WP 4 update (Bertrand Lecordier - CORIA)

Coupling PIV with complementary diagnostic methods is the only approach enabling to extend measurement capabilities to problems that involve both the fluid flow process and other thermo-chemical, acoustic or structural interactions. This requires a skilful combination of PIV with other diagnostics, which success strongly depends upon the nature of such combinations (i.e. optical/electronic interference, ensuring simultaneous and compatible outputs). The interpretation of inhomogeneous experimental data also requires developing proper post-processing and visualizing techniques, which are almost non-existent to date.

In WP4, combination of PIV with different diagnostics in various configurations at laboratory-scale is demonstrated to bring new knowledge in terms of technical difficulties and potential interests for future uses in industrial configurations for aeronautic. Experiments in combustion facilities will verify the feasibility to integrate and simultaneously operate PIV and spectroscopic imaging methods such as laser induced incandescence (LII) or planar laser induced fluorescence (PLIF) for correlated flow diagnostics in combustors (T4.1). The combination of TR-PIV and microphones is intended to provide the basis for aero-acoustic analysis of aerodynamic systems (T4.2). Finally the field of flow induced vibrations and aero-elasticity will be covered by setting up a combined measurement technique based on TR- PIV and IPCT for non-linear aero-elastic interactions in subsonic flows (T4.3).

T4.1 **Flow, species and temperature mapping by PIV, PLIF and LII for combustion diagnostics (CNRS-CORIA/LML/PC2A – DLR –IOT)**

The main goal of that task for CORIA, is to demonstrate the combination of double-pulse OH fluorescence imaging and PIV to investigate turbulent flame, and especially flame stabilisation processes. The first stage of this work was devoted to the achievement of the burner and the combination of the optical diagnostics. In collaboration with LML and PC2A partners, but also researchers in computer simulation, CORIA has taken in charge the design and manufacture of the burner (cf. Figure 4.1). The burner is now operating in CORIA laboratory, where the qualification tests (burner/seeder/flow control) have been successfully completed in September 2012. Next, the selection and the validations of operating conditions have been considered in collaboration with LML and PC2A and the optical arrangement of the SPIV technique and double-pulsed OH fluorescence techniques have been installed. Two PIV cameras placed at 45° are combined with two ICCD cameras (Figure 4.1). For the double-pulsed OH fluorescence imaging technique, two dye-laser at 284 nm have been combined and associated with a 400 mJ PIV laser. Mid-November 2012, all the optical arrangement and experimental are operational and the first test campaign of two months is started.

In PC2A laboratory, in collaboration with LML and CORIA, the combination of laser induced incandescence (LII) and PIV in a jet flame configuration is demonstrated in order to obtain simultaneous measurements of velocity and soot volume fraction fields. For the preliminary tests a jet flame burner provided by CORIA has been set-up at Lille (PC2A lab). Laser sheets for PIV and LII were combined using appropriate optics leading to coincident laser sheets of around 6 cm in height. Figure 4.2 shows the complete set-up combining the two laser techniques. For different mixtures of methane, propane and/or ethylene, the LII and the PIV set-up have been separately tested and validated in that configuration. The LII has been first tested at 1064 nm to prevent any perturbation from PAH LIF occurring under visible or UV excitation and next to 532 nm. It has been shown that each diagnostics provide reliable measurements in our conditions. From September 2012, the work has been focused on the simultaneous LII and PIV measurements in order to evaluate any interference between diagnostics and ensure that the linear relationship between LII signal and soot volume fraction is conserved when PIV is used simultaneously. In 2013, the test campaign of combined LII/SPIV techniques on the burner of CORIA will start to obtain the instantaneous measurement of the soot and velocity fields in turbulent flame.

Figure 4.1 – Configuration set-up of SPIV and double-pulsed OH fluorescence technique on the burner at CORIA laboratory (CNRS PC2A/LML/CORIA)

