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WIND
ENGINEERING
FLUID
DYNAMICS

Anemometer calibrations

Investigation of calibration repeatability

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The present memo investigates the repeatability of anemometer calibrations performed in the Svend Ole Hansen ApS wind tunnel in Copenhagen.

Background

163 calibrations of the same WindSensor P2546A-OPR cup anemometer performed in the period January 2017 to April 2019 are considered. The calibrations were performed in the SOH wind tunnel in Copenhagen and are standard calibrations following the IEC 61400-12-1 standard [1], Annex F, having a calibration velocity range of 4 to 16 m/s. Between calibrations the anemometer is kept in a protective case under indoor conditions and is therefore assumed unaltered throughout the period.

A target calibration equation for the anemometer is taken as the overall mean of all the individual calibrations. The target equation is written:

$$U = a_{\mathrm{T}} \cdot f + b_{\mathrm{T}}, \tag{1}$$

where a_{T} is the target slope and b_{T} is the target offset, taken as the overall average of all the individual calibration equation slopes a and offsets b. U is the mean wind speed in [m/s] and f is the anemometer pulse frequency in [Hz].

Results

The calibration repeatability for the slope and offset parameters is evaluated through the relative slopes a/a_{T} and the relative offsets b/b_{T}. These are plotted in Figure 1 panel (a) and (b) with the overall standard deviation written above each panel. Panel (c) shows the two parameters plotted against each other with their correlation coefficient written above the figure.

For each individual calibration, the absolute deviation e_f from the target velocity at the anemometer pulse frequency f is found from:

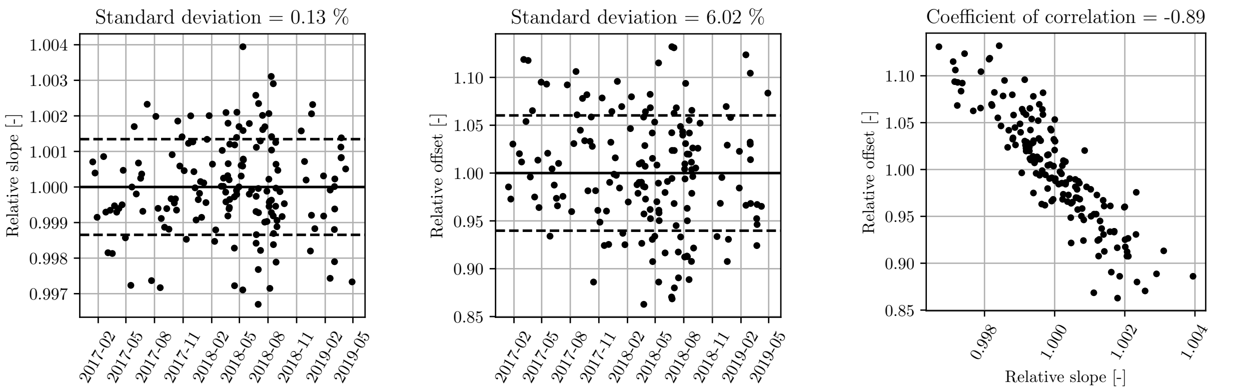
$$e_f = (a \cdot f + b) - (a_{\mathrm{T}} \cdot f + b_{\mathrm{T}}), \tag{2}$$

where a and b are the slope and offset, respectively, obtained from the specific calibration.

The relative deviation ε_f is found from:

$$\varepsilon_f = \frac{e_f}{U_{f,\mathrm{T}}}, \tag{3}$$

where $U_{f,\mathrm{T}}$ is the velocity found for the pulse frequency f using the target calibration equation (1).



(a) Relative slopes, a/a_T *(b) Relative offsets, b/b_T* *(c) Relative slopes vs. relative offsets*

Figure 1. Obtained slope and offset parameters of the 163 calibrations relative to the target calibration equation. The standard deviation is written above each panel. Dashed lines indicate ± one standard deviation.

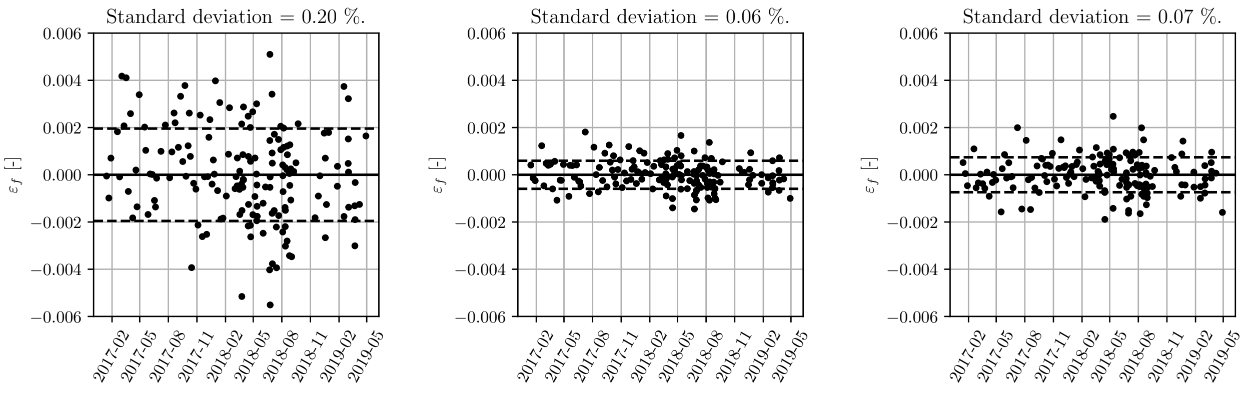
A secondary, *weighted* relative deviation $\varepsilon_{f,\mathrm{w}}$ is found from:

$$\varepsilon_{f,\mathrm{w}} = \frac{e_f}{w_f}, \tag{4}$$

where w_f is a weighting function adopted from [1], Annex I. The weighting function averages the influence of absolute and relative deviations and is here expressed as:

