Labor Windkanal/Strömungsmesstechnik

OSTBAYERISCHE TECHNISCHE HOCHSCHULE REGENSBURG

Calibration of a Multi-Hole Probe in Yaw and Pitch for High Spatial Resolution and Investigation of Capability of Turbulence Measurement

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1. Outline

Multi-hole probes (MHPS) are employed for gaining insight into vortex interaction. Thus, high spatial and temporal resolution is required. Due to the non-nulling feature, the orientation of the probe remains fixed and flow properties may be determined up to 360 degrees. The Multi-hole probe is developed for measurements in the outdoor environment for meteorological purposes. Attached to an Unmanned Aerial System (UAS) the probe is designated to close the gap between ground measurement stations and manned aerial systems and is therefore a unique approach to investigate the flow properties in the Atmospheric Boundary Layer (ABL)

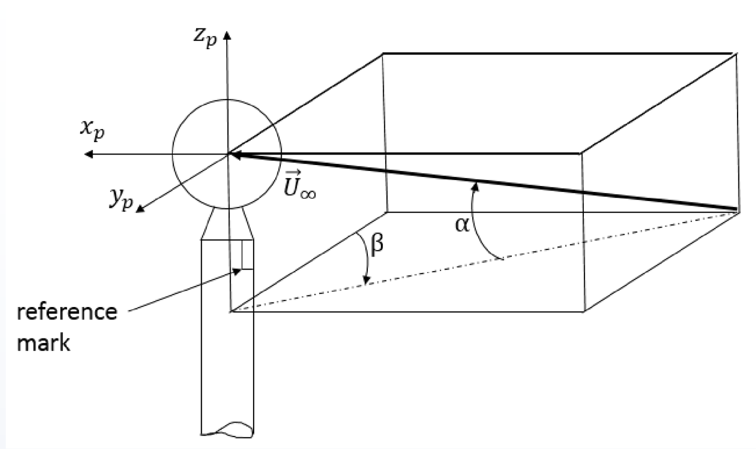

Fig. 1: Description of velocity field vector in the probe fixed coordinate system

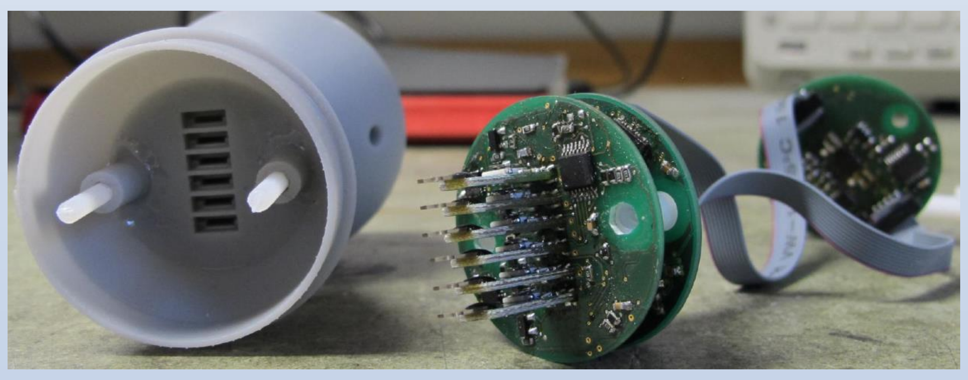

Fig. 2: MHP Geometrical Shell (left) fibre film based sensor elements and PCB (right)

The base body which is produced by rapid prototyping provides six flow channels which are molded in the inner of the sphere. Subtle fiber film based flow sensors can be inserted in the cannel at the base. Due to the measurement principle of Constant Temperature Anemometry (CTA) the Probe is even sensitive to very low velocities

2. Calibration Method

In order to obtain the flow properties from the probe inserted in an unknown flow, a calibration procedure is developed gradually. A third- order polynomial of three variables is applied to determine the flow properties explicitly from the calibration dataset. The initial approach splits the total range of $0° \leq \alpha \leq 45°$ and $0° \leq \beta \leq 180°$ into six subsectos where the polynomial fit is applied.