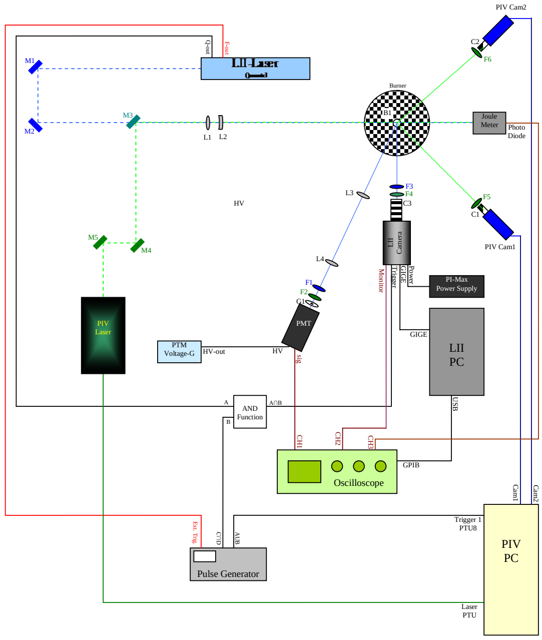

Figure 4.2 - Complete set-up of combined LII and PIV measurements (CNRS PC2A/LML/CORIA)

The combination of OH-Temperature PLIF [1] with simultaneous PIV and other imaging diagnostics is part of an on-going DLR internal project as well as AFDAR Task 4.1.3. The aim is to eventually provide near wall data of turbulent combustion inside a pressurized combustor at flight relevant conditions. Preliminary tests on a laboratory scale combustor (Figure 4.3, left) were aimed at optimizing the PIV imaging such that the flow issuing from 0.5 mm diameter effusion cooling holes could be properly resolved. Figure 4.3, right shows an averaged velocity field obtained with 2-C PIV. The minimum distance at which reliable velocity could be obtained was about x=0.5 mm from the wall and is a direct result of strong laser flare arising from the laser light sheet impinging directly on the steel combustor liner wall.

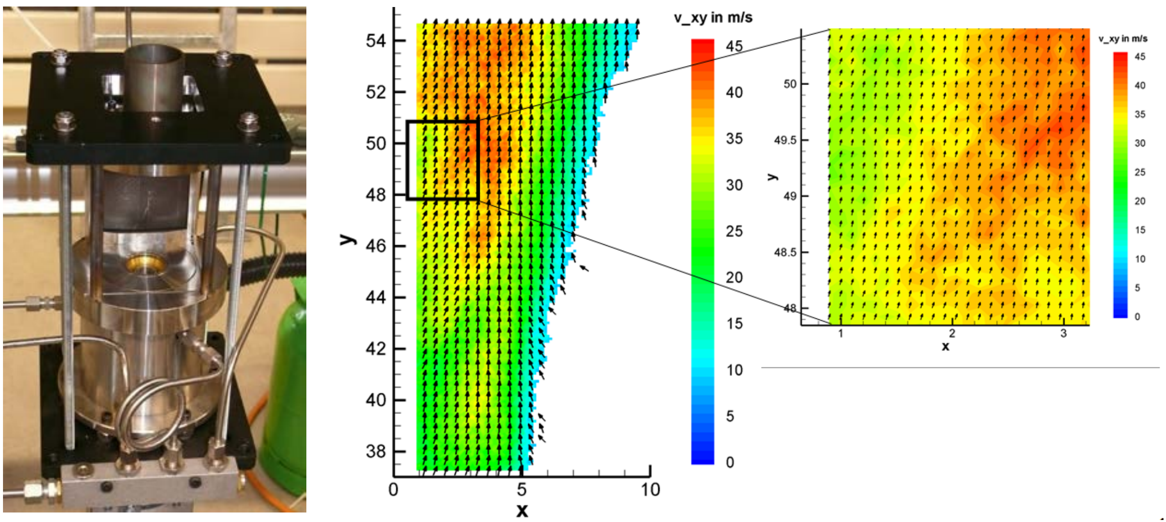

Figure 4.3 Lab-scale gas-film swirl burner with effusion cooled wall (left). Near wall PIV measurements obtained with reacting flow (middle, right). Vector spacing on the right is 0.1 mm.

In a second step both OH-Temperature PLIF and 2-C PIV measurements were performed in a pressurized facility operated with a kerosene air-blast swirl burner, to characterize both the global flow and temperature field. Figure 4.4 shows a first result of simultaneous single shot PIV/ OH-T-PLIF measurements in a plane perpendicular to the cooled wall along a row of effusion cooling holes. Based on the superimposed presentation of results of both simultaneous measurements the intricate structure of the cooling film and the reaction zone is visualized.

