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Particle Image Velocimetry as Validation Tool in Aeronautics

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ABSTRACT

PIV is an advanced optical measurement technique which allows measuring large numbers of instantaneous velocity vector fields in a plane or volume of a flow with high spatial resolution and within short wind tunnel run times. From these velocity fields it is possible to calculate averages and related RMS- and fluctuation velocity fields, vorticity and other derivatives or products of fluid mechanical significance. PIV data are therefore well suited for validation of numerical codes. In several aeronautical research projects CFD, PIV and other experimental measurement techniques have been used jointly in order to capture a more holistic image of the complex flows e.g. around high-lift-configurations (EUROLIFT 2), behind TPS- (CRUF) or propeller flows (HICON). In the presentation we will show some examples of interactions between numerical and experimental investigations where experimental data served either for a comparison with, a validation of or as input for CFD or CAA calculations. As an outlook for future cooperation of simulation tools and velocity measurements a most recent development of the PIV technique, which delivers instantaneous 3D velocity vector volumes and therefore the full velocity gradient tensor, will be explained and demonstrated at a turbulent boundary layer.

As a first example, a joint experimental and numerical study on the characterisation of shear flow mixing and turbulence in the flow behind a CRUF- (counter rotating ultrahigh-bypass fan)-TPS (turbine power simulator) performed at DLR will be described briefly. This investigation engrosses the understanding of separated and mixing flows, enables a direct comparison of both methods and provides data for the validation of the DLR own numerical code *Tau*. Stereo PIV measurements with very high spatial resolution have been carried out at the low speed wind tunnel of DNW-NWB by using two 11 megapixels *PCO4000* cameras and a high power Nd-YAG double pulse laser with 380 mJ per pulse output energy. A forward scattering Stereo PIV set-up was used in a plane perpendicular to the main flow and x = 450 mm downstream of the CRUF-TPS core trailing-edge in order to measure all three components of a large number of instantaneous velocity vector fields in a region of 330 x 410 mm² for many different flow and TPS conditions. A second SPIV set-up was realized in order to measure the velocity fields in a plane parallel to the main flow depicturing the shear layer developments between free stream, fan flow, and core flow between x = 20 and x = 370 mm downstream of the CRUF trailing-edge for the same flow parameter matrix. For all cases both, a phase-locked triggering to a fixed fan blade position and a random triggering of the PIV system have been applied. This enables analysing the differences between periodic and non-periodic effects of the turbulence mixing in the shear layers. For evaluation of the PIV images an iterative multi-grid cross-correlation scheme with image deformation has been applied with 32 x 32 pixels² final

window resolution leading to instantaneous velocity vector fields with more than 50000 3C-vectors each. A number of 1000 double images have been acquired per case for reaching convergence of the averages and *rms*-values.

For some cases, CFD calculations of the CRUF flow have been conducted by using the DLR own *Tau*-code. The focus of investigation was clarifying the influences of grid resolution, dissipation rate, grid geometries (tetra-/hexagonal) and different turbulence models. The turbulence models Spalart-Allmaras and Menter SST have been used in a first step. The Menter SST model shows good results including the prediction of separated flow appearing at the strut and half wing geometry faced to the nacelle as measured experimentally, but concerning the calculation itself, convergence problems appear regarding density residuals and unsteady effects. The turbulence models MenterBaseline, RSM and k-Omega have been checked providing similar results, while MenterBaseline shows the best prediction for the mass flow at the core outlet. An analysis of the different influences on the calculated flow field and a comparison with the experimental results has been performed.

The experimental and numerical results obtained by SPIV and 5-hole-probe-rakes on one side and *Tau*-code simulations on the other provide a valuable data-set for a direct comparison of the various flow features of the CRUF-TPS flows. Especially the SPIV data give detailed insights into the flow structures and can be used as a basis for the validation of turbulence models. As an example, the results of a Stereo PIV measurement averaged over 1000 instantaneous samples and of a *Tau*-code simulation using Menter SST both for Ma = 0.19 and 7400 rpm pictured in a plane perpendicular to mean flow direction and downstream of the CRUF-TPS is shown in Figure 1.

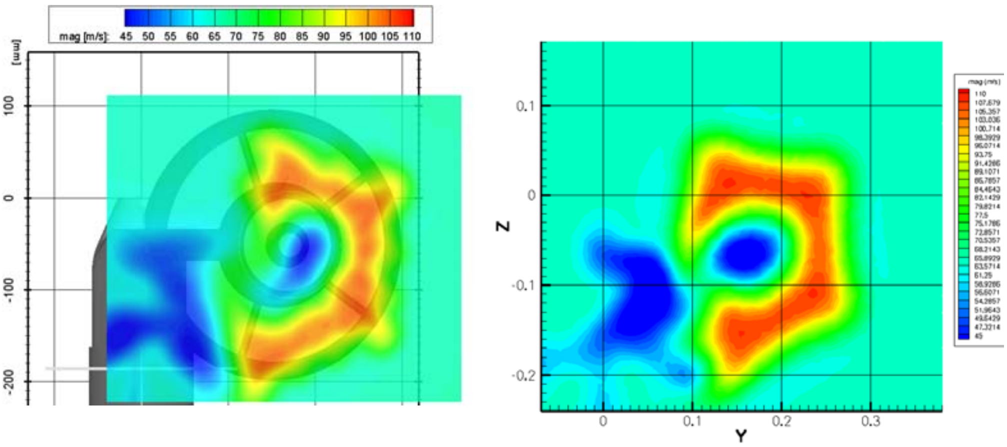

Figure 1: Averaged 3C velocity vector field measured by Stereo PIV in DNW-NWB (left) and result of a Tau-code calculation with SST-Menter model (right) pictured in a plane perpendicular to the main flow and at x = 450 mm downstream of the trailing-edge of the CRUF-TPS at Ma = 0.19 and 7400 rpm.

As most aerodynamically relevant flows under consideration for validation of numerical simulations are unsteady and therefore three-dimensional, a new PIV development for measuring full 3D-and 3C velocity vector volumes will be of major interest for future wind tunnel applications: Tomographic Particle Image Velocimetry is a 3D PIV technique based on the illumination, recording, reconstruction and analysis of tracer particle displacements within a three-dimensional measurement volume in a flow. The technique makes use of several simultaneous views of the illuminated particles, typically four, and their three-dimensional reconstruction as a light intensity distribution by means of algebraic tomography. The reconstructed tomogram pair is then analyzed by means of 3D cross-correlation with an iterative multigrid volume deformation technique, returning the three-component velocity vector distribution over the measurement volume. The implementation of the tomographic technique in time-resolved mode by means of high-repetition rate PIV hardware has the capability to yield 4D velocity information. As a result the fully (time-dependent) instantaneous velocity gradient tensor is available.