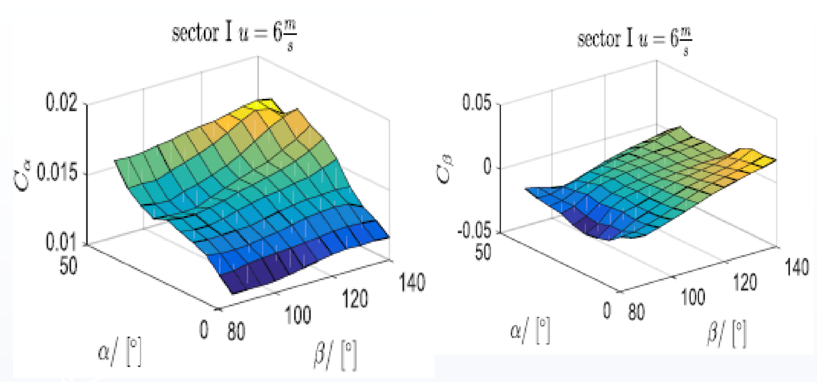

Fig. 3: Dimensionless coefficients defined by port signals of sector I

$$\begin{bmatrix} A_{i,1} \\ A_{i,2} \\ A_{i,3} \\ \vdots \\ A_{i,m} \end{bmatrix} = \begin{bmatrix} 1 & C_{\alpha r,1} & C_{\beta r,1} & C_{M,1} & \dots & C_{\alpha r,1}C_{\beta r,1}C_{M,1} \\ 1 & C_{\alpha r,2} & C_{\beta r,2} & C_{M,2} & \dots & C_{\alpha r,2}C_{\beta r,2}C_{M,2} \\ 1 & C_{\alpha r,3} & C_{\beta r,3} & C_{M,3} & \dots & C_{\alpha r,3}C_{\beta r,3}C_{M,3} \\ \vdots & \vdots & \vdots & \vdots & \ddots & \vdots \\ 1 & C_{\alpha r,m} & C_{\beta r,m} & C_{M,m} & \dots & C_{\alpha r,m}C_{\beta r,m}C_{M,m} \end{bmatrix} \begin{bmatrix} K_{i,1} \\ K_{i,2} \\ K_{i,3} \\ \vdots \\ K_{i,20} \end{bmatrix}$$

Source: [Wörrlein, 1990]

$$A = CK \longrightarrow K = [C^T C]^{-1} C^T A \quad \text{(Pseudolinksinverse*A)}$$

Fig. 4: Matrix formulation of least square fit to data

Equation A=CK represents matrix formulation on the left (Fig.4). Matrix C contains the third-order polynomial of three variables which is defined by the dimensionless coefficients C_α, C_β and C_M. A holds the flow properties. Matrix K contains the desired calibration constants.

For gathering data in wind tunnel experiments, the MHP is attached to an automatic calibration system which allows automated positioning in yaw and pitch. In particular, a dataset in the interval $0° \leq \alpha \leq 45°$ and $0° \leq \beta \leq 180°$ by a step width of 5 degree and the velocity of $4\frac{m}{s} \leq U_\infty \leq 10\frac{m}{s}$ is gathered.

Fig. 4: The RG-15 airfoil in the closed test section of the RWT

3. Turbulence Measurement

Several wind tunnel experiments are carried out to classify the MHP's capability of turbulence measurement. The measurements are additionally carried out with a CTA-based laboratory measurement system from Dantec.

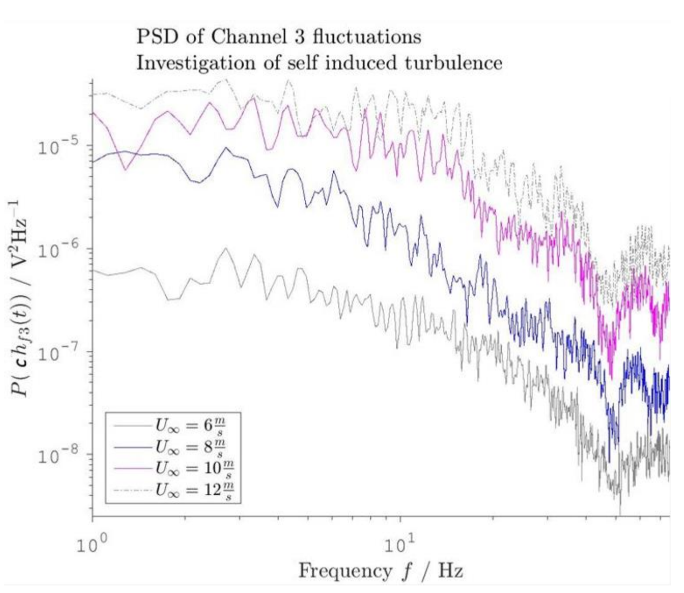

Fig. 6: PSD of turbulent fluctuations measured at different velocities by the MHP

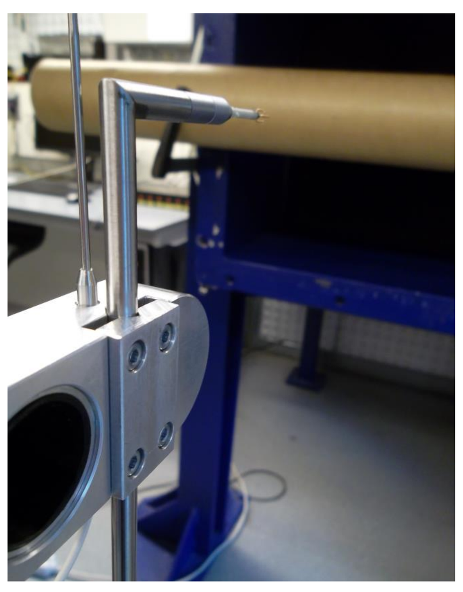

Fig. 5: Dantec reference measurement system placed in the wake of a cylinder (Probe P55R62)

The MHP provides a sampling frequency of approx. 150 Hz. By keeping the Nyquist criterion $f_s = 2f_{max}$, frequencies up to 75 Hz can be investigated.