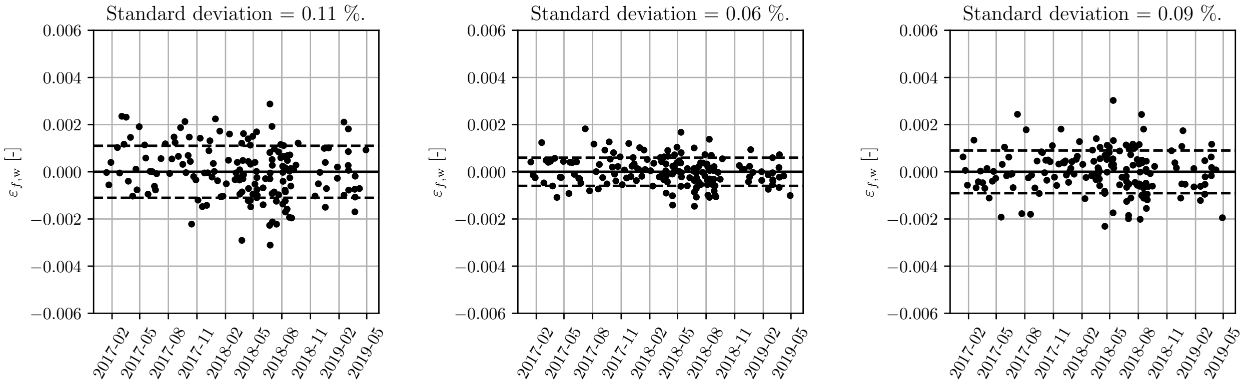
$$w_f = 5\,\mathrm{m/s} + 0.5 \cdot U_{f,\mathrm{T}}. \tag{5}$$

The relative deviations ε_f for all the considered calibrations of the control anemometer are shown in Figure 2 for reference pulse frequencies of 6, 16 and 25 Hz, corresponding approximately to wind speeds of 4, 10 and 16 m/s. The standard deviation σ_ε of the relative deviations is written above each plot. Corresponding results for the weighted relative deviations $\varepsilon_{f,\mathrm{w}}$ are shown in Figure 3.



(a) At f=6 Hz (app. 4 m/s) *(b) At f=16 Hz (app. 10 m/s)* *(c) At f=25 Hz (app. 16 m/s)*

Figure 2. Relative deviations ε_f at the reference pulse frequencies 6, 16 and 25 Hz. The standard deviation is written above each panel. Dashed lines indicate ± one standard deviation.



(a) At f=6 Hz (app. 4 m/s) *(b) At f=16 Hz (app. 10 m/s)* *(c) At f=25 Hz (app. 16 m/s)*

Figure 3. Weighted relative deviations $\varepsilon_{f,\mathrm{w}}$ at the reference pulse frequencies 6, 16 and 25 Hz. The standard deviation is written above each panel. Dashed lines indicate $\pm$ one standard deviation.

Discussion

As expected, a strong negative correlation between the obtained slope and offset parameters for repeated calibrations is observed. This means that the scatter seen for one of the parameters is to some extend compensated by the outcome of the other.

The results for the relative velocities show the least scatter at 10 m/s, which is to be expected as this is at the center of the calibration velocity interval. After applying the weighting to the relative deviations, the levels of scatter at the ends of the calibration interval, at 4 and 16 m/s, are approximately the same.

In the AWEA paper [2], relative deviations at 10 m/s for repeated calibrations of the same WindSensor P2546A cup anemometer are presented, showing typical relative deviations of 0.05 % and maximum deviations of approximately 0.2 %. The paper results agree well with the results presented above.

Conclusion

The calibration repeatability of standard anemometer calibrations in the SOH wind tunnel in Copenhagen has been investigated.

The variation between 163 calibrations of the same WindSensor P2546A-OPR anemometer was expressed by the obtained slope and offset parameters divided by their overall mean values. This showed a standard deviation of 0.13 % for the slope parameter and 6.02 % for the offset parameter. The coefficient of correlation between the two parameters was $\rho = -0.89$.

To evaluate the variation on the predicted wind speed, a relative deviation ε_f and a *weighted* relative deviation $\varepsilon_{f,\mathrm{w}}$ were introduced, see Equations (3) and (4), respectively. The standard deviation of these two relative deviations evaluated at reference pulse frequencies of 6, 16 and 25 Hz, corresponding approximately to 4, 10 and 16 m/s, are given in Table 1.

The obtained results for the relative deviations at 10 m/s agree well with the corresponding results presented in [2].

Frequency, f [Hz]	Approximate wind speed, U [m/s]	Std.dev. of rel. dev. [-]	Std.dev. of weighted rel. dev. [-]
6	4	0.20 %	0.11 %
16	10	0.06 %	0.06 %
25	16	0.07 %	0.09 %

Table 1. Standard deviation σ_ε of weighted relative deviations of the calibration result output velocity at pulse frequencies of 6, 16 and 25 Hz.

Copenhagen, January 6, 2020
Head of Calibrations

Søren Frølund Østbirk

References

[1] International standard IEC 61400-12-1:2005 *Wind energy generation systems – Part 12-1: Power performance measurements of electricity producing wind turbines*.

[2] O. F. Hansen, S. O. Hansen and L. Kristensen, *Wind tunnel calibration of cup anemometers*, AWEA Wind Power, Atlanta 2012.