At IOT, a strongly swirling propane-air lifted turbulent flame has been investigated by stereoscopic PIV and by short-exposure CH* imaging. Response of the open turbulent flame to a high-amplitude periodical forcing was also investigated. According to PIV and chemiluminescence data, the forcing resulted in a suppression of vortex core precession and increased overall combustion rate near the burner exit. Based on Proper Orthogonal Decomposition analysis it was concluded that the effects were provided by forced formation of large-scale vortices in shear layers and by periodical vanishing of the central recirculation zone. Mid-2012, stereoscopic PIV measurements in premixed propane-air and methane-air swirling flames were performed by using a high-repetition system (running at 0.8 kHz). The objective was to relate type of vortex breakdown in the flow with combustion regimes. Shape of the flame, the mean flow structure and dynamics of large-scale helical vortices were analysed. Dynamics and scales of vortices were investigated by means of Dynamics Mode Decomposition, and the flame front was visualized by short-exposure registration of chemiluminescence signal. The results confirm previous conclusions made from POD analysis for the lifted regimes that the flow dynamics was determined both by precession of the vortex core (see Figure) and by unsteady entrainment of the ambient air.

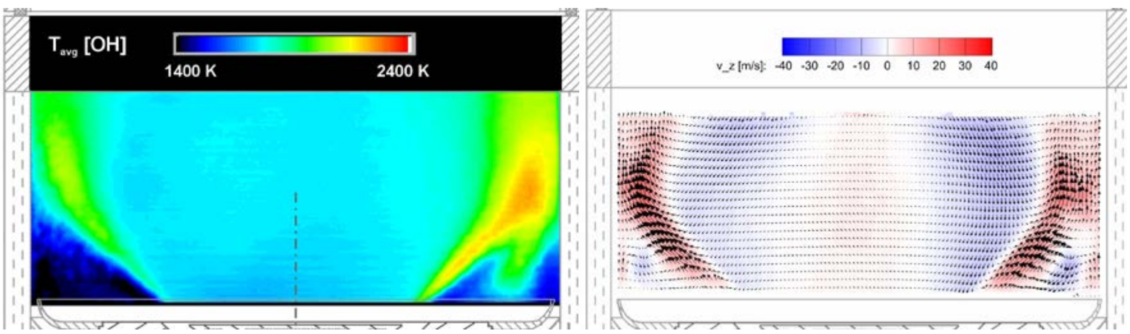

Figure 2.4 - Averaged temperature field (left) and flow field (right) inside a pressurized combustor operated at 5 bar obtained with OH-T-PLIF and PIV respectively

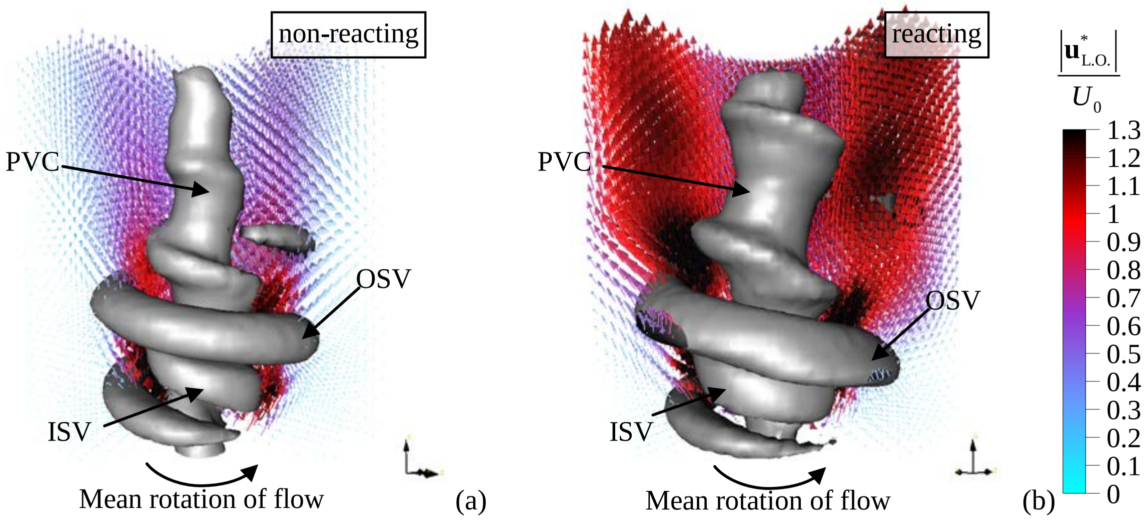

Figure 4.5 - Visualization of coherent structures (precessing vortex core, PVC, and inner and outer secondary vortices, ISV and OSV), extracted from POD modes for a strongly swirling (a) non-reacting jet and (b) lifted propane-air flame.

