EFFECT OF MULTI-HOLE PROBE FINITE DIMENSIONS ON PRESSURE MEASUREMENTS IN THE WAKES OF LINEAR BLADE CASCADES

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ABSTRACT

This paper investigates non-local sampling effects in multi-hole pressure probe measurements performed in the wake of a linear blade cascade. Due to the finite spatial separation of pressure taps, measured differential pressures are influenced by local velocity gradients, leading to systematic errors in shear-flow regions. A post-processing correction method based on a virtual shift of the effective pressure tap locations is proposed. The approach employs spline-based reconstruction of the pressure field together with gradient- and curvature-based masking to identify regions requiring correction. The results demonstrate a reduction of artificial oscillations in the wake region and improved consistency of the pressure distribution.

INTRODUCTION

Multi-hole pressure probes [1, 2, 3] are widely used for flow-field investigations in turbomachinery. A persistent issue is the non-local nature of the measurement: because individual pressure taps are physically separated, each samples the flow at a slightly different location. In a shear flow with strong velocity gradients, this causes the measured pressures to no longer correspond to a single point, introducing systematic errors in the evaluated flow quantities [4, 5, 6].

Reducing probe dimensions improves spatial resolution as reported in [7]. Post-processing corrections offer an alternative: local velocity gradients can be used directly [8, 9].

A further method virtually shifts the pressure tap positions within the probe head to account for their spatial separation, relying on simultaneous absolute pressure measurement at all taps. This paper investigates the influence of non-local measurements obtained with a four-hole needle probe at the outlet of a linear blade cascade. Although the directional taps are nominally placed symmetrically relative to the velocity gradient, small non-physical variations in the measured pressure difference still occur, arising from the finite tap dimensions over which pressure is spatially integrated.

EXPERIMENTAL SETUP AND METHOD

Experiments were performed in the VZLU Laboratory of High-Speed Aerodynamics, in a low-pressure closed-loop wind tunnel allowing independent control of Mach and Reynolds numbers. Two linear blade cascades, differing only in trailing-edge radius (0.4 mm and 0.8 mm) to produce different velocity gradients, were tested; each consisted of 13 blades with pitch-to-chord ratio $t/c = 0.65$, chord $c = 50$ mm and blade height 100 mm. Measurements were taken with a four-hole needle pressure probe: a central total-pressure tap surrounded by two inclined directional taps ($35°$), plus a separate static tap on a conical tip section. Tests were run at constant $\mathrm{Re}_{2,\mathrm{is}} = 5 \times 10^5$ and $\mathrm{M}_{2,\mathrm{is}} = 0.5$, with no shock waves present.

Since the virtual-shift method alone proved insufficient, a combined, gradient-masked variant was adopted. The pressure distribution is measured across the cascade pitch and interpolated (cubic spline) to the exact tap locations, and the first and second spatial derivatives of the total pressure are computed and normalized by their maxima. Wherever these normalized derivatives exceed prescribed thresholds, the differential pressure is recalculated from the spline using the true tap separation; elsewhere, the original signal is retained, producing a piecewise-corrected signal that blends smoothly between corrected and uncorrected regions.

RESULTS AND DISCUSSION

The configuration with the smaller trailing-edge radius (0.4 mm) shows lower pressure losses but steeper pressure gradients than the 0.8 mm case, as seen in the normalized stagnation-pressure and gradient distributions (Figure 1, top row). The absolute pressures p_2 and p_3 (bottom-left) are not identical between taps; this stems mainly from small residual probe misalignment and minor manufacturing asymmetry, both of which remain within the probe's calibration range and are therefore not a significant source of error, provided the probe is not operated in nulled mode.

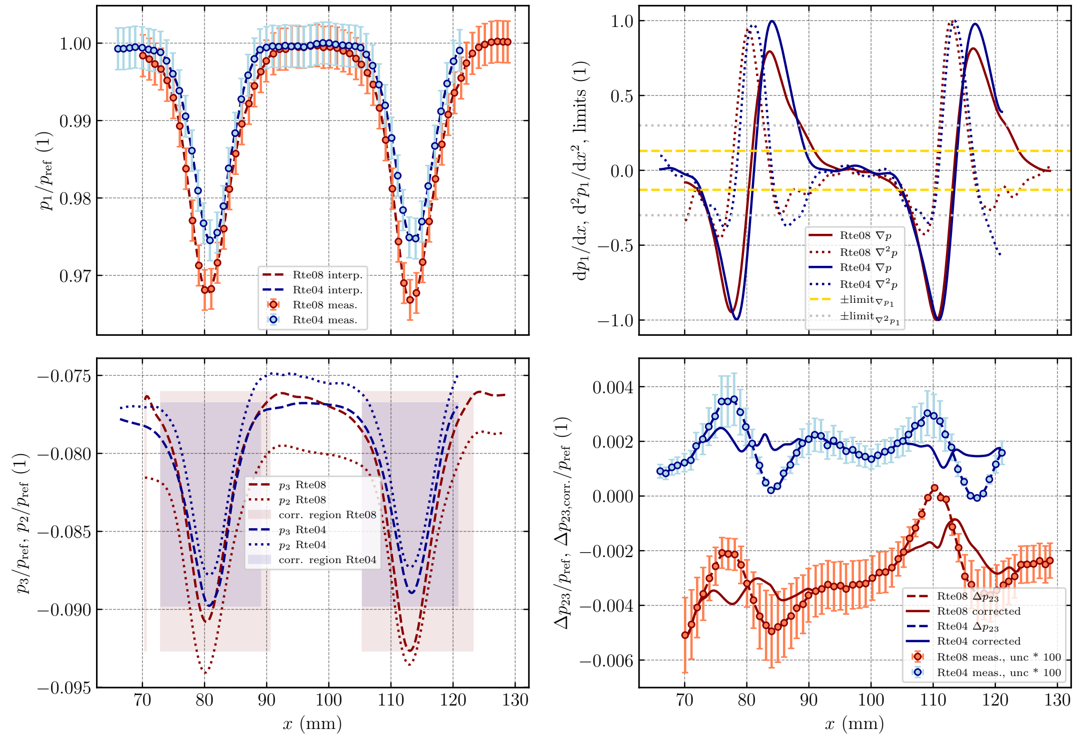

Figure 1: Correction of the measured pressure difference.

The corrected differential pressure Δp_{23} (bottom-right, solid lines) shows a clear reduction in the spurious oscillations present in the raw signal (dashed lines) within the wake region, for both cascade configurations. Some residual artefacts remain, attributable to two effects: first, the finite tap area integrates pressure over a region, so the effective sensing location depends on the local velocity-profile shape, whereas this study assumes a constant shift; second, the cubic-spline reconstruction itself can introduce oscillations in regions where it is not well suited to the data, despite its implementation simplicity.

CONCLUSIONS

Non-local sampling effects in multi-hole probe measurements downstream of a linear blade cascade were examined, showing that residual inconsistencies in the differential-pressure signal can persist after standard calibration, due to the finite separation of pressure taps in regions of strong velocity gradient. A virtual-shift correction combining spline-based field reconstruction with gradient and curvature masking was proposed and shown to reduce unphysical oscillations and improve the smoothness of the reconstructed pressure distribution. Remaining discrepancies are attributed to finite tap-area averaging and spline-related interpolation artefacts. Future work will incorporate the local pressure-gradient shape directly into the correction and explore improved interpolation strategies for sparse experimental data.

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