LECTURE 19: ADVANCED 3D PARTICLE IMAGE VELOCIMETRY TECHNIQUE

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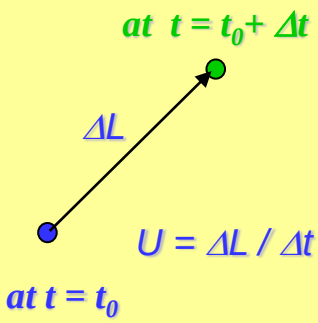
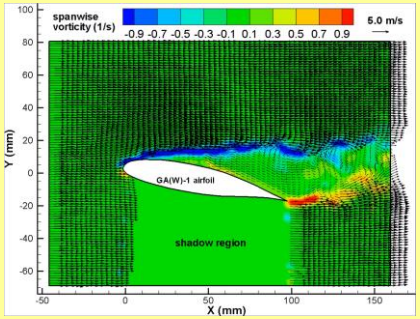
❑ Particle-based techniques: Particle Image Velocimetry (PIV)

- *To seed fluid flows with small tracer particles (~μm), and assume the tracer particles moving with the same velocity as the low fluid flows.*
- *To measure the displacements (ΔL) of the tracer particles between known time interval (Δt). The local velocity of fluid flow is calculated by U = ΔL/Δt .*

