AN EFFICIENT CORRECTION FOR THE FINITE-SIZE EFFECTS OF MULTIHOLE PRESSURE PROBES IN VELOCITY GRADIENTS

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Summary This study describes an implementation and verification of an efficient and reliable correction for the finite-size effects of pressure probes in application to highly three-dimensional flows. The correction performance is scrutinized through a detailed side-by-side comparison with corresponding cross hot-wire data, and it is demonstrated that the correction lead to a significant improvement of the measurement results.

INTRODUCTION

Multihole pressure probes are widely used as accurate, robust, and versatile flow-measuring instruments with numerous advantages over other flow measuring devices. Surprising though that a very few experimentalists, which use the multihole pressure probes in strong gradient fields, e.g. traversing wakes or shocks, apply the spatial resolution and downwash velocity corrections. In such situations the spatial resolution errors are unavoidable even for very small probes if the gradients in the flow are strong.

In experiments performed in a low pressure turbine outlet guide vane (OGV) cascade at Chalmers University by Hjärne et al. [1, 2] the five-hole probe measurement data were complemented with the cross hot-wire measurements. During the data analysis it was found that the crossflow velocity components measured by the fivehole pressure probes disagreed with those obtained using the cross hot-wires. Differences between these two measurement data sets were observed in the zones of vane wakes and sidewall boundary layers where velocity gradients are strong. Our subsequent research has revealed that correction by Ligrani et al. [3] is sufficient to compensate for the 5-hole probe errors caused by the velocity gradients. The implementation and verification of the correction is described in the current paper. The efficiency of the obtained correction is scrutinized through detailed side-by-side comparison with corresponding cross hotwire data. To our knowledge, such verification was not performed previously. Our study demonstrates very good efficiency and reliability of the correction, which lead to a significant improvement of the corrected velocity data. A very important fact is that the described correction is not found to over-correct and distort the data and can be used safely.

EXPERIMENTAL SETUP

The experiments were performed in the linear cascade facility at Chalmers University. The cascade is designed and developed in the frame of a longtime research project and used in several years for validation of numerical tools, and for gaining an increased understanding of the detailed aerodynamics around outlet guide vanes (OGVs) including secondary flows and separation margins. This facility operates at realistic Reynolds number range (Re ~ 300,000) and the inlet velocity in the cascade is 20 m/s. The measurements described here were taken in the wake part of the cascade at different streamwise locations downstream of the OGV trailing edge, see papers [1, 2] for more details.

MULTIHOLE PROBE CORRECTION

A finite size of multihole probe leads to the erroneous measurements in flows with spatial gradients. The errors are unavoidable even for very small probes if the spatial gradients are strong. Two error sources are known, see figure below for illustration: (1) the probe is deflecting the incoming streamlines (2) the probe resolution error arises since the probe ports are spatially separated, thus different ports are located in different parts of the flow.

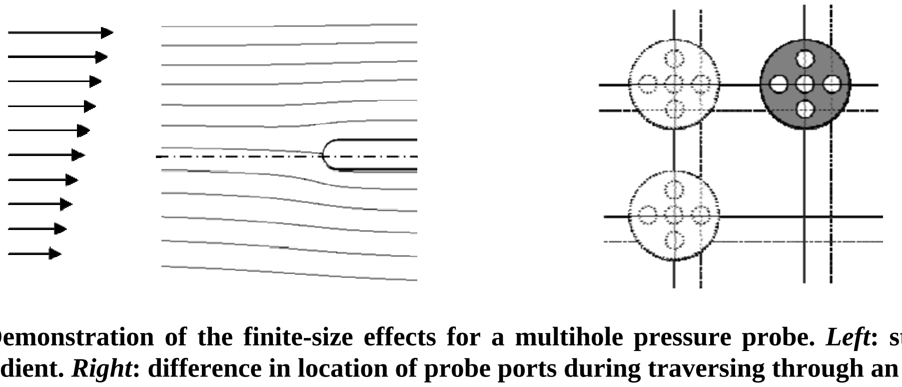

Figure 1. Demonstration of the finite-size effects for a multihole pressure probe. *Left*: steamline deflection in velocity gradient. *Right*: difference in location of probe ports during traversing through an experimental mesh.

The correction procedure consists of two steps. At first it corrects the probe pressures to account for the fact that they are not measured at the same physical location by adjusting pressures from the peripheral ports so that they appear to be measured at the location of the central port. Second step of the correction is applied after the velocity components are derived from the probe pressures, and is based on the idea that the downwash velocity in a particular direction scales with the transverse gradient of streamwise velocity in the same direction. Additional details can be found in paper [4].
The major idea of Ligrani et al. [3] is that the downwash velocity correction along with the spatial resolution correction is sufficient to compensate for the errors of multihole probes in velocity gradients. The verification of this idea is performed in current paper.

