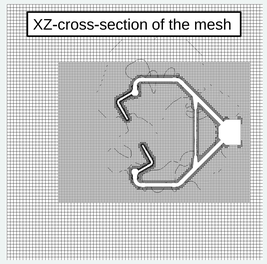


Case B0000

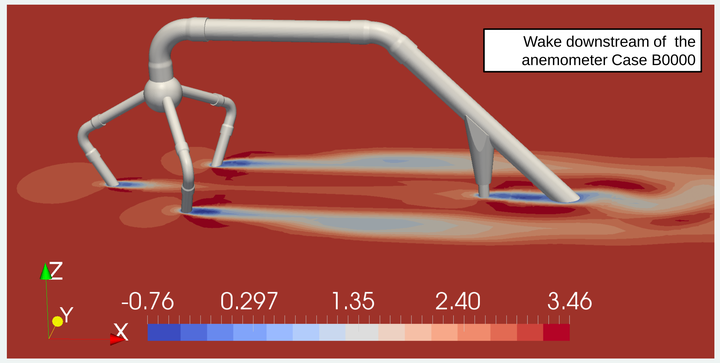


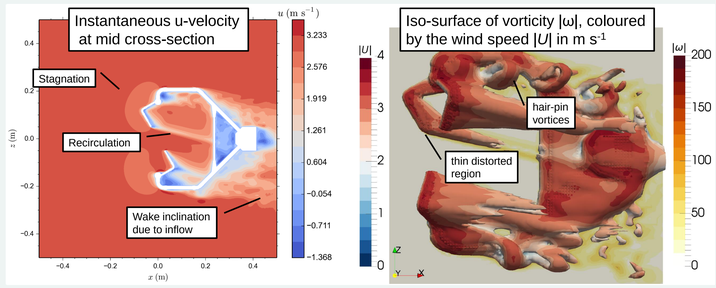
Virtual Probes

- CSAT3 has 3 acoustic paths
- Data recorded at 11 points @ 100 Hz
- Resampled to 20 Hz by block averaging
- Three virtual paths are then averaged to arrive at velocity components *u*, *v* and *w*.

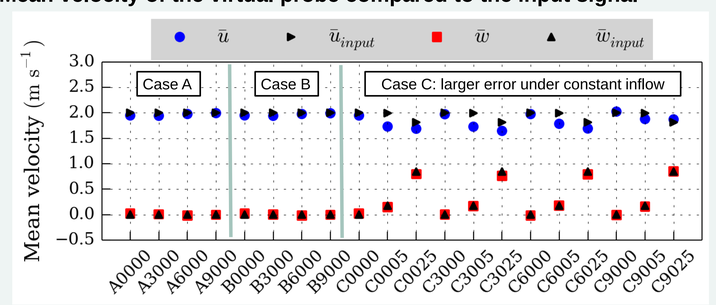


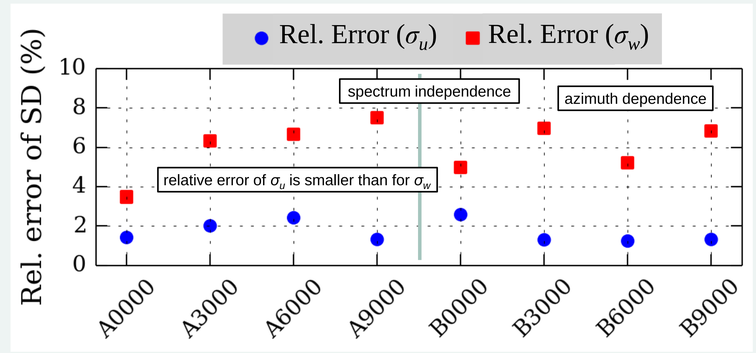
Results



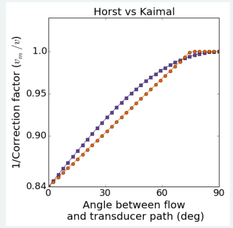


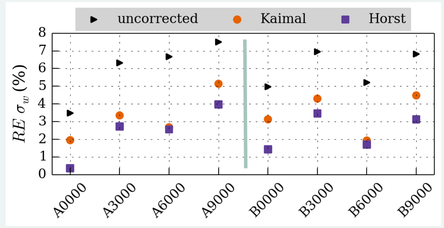
Mean velocity of the virtual probe compared to the input signal





Azimuth independent flow distortion corrections for *w* by Kaimal et al (1990) and Horst et al (2015) reduce the error by about 1-3%. The remaining error of *w'* will influence the measurement of the scalar fluxes.





Conclusions

- Probe-induced flow distortion of the CSAT3 affects turbulence measurements, underestimating fluxes between 3 and 7%.
- Fluctuations in *u* are measured more accurately than those in *w*.
- The errors are smaller for fluctuating flow, nevertheless spectrum-independent. Hence, wind-tunnel based corrections are not directly transferable to turbulence measurements in the field.
- Existing transducer-shadowing corrections partially reduce the dampening but neglect the azimuth dependence. Even corrected fluxes have an azimuth dependent error of up to 5%.

YouTube

Acknowledgements

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