A. $t=t_0$

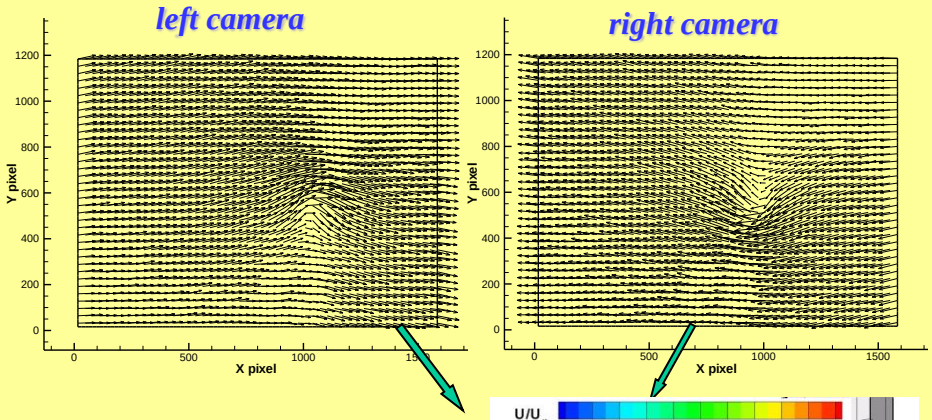


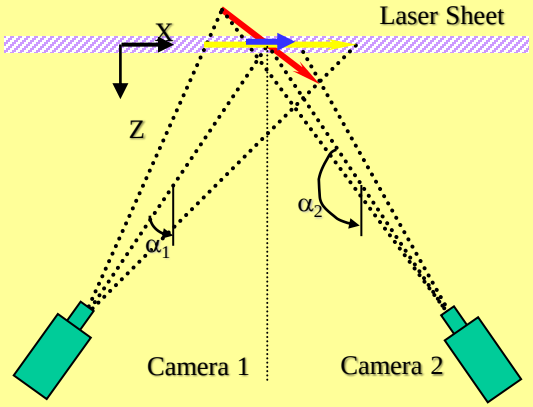
B. $t=t_0+10\mu s$

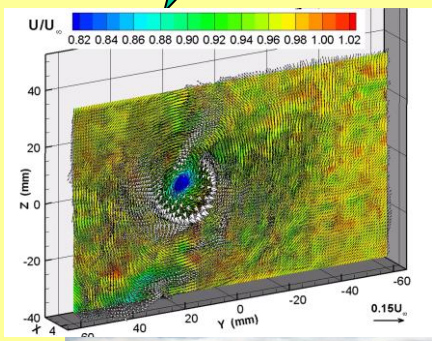


C. Derived Velocity field

Classic 2-D PIV measurement

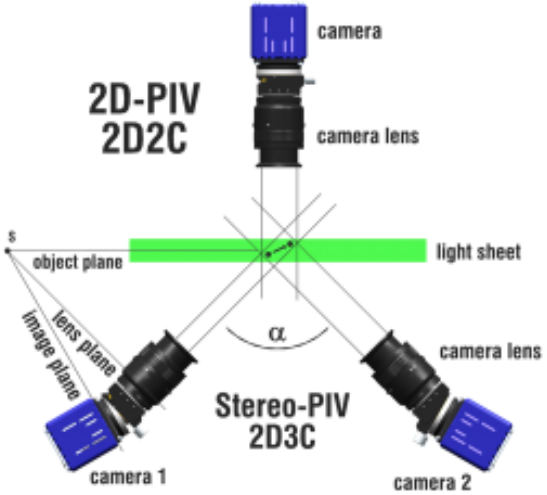




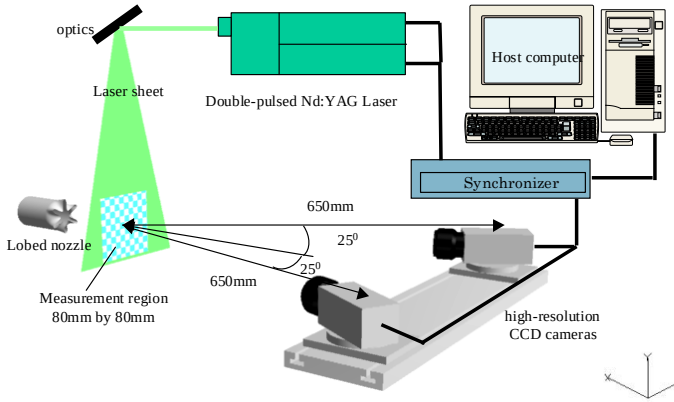


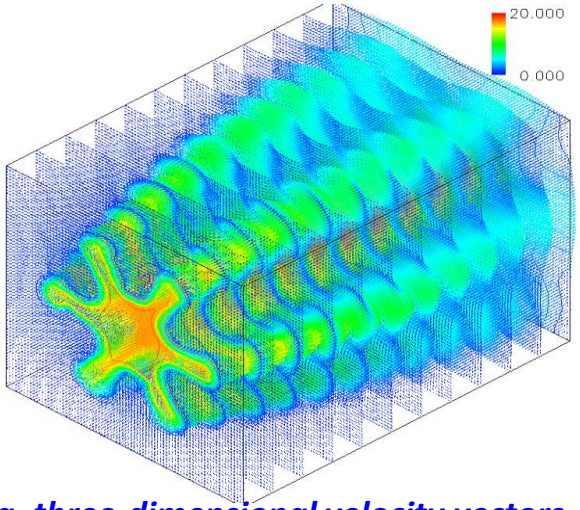
Stereoscopic PIV measurement

Reconstructed Three-dimensional Flow Field

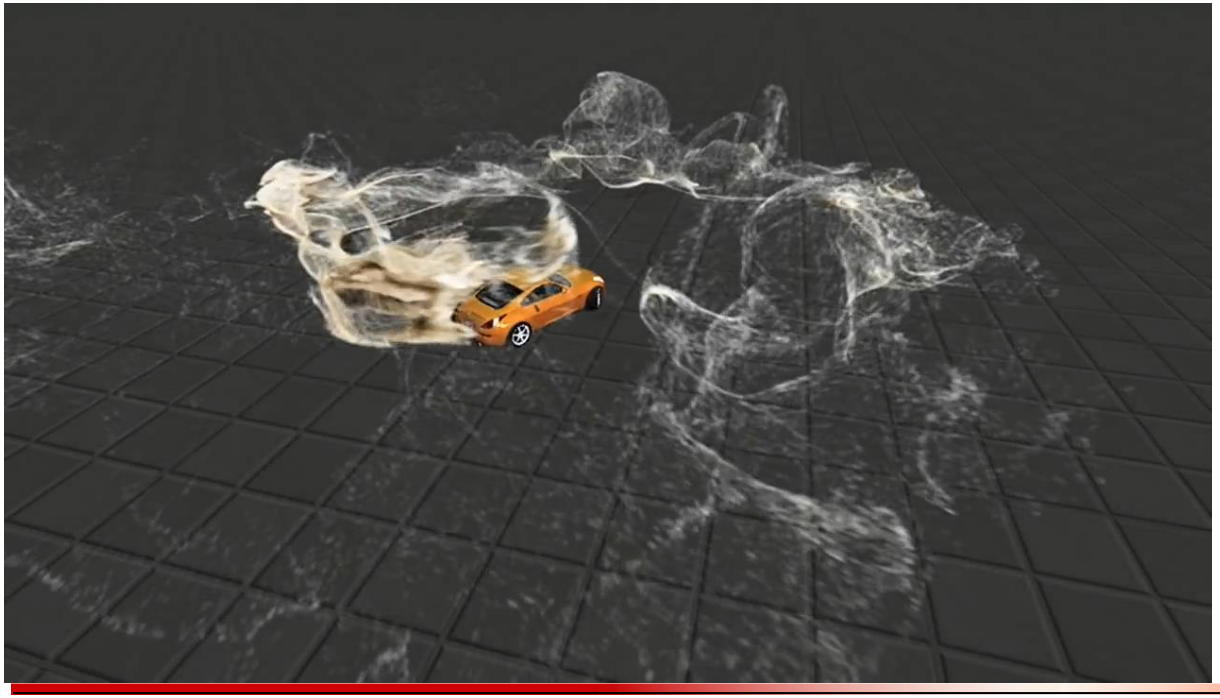


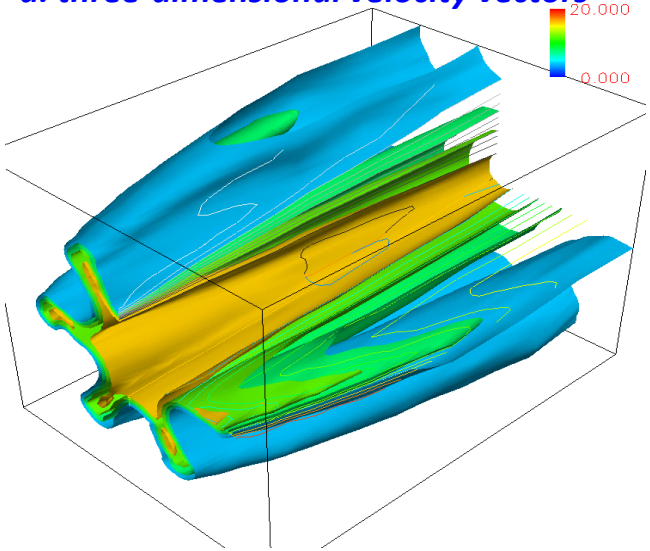
Stereoscopic PIV measurements





a. three-dimensional velocity vectors





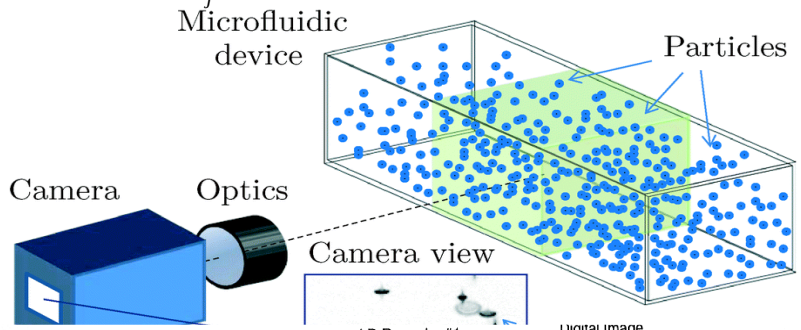
