Achievements in sheet and volumetric PIV techniques with micron resolution

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• My early days at DLR
• Long Range μ-PIV
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Faszination of Visualization in 1995
Photographic PIV in 1995
Digital PIV in 1996
Digital PIV in 1996

![Graph showing data for different resolutions (32x32, 64x16, 64x32, 64x64) and their corresponding u [m/s] values.]
Digital Stereo PIV in 1996
Digital Stereo PIV in 1996
Multiplane Stereo PIV in 1999
Multiplane Stereo PIV in 1999

DLR-FB-2004-24
• My early days at DLR
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Long Range μ-PIV

<table>
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<tr>
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<th>LR μ-PIV</th>
<th>PIV</th>
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<tbody>
<tr>
<td>magnification</td>
<td>~ 1 – 50</td>
<td>~ 0.1 – 1</td>
</tr>
<tr>
<td>light-sheet width</td>
<td>~ 4 mm</td>
<td>~ 200 mm</td>
</tr>
<tr>
<td>light-sheet thickness</td>
<td>~ 0.01 mm</td>
<td>~ 0.5 – 1.0 mm</td>
</tr>
<tr>
<td>particle concentration</td>
<td>~ 1000 mm(^{-3})</td>
<td>~ 10 mm(^{-3})</td>
</tr>
</tbody>
</table>
Long Range μ-PIV
Single Pixel Ensemble Correlation

Two-point ensemble correlation approach and normalised correlation peak
Assumptions: stationary, laminar flow or symmetric turbulence distribution
Boundary Layer Measurements

Interference effects close to the wall (red line) responsible for the local velocity maximum at $y < 20 \mu m$ (upper left image).

Resolution: $0.00071 \text{ mm} \rightarrow 0.028 \text{ wall units}$!

Trisonic Windtunnel Munich (TWM)

Compressor system
Pressure: 20 bar
Volume: 1600 m³/h

Pressure reservoir
Volume: 2 x 190 m³

Pressure regulation
Range: 1.2 - 5 bar
Adjusting time: < 1 sec
Pressure uncertainty: < 5 mbar
Max. Massflow: 250 kg/s

Settling chamber
Volume: 8.5 qm
Pressure: 20 bar

Laval nozzle
Mach number: 0.15 - 3.0
Uncertainty: < 0.005
Adjusting time: < 30 sec
Reynolds number: 7 - 70x10⁶ m⁻¹

Test section
Height: 675 mm
Width: 300 mm
Cross section: 0.2025 m²
Run time: 0.5 min (Ma=1); 2 min (Ma=3)
Long Range μ-PIV Result

\[ 32 \times 32 \text{ px}^2 \equiv 0.25 \text{ mm}^2 \]
Single Pixel Analysis

Bitter M, Hain R, Müller J, Kähler CJ. PIV09, 2009
Turbulence Estimation 2006

Dependency of the correlation diameter in dependency on the turbulence level

\[ \hat{d}_{turb} = \sqrt{d^2 + 16\sigma^2} \]

\[ d_{corr} = \frac{4}{\sqrt{\pi} \text{erf} \left( \frac{\sqrt{2}}{d} \right)^2} \sqrt{1 + \left( \frac{1}{2} \frac{\partial u}{\partial y} \right)^2} \]

Kähler CJ, Scholz U, 12th Int. Symp. on Flow Visualization, 2006
Turbulence Estimation 1986

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Turbulence level measurement by speckle velocimetry

W. Arnold, Klaus D. Hinsch, and D. Mach

Universität Oldenburg, Fachbereich 8 - Physik, Postfach 25 03, D-2900 Oldenburg, Federal Republic of Germany.
Received 9 September 1985.
0003-6935/86/030330-02$02.00/0.
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Speckle velocimetry1 or particle imaging velocimetry is of increasing interest in experimental flow studies due to the possibility of studying large flow fields simultaneously. Recently,2 possibilities have been pointed out for obtaining data on random flow components from an analysis of the visibility in Young’s fringe pattern produced in the evaluation of the double-exposure flow record. It was shown that the visibility as a function of position equals the modulus of the characteristic function associated with the probability density function of the flow velocity within the region inspected. Furthermore, it was proposed that this relation-

References
• My early days at DLR
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• Wave Front Deformation $\mu$-PIV
Fundamental $\mu$-PIV Limitations

Kloosterman et al. PIV 2009

Error >10 %

$DOC = 2 \left[ \frac{1 - \sqrt{\epsilon}}{\sqrt{\epsilon}} \left( f^2 \frac{d_p^2}{\lambda^2} \right) + \frac{5.95(M + 1)^2 \lambda^2 f^4}{M^2} \right]^{1/2}$
Wave Front Deformation $\mu$-PIV 2009

- In the xz-plane only the spherical lens acts.

- Stronger focusing in the yz-plane by the spherical and cylindrical lens.

- The position in z is coded by the axis ratio $a_x/a_y$. 

$$z = f(a_x/a_y).$$
μ-Fluidic Experiment at UniBw Munich

Integration of cylindrical lens in the system
Dataprocessing

Position error

Error on the axis ratio

- error on position = 0.1 px
- error on axis ratio < 3 % for $a_x,a_y > 3$ px
Results for a channel flow
Validation

quality of the data equal in both directions

good agreement with analytical solution

PIV underestimates the gradients close to the wall.
Backward Facing Step Flow

Velocity measurement in a micro channel with a backward-facing step.
Summary

Long Range μ-PIV

• High resolution results up to large Mach numbers
• Velocity profile with single pixel resolution
• Turbulence estimation possible

Wave Front Deformation μ-PIV

• Easy to implement
• Only single optical access required
• 3D3C time accurate velocity information
• No bias error due to DOF and DOC