Characteristics of large volume tomographic particle image velocimetry using helium filled soap bubbles in forced and thermal convection

Matthias Kühn¹, Klaus Ehrenfried¹, Johannes Bosbach¹, Claus Wagner¹

1: Institute of Aerodynamics and Flow Technology, German Aerospace Center (DLR), Germany, matthias.kuehn@dlr.de

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The characteristics of large-scale tomographic PIV (Kühn et al. 2009) in thick measurement volumes are investigated. With increasing thickness of the measurement volume the number of illuminated particles outside the measurement volume, which are not seen by all cameras, increases. However, the complete projected intensity needs to be back projected in the reconstruction process. This situation is illustrated in Fig. 1. Conducting advanced numerical simulations of a tomographic PIV experiment the influence on the accuracy was investigated. It was found that the complete projected intensity outside the reconstructed measurement volume is back projected as ghost particles. If the displacement gradient in volume depth direction is sufficiently high the influence of ghost particles vanishes (Elsinga et al. 2009). Under this circumstances illuminated particles outside the measurement volume, which are not seen by all cameras, do not have a systematic influence on the measurement accuracy.

With increasing thickness of the measurement volume a much larger amount of data needs to be processed. Beside run-time optimized tomographic PIV algorithms a parallel version of these routines becomes necessary. In this course an implementation of the recently proposed simultaneous multiplicative algebraic reconstruction algorithm by Atkinson and Soria (2009) for tomographic PIV is discussed and validated for large-scale tomographic PIV. Finally, a concept to process the parallelized tomographic PIV routines on a high performance computer cluster is introduced.

Finally, the large-scale tomographic PIV system is applied to forced and thermal convection in a long rectangular convection cell. Large-scale structures in forced convection at Reynolds numbers Re of 345, 530 and 800 as well as thermal convection at the same Reynolds numbers at a Rayleigh number Ra = 1.65 \times 10^8 are investigated.

The measurement of forced convection reveals an almost two-dimensional roll-structure in cell length direction in the mean flow field. However, the mean core line of this roll shows a wavy shape with a wavelength corresponding to the height of the cell. Furthermore, the amplitude in height direction is larger compared to the amplitude in depth direction. If the heating plate is turned on additionally, the global structure of the flow field changes significantly. At the two higher Reynolds numbers the roll structure can still be detected. However, at the lowest Reynolds number four counter-rotating convection rolls are formed (Fig. 2). The orientation of these rolls is expected to be shaped like a “W” in the X-Z plane as illustrated in Fig. 3.

Fig. 1 Illustration of the effect of illuminated particles outside the measurement volume, which are not seen by all cameras. a – light sheet, b – measurement volume, c – area not seen by all cameras, d – back projected area of illuminated particles outside measurement volume.

Fig. 2 Mean flow field of thermal convection at Re = 345 and Ra = 1.65 \times 10^8. Flow field is visualized by iso-surfaces and contour plots of velocity magnitude. A corresponds to path of supplied air jets mixed with hot rising fluid, B to area of hot rising fluid and C to counter-rotating convection rolls.

Fig. 3 Sketch of expected orientation of the four counter-rotating convection rolls in X-Z plane. * corresponds to hot rising fluid and × to falling fluid. Yellow box indicates the size and position of the measurement volume. The arrows at the lower border (Z = 0 mm) indicate the air flow in and out of the convection cell.

References