b.iso-surface of velocity field

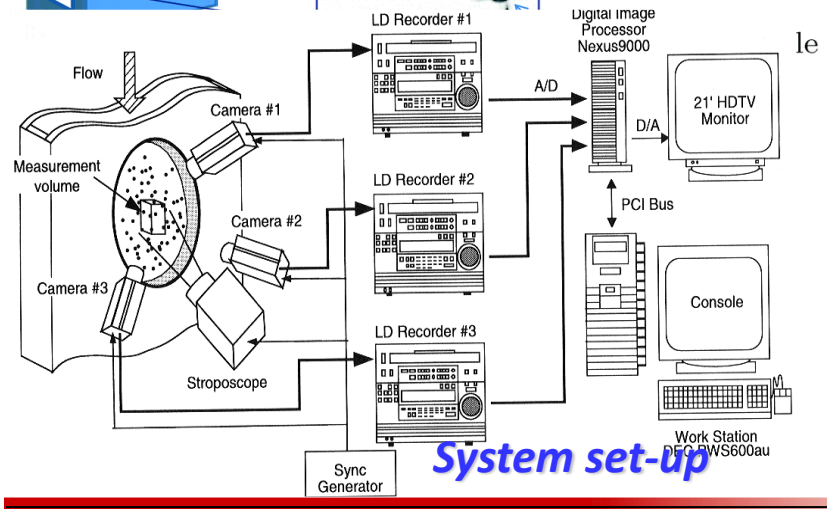
3D-PTV Techniques

$$X^{(c)} = F^{(c)}(x_i)$$

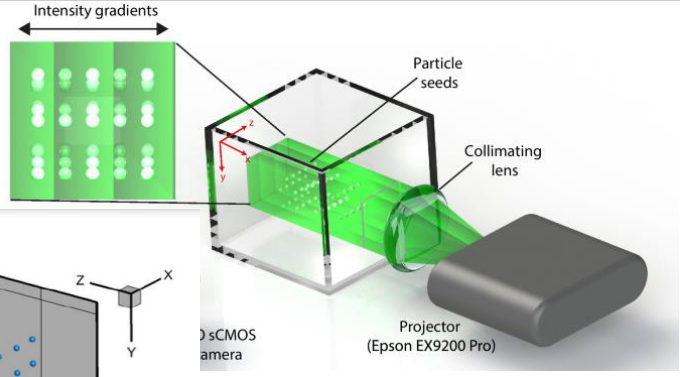
$$\begin{pmatrix} \overline{\frac{\Delta X_1^{(1)}}{\Delta X_2^{(1)}}} \\ \overline{\frac{\Delta X_1^{(2)}}{\Delta X_2^{(2)}}} \end{pmatrix} = \begin{pmatrix} F_{1,1}^{(1)} & F_{1,2}^{(1)} & F_{1,3}^{(1)} \\ F_{2,1}^{(1)} & F_{2,2}^{(1)} & F_{2,3}^{(1)} \\ F_{1,1}^{(2)} & F_{1,2}^{(2)} & F_{1,3}^{(2)} \\ F_{2,1}^{(2)} & F_{2,2}^{(2)} & F_{2,3}^{(2)} \end{pmatrix} \begin{pmatrix} \overline{\Delta x_1} \\ \overline{\frac{\Delta x_2}{\Delta x_3}} \end{pmatrix}$$