An experiment where the MHP was placed in the flow field produced by a fan approved the capability of detecting turbulent structures. The results were in good agreement with the measures of the reference system. Different speed levels of the fan were detected. In particular, the frequencies were 8,5 Hz, 11,8 Hz, and 16,7 Hz.

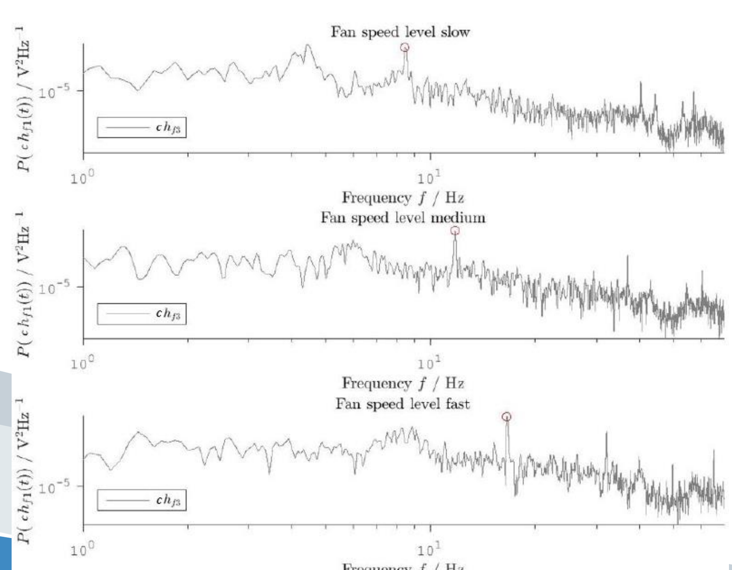

Fig. 7: Detection of turbulent peak frequencies produced by a fan

4. Results and Conclusion

The calibration approach of determining the flow properties was evaluated by calculating the standard errors between the experimental data and the polynomial determination of those data

$$\sigma = \sqrt{\frac{\sum_{i=1}^{I} (\phi_i - \phi_i')^2}{I-1}}.$$

$$\sigma_\alpha = \pm 3,4°$$

$$\sigma_\beta = \pm 2,9°$$

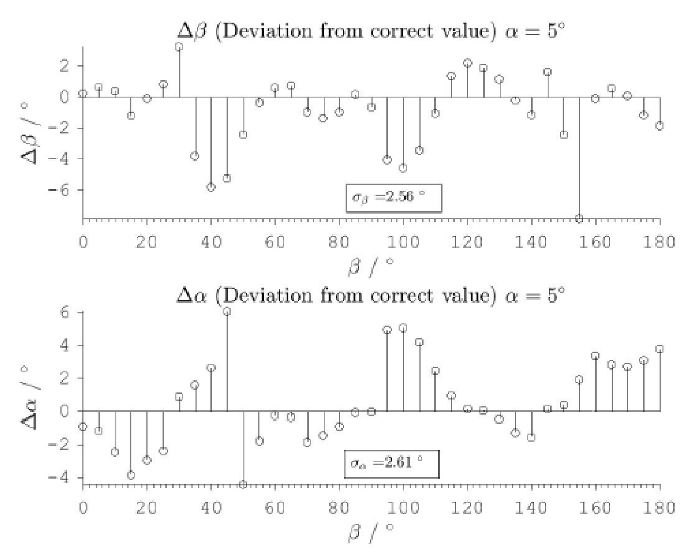

Fig. 8: evaluation of the calibration method. Absolute errors and standard deviations of a dataset

Evaluations show that the standard errors yielded by the method are high. By an absolute error of 13° in α and 9 ° in β the accuracy is not sufficient

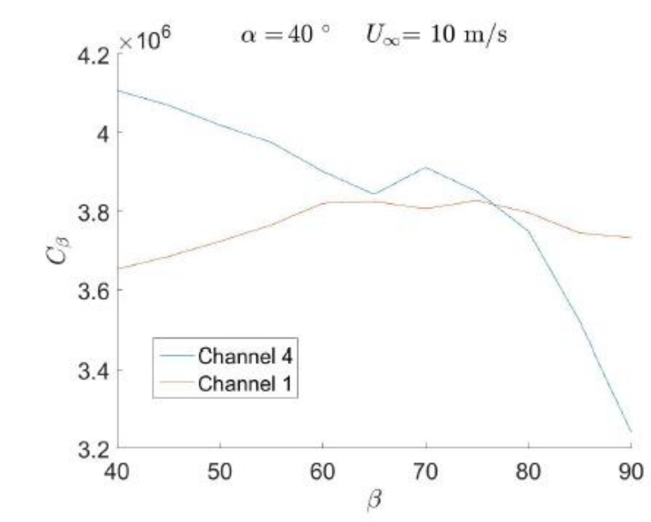

Fig. 10: Rugged signal curve of dimensionless coefficient C_β

Due to the rugged channel signals the dimensionless coefficient are not feasible to provide a high performance of the method. Some methods which may lead to a higher performance are:

- new base body shape with larger channels
- decrease the MHPs total shape especially connection rod
- new approach which employs neuronal networks