Developments for industrial PIV

A. Schröder, J. Agocs, R. Geisler, A. Heider, C. Politz, F. Boden, R. Konrath, E. Roosenboom, C. Willert, J. Kompenhans,


DLR Göttingen

Deutsches Zentrum für Luft- und Raumfahrt
Institut für Aerodynamik und Strömungstechnik
Experimentelle Verfahren
My first and last photo PIV experiment in a wind tunnel

Double-exposure photo-PIV on a cylinder-wake
(diploma thesis 1995)
Here with new PivView evaluation
Development towards advanced PIV systems

Components of the velocity gradient tensor

\[
\frac{d\mathbf{u}(x,y)}{d\mathbf{x}} = \begin{bmatrix}
\frac{\partial U}{\partial x} & \frac{\partial V}{\partial x} \\
\frac{\partial U}{\partial y} & \frac{\partial V}{\partial y}
\end{bmatrix}
\]

Particle Image Velocimetry 2D - 2C

\[
\frac{d\mathbf{u}(x,y)}{d\mathbf{x}} = \begin{bmatrix}
\frac{\partial U}{\partial x} & \frac{\partial V}{\partial x} & \frac{\partial W}{\partial x} \\
\frac{\partial U}{\partial y} & \frac{\partial V}{\partial y} & \frac{\partial W}{\partial y}
\end{bmatrix}
\]

Steroscopic PIV 2D - 3C

\[
\frac{d\mathbf{u}(x,y,z,t)}{d\mathbf{x}} = \begin{bmatrix}
\frac{\partial U(t)}{\partial x} & \frac{\partial V(t)}{\partial x} & \frac{\partial W(t)}{\partial x} \\
\frac{\partial U(t)}{\partial y} & \frac{\partial V(t)}{\partial y} & \frac{\partial W(t)}{\partial y}
\end{bmatrix}
\]

HS-(Tomographic) PIV 3D(t) - 3C

Velocity gradient tensor by PIV

→ Vorticity vector, space-time-correlation, spectra, LSE, POD, conditional averaging etc.
Combination of advanced imaging systems in industrial aerodynamics

- Velocity gradient tensor by PIV (Stereo, TR, Tomo)
- (Unsteady) Pressure distribution on model by PSP
- Model deformation and position by IPCT
- Sound source fields by Acoustic Array Technique
- Density gradient fields by BOS
- Transition line detection by TSP
- Closer interaction with CFD methods enhance physical understanding
Introduction: Industrial aerodynamic research

- Increasing requirements on flow measurement techniques:
  Investigated flow configurations become more and more complex while the interest in unsteady and vortical flow phenomena in research and aeronautics industry is growing especially for high Reynolds numbers.
  Increasing needs on experimental data describing the flow more completely and in whole fields or volumes for validation and comparisons with numerical calculations and modeling.

- PIV is able to provide unsteady as well as averaged flow velocity fields, related $rms$ values, vorticity etc.
  Reliable and well developed measurement tool.
  Further developments of the PIV technique still increases the capabilities towards time-resolution and 3D Adaptations for mobile system is necessary for each single campaign.
Stereo PIV at TPS in DNW-NWB, Braunschweig
Decoupling of cameras from wind tunnel vibration by separate support

One of two PCO4000 CCD-cameras with 11 mio. pixel resolution mounted in a two-axis Scheimpflug adapter
CFD data achieved with Tau and Menter SST cut-off 2

W/T -corr
Result of Stereo PIV measurement
Stereo PIV results in both planes
Experimental Setup at 1:1 scale wind tunnel
Sunroof buffeting with TR-SPIV system
Experimental Setup at 1:1 scale wind tunnel
Sunroof buffeting with TR-SPIV system
Introduction 2: PIV in trans- and hypersonic flows

- Encountering problems when applying PIV at industrial and trans- and hypersonic facilities

  High speed flows requires a precise triggering of cameras, lasers – in some cases a dependency of specific oscillation frequencies or single events is necessary

  Generation and distribution of small flow tracers - able to follow flow accelerations in vortices and through shocks within very short relaxation times < µsec

  Changing of total pressure or temperature within wind-tunnels causes light beam deflections after transmitting windows, which itself can cause e.g. astigmatism

  Optical access for cameras and laser light sheet becomes a special issue for trans- and supersonic wind tunnels

  Vibrations can spoil calibration and background illumination decreases SNR of results
Buffeting due to SWBLI

$Ma = 0.736$

$\alpha = 5.16^\circ \rightarrow alpha\_cor = 3.5^\circ$

$\text{blow} = \text{no}$
Application of PIV to transonic flows

Transonic Wind-tunnel in Göttingen (TWG)

- Pressure controlled continuously working wind tunnel, exchangeable test sections 1 m x 1 m

screens
flow straightener
cooler

Laval test section (supersonic)
perforated test section (sub-, transonic)
adaptive test section (subsonic)

axial compressor (2 x 4 stages)
motor (12 MW)

46.5 m
Several cross flow planes over a delta-wing by SPIV

- Stereo PIV arrangement
Several cross flow planes over a delta-wing by SPIV

Stereo PIV arrangement
Damping of laser reflexions at model surface by a mixture of a fluorescent dye in acrylic paint

Coating of model to avoid light scattering at the surface

Comparison of two different paints

Optimized paint enables PIV measurements close to the model surface
Several cross flow planes over a delta-wing by SPIV
PIV at Ma 6 and 7 in High-Enthalpy-Tube Göttingen (HEG)

PIV velocity world record at ~2230 m/s!
Comparison of PIV and CFD stream traces

Streamtrace from PIV Measurement

Streamtrace from CFD

Mach number distribution from CFD
Next-step: In-flight PIV

21.09.2009
Next-step: In-flight PIV
Momentane Geschwindigkeitsvektorvolumen mit 1 kHz

Voxelgröße: 85.9 µm

Volumen 63 x 15 x 68 mm³:
734 x 176 x 793 Voxel³
1.66δ x 0.39δ x 1.79δ
1380 x 328 x 1490 wall units

Korrelationswürfelgröße:
32³ Voxel = 2.75³ mm³
= 60 wu in jede Richtung (!)

Schrittweite:
8 Voxel = 0.687 mm = 15 wu

Vektoren:
92 x 99 x 22 = 200376
5 x 1020 Vektorvolumen

Zeitfolge von momentanen Geschwindigkeitsvektorvolumina mit $\lambda_2$-Isokonturflächen zur Wirbelvisualisierung in einer TBL, $Re_\theta = 2460$
Conclusions: PIV for industrial aerodynamics

- PIV is an advanced optical measurement technique for industrial and scientific needs
- Data useful for validation of numerical codes
- Phase trigger, traversing systems, calibration tools, evaluation algorithms have been improved for applications in various industrial facilities
- Future advancements: Fat-sheet Tomo PIV, High Reynolds number and In-flight PIV
- Use of combined imaging techniques for a more holistic view of the w/t aerodynamics (PSP, TSP, Acoustics, IPCT...
Thank you for your attention!

Questions ?????

andreas.schroeder@dlr.de