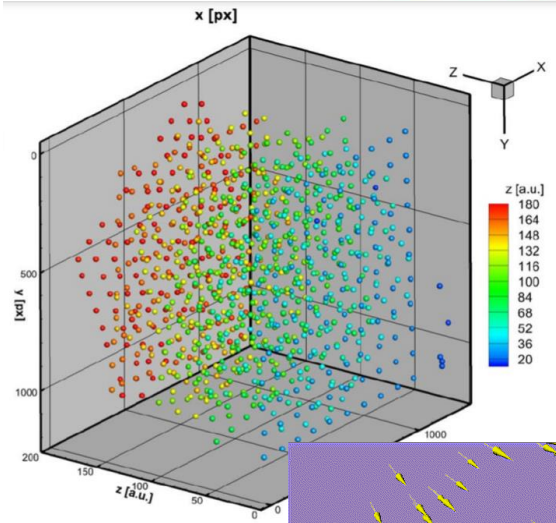
$$F_{i,j}^{(c)} = \frac{\partial F_i^{(c)}}{\partial x_j} \qquad c = 1,2 \quad , \quad i = 1,2 \qquad j = 1,2,3$$

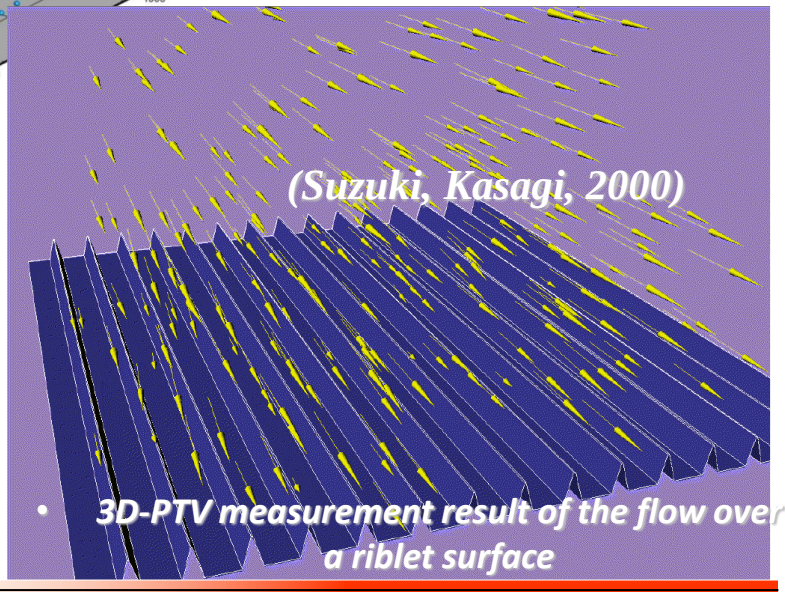




System set-up



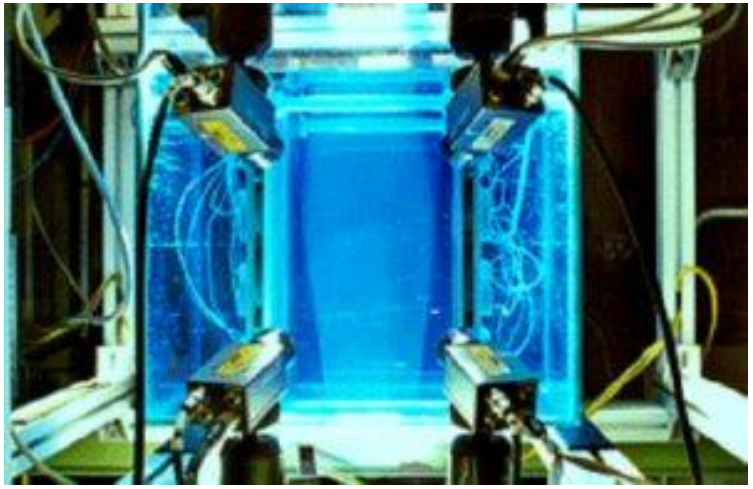