EXAMINATION OF CORRECTION PERFORMANCE

The correction performance was examined through a side-by-side comparison of the five-hole pressure probe measurements with corresponding data obtained using the cross hot-wires. Measurement data sets at two different turbulence intensities for different streamwise position planes were analyzed. The influence of the correction on all three velocity components, flow streamlines and streamwise vorticity fields is thoroughly examined, and contribution of each of two correction steps is investigated.
Figure 2 shows typical comparisons between the uncorrected five-hole probe measurements, corrected five-hole probe measurements and the cross hot-wire reference data. For the vertical velocity component, which is depicted here, the uncorrected five-hole probe measurements demonstrate a significant deviation from the reference data in the zone of a vane wake (vertical coordinate *y*=0.28–0.3). Shown data sets demonstrate a remarkably good efficiency of the correction. The correction helps to decrease the data discrepancy drastically and is not found to over-correct and distort the data which means that it can be used safely. The influence of the correction on other two velocity components, flow streamlines and streamwise vorticity fields is thoroughly examined and will be presented as well.

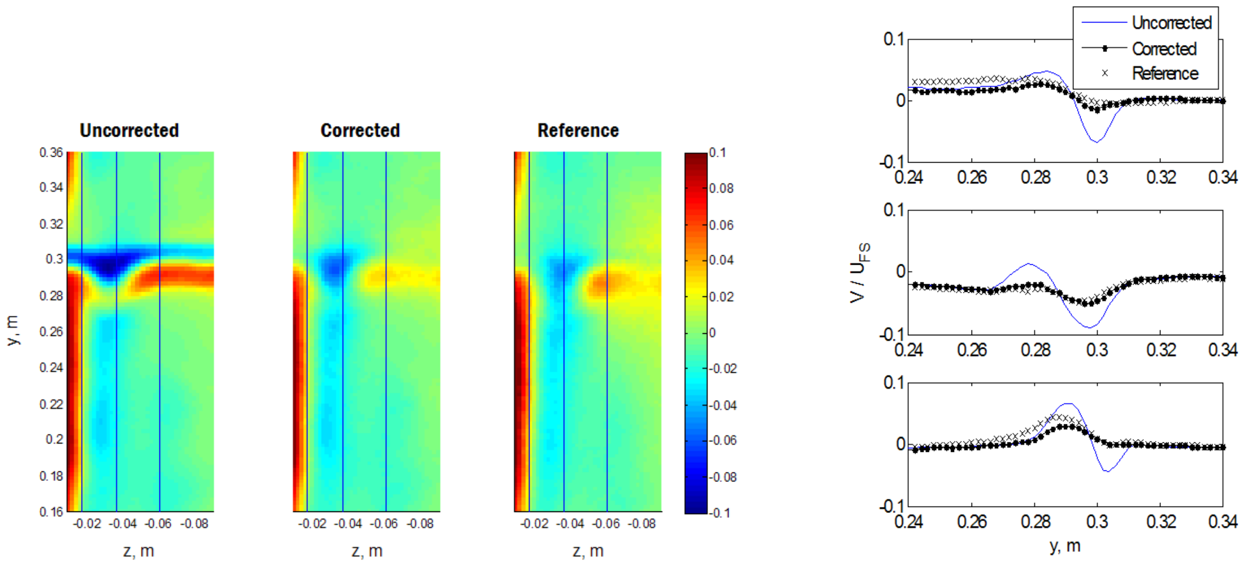

Figure 2. Performance of correction for the vertical velocity component. *Left*: velocity contours showing uncorrected 5-hole probe measurements, corrected 5-hole probe measurements, and cross hot-wire measurements. *Right*: velocity profiles at *z* = -0.016, -0.036, -0.060 m (from top to bottom). The velocities are scaled by the velocity in the free-stream, U_{FS}, which is in the potential core of the flow.

CONCLUSIONS

A very good performance of the correction for the finitesize effects of pressure probes presented in this study allows us to recommend it as a mandatory step in postprocessing procedures for multihole pressure probes.

References

[1] Hjärne, J., Chernoray, V., Larsson, J., Löfdahl, L.: An experimental investigation of secondary flows and loss development downstream of a highly loaded low pressure turbine outlet guide vane cascade, *ASME paper GT2006-90561*, 2006.

[2] Hjärne J., Chernoray V., Larsson J., Löfdahl L.: Numerical Validations of Secondary Flows and Loss Development Downstream of a Highly Loaded Low Pressure Turbine Outlet Guide Vane Cascade, *ASME paper GT2007-27712*, 2007.

[3] Ligrani P.M., Singer B.A., Baun L.R.: Spatial Resolution and Downwash Velocity Corrections for Multiple-Hole Pressure Probes in Complex Flows, *Exp. Fluids*, Vol. 7, pp. 424-426, 1989.

[4] Chernoray V., Hjärne J.: Improving The Accuracy Of Multihole Probe Measurements In Velocity Gradients, *ASME paper GT2008-5049*, 2008.