T4.2 Combined PIV and acoustic measurements for noise source identification

In 2011 the focus for TUD and NLR was on finding the ideal experimental configuration that will allow us to achieve our goal: demonstrate the feasibility of broadband noise prediction based on PIV measurements. Some exploratory measurements for potential were carried out by hotwire and it was decided that the measurements will be carried out at the trailing edge of flat plate, immersed in a flow at zero degrees angle of attack. NLR have carried out acoustic measurements on the flat plate configuration in the KAT using an acoustic array.

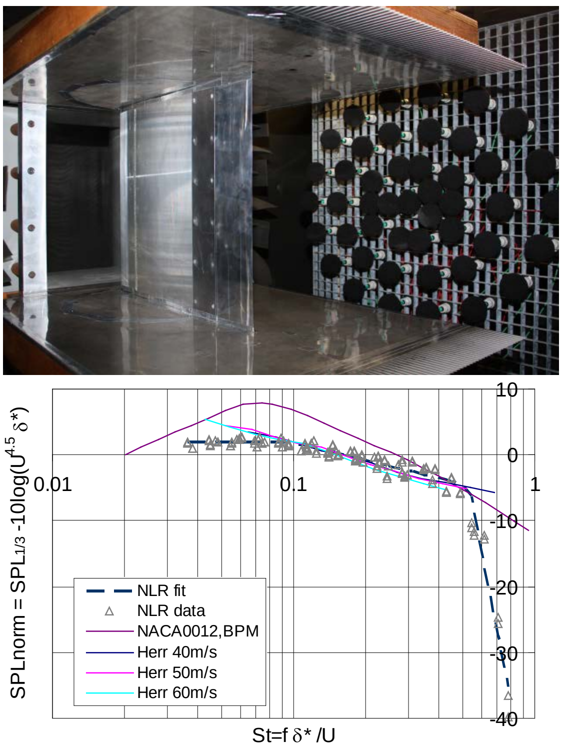

Figure 4.6 – Left: Flat plate configuration in NLR's small anechoic tunnel; Right: Normalized measured spectra compare with flat plate measurements by Herr

The measurements, also presented at the AFDAR PIV in Aeroacoustics workshop, were carried out for 15m/s, 20m/s and 30m/s as defined above. As a backup, measurements were carried out a higher velocity (up to 70m/s) so that an acoustic spectrum can be acquired at lower velocities by scaling laws. The measurements showed good signal to noise ratio and compared well with what is found in literature.

TUD has carried out tomographic PIV measurements on the flat plate configuration at 15m/s and 20m/s. Preliminary results were presented at the AFDAR PIV in Aeroacoustics workshop. Two measurement volumes were considered: 1.5x0.5x3.5d (lxhxw) and 0.3x1.5x3.5d (lxhxw). Preliminary processing showed good quality of the results.

The VKI started their assessment of the use of Green's function with incompressible flow data based on numerical calculations (LES) on an airfoil.

This work will be on-going for the duration of the task and support noise prediction strategies based on PIV measurements. Three databases are made available to the partners in task 4.2:

- Tomographic PIV measurements (TUD)
- Acoustic measurements (NLR)
- Numerical calculations on an airfoil (VKI)

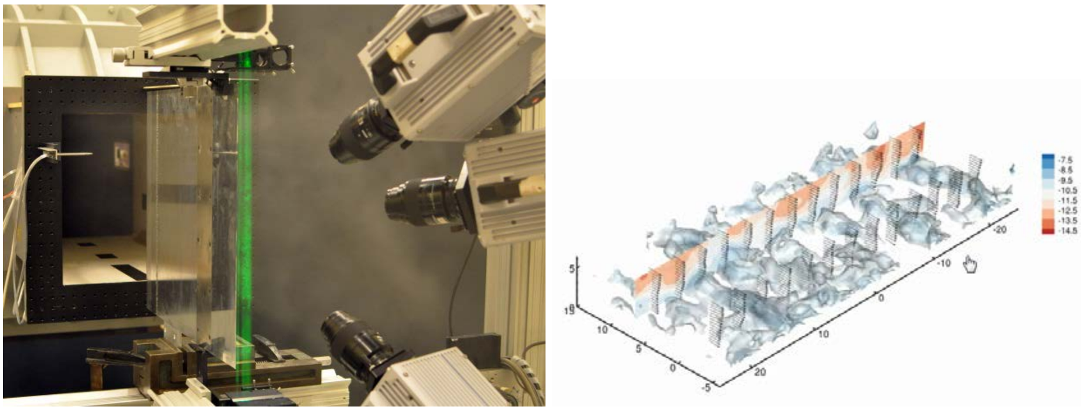

Figure 4.7 - Left: Flat plate configuration at W-Tunnel TUD; Right: Instantaneous tomographic recording

T4.3 Combined time-resolved PIV and structure deformation measurements for aero-elastic investigations (DLR)

Experimental investigations of passive and active aero-elastic phenomena for wings still represent great challenges and the aspects such as the control of aerodynamic forces and aircraft stability needs reliable and time-resolved data. A generic flow-structure-interaction experiment using a thin plate forced to aeroelastic flutter in a low speed wind tunnel has been performed by using synchronous High-speed PIV and –IPCT. The acquired time-resolved flow field- and surface deformation data enables solving the respective aero-elastic triangle of forces in which aerodynamic-, inertia- and elastic- forces are governing the coupled flutter dynamics. The achieved data-set is also useful for computational code validation aiming in coupling CFD and CSM-codes in subsonic flows.

In month 12 (November/December 2011) the a.m. experiment has been performed in the 1m-wind tunnel of the DLR in Göttingen using different thin plates (thicknesses between 0.05 and 0.3 mm) with 150 mm span and 75 mm (free) chord length fixed on the downstream side of a flat plate with 300mm chord length and an elliptical leading edge (see Figure 1 and 2). The main forcing events from the assumed 2D-flow dynamics which are based on a coupling of the eigenfrequencies of the thin plate (~30-80 Hz) and the (finally forced) Kelvin-Helmholtz-waves formed in the shear layer of separated flow are well resolved for the used free stream velocities between U = 3 m/s and 12 m/s. Two glass end plates on the lateral sides of the thin plates (with a small gap of ~0.4 mm) inhibit a 3D-flow exchange at the plate side ends.

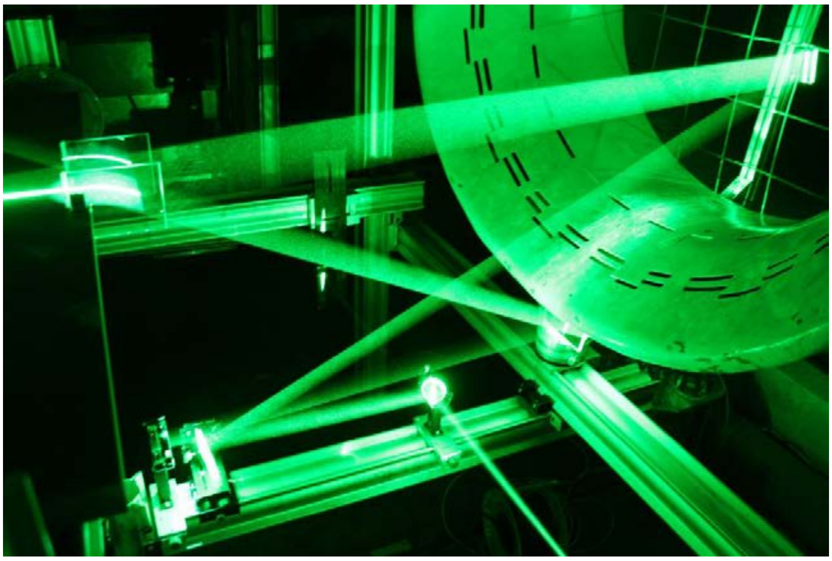

Figure 4.8: HighSpeed PIV (5 kHz) laser light-sheet splitting and thin plate under aero-elastic forces (upper left) at 1m-WT of DLR in Göttingen (flow from left to right).

The used high-speed IPCT system consists of two Photron SA1.1 CMOS cameras in Scheimpflug mounts and two LED pulse light illuminators developed at DLR. The two LED light sources illuminated a random pattern of small white paint dots on one side of the thin plate surface with 12 µs per pulse at 2.5 kHz which has been imaged by the two Photron SA1.1 cameras at 1024 x 544 pixel and according frame rate in stereo viewing (see Figure 2). The cameras were equipped with f = 60 mm Zeiss lenses imaging at f# = 5.6 in order to expand the depth of focus to the largest possible amplitudes of the oscillating plate. A two-plane calibration target has been imaged within the measurement volume for calculating a function for all possible lines-of-sight of the two IPCT cameras. This function enables a local triangulation of the found dot-correspondences from both camera viewings, which have been estimated by using an initial mapping of the surface dot pattern image and a successive iterative 2D cross-correlation scheme (similar to a PIV evaluation).

Both systems ran simultaneously so that a time-resolved series of 2C velocity vector fields at 5 kHz and surface deformation fields at 2.5 kHz as shown exemplary in Figure 3 can serve as a basis for further calculations of the involved unsteady forces. The inertia forces will be calculated by the measured acceleration of the plate surface e.g. by a central difference operator and by using the corresponding mass elements of the plate. The elastic forces can be calculated by the measured deflection of the surface and using the E-module with an analytical model of the plate stiffness (setting the known parameters of the steel material) or by using an experimental calibration procedure. The estimation of the unsteady aerodynamic forces on the plate surfaces rely on the assumption of a 2D- flow and can be realized by integrating the Poisson equation for each time step and extend the related pressure fields close to the plate surface along the span of the plate.

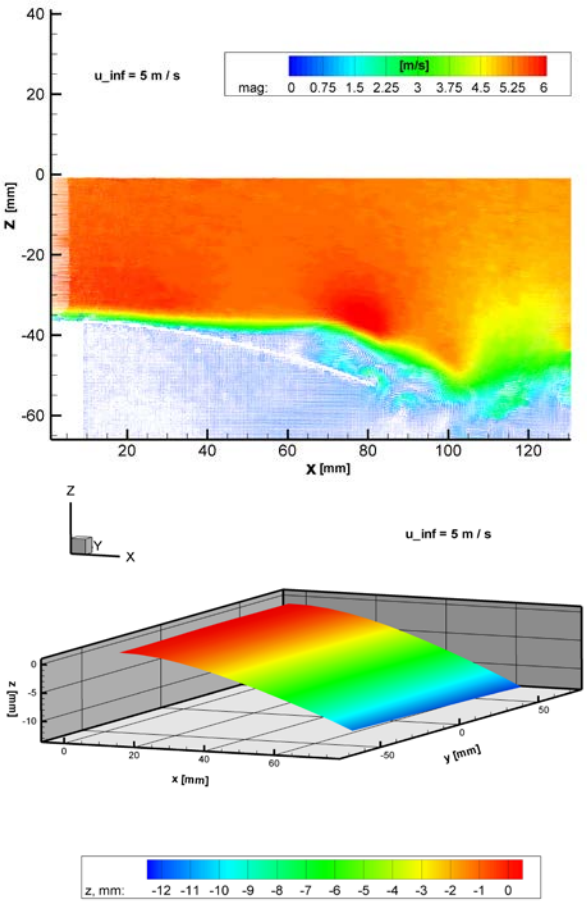

Figure 4.9: Results of the HS-PIV (left) and HS-IPCT (right) measurement at the thin plate under aero-elastic forces at U = 5 m/s and at one time instant of the plate in flutter

Relevant publications:

[1] Heinze J., Meier U, Behrendt T, Willert C, Geigle K-P, Lammel O, Lueckerath R (2011) *PLIF thermometry based on measurements of absolute concentrations of the OH radical.* Zeitschrift f. Physikalische Chemie, 225 (11-12), pp. 1315-1341. DOI: 10.1524/zpch.2011.0168.

[2] Lange L, Heinze J, Schroll M, Doll U, Voges M, Fischer M, Stockhausen G, Willert C (2012) *Combination of Planar Laser Optical Measurement Techniques for the Investigation of Pre-mixed Lean Combustion*. 16th International Symposium on Applications of Laser Techniques to Fluid Mechanics, 09-12 July 2012, Lisbon, Portugal.

[3] Pröbsting S, Scarano F, Bernardini M, Pirozzoli S (2012) A comparative study of turbulent boundary layer wall pressure fluctuations obtained from high-speed tomographic PIV and DNS, 16th Int Symp on Applications of Laser Techniques to Fluid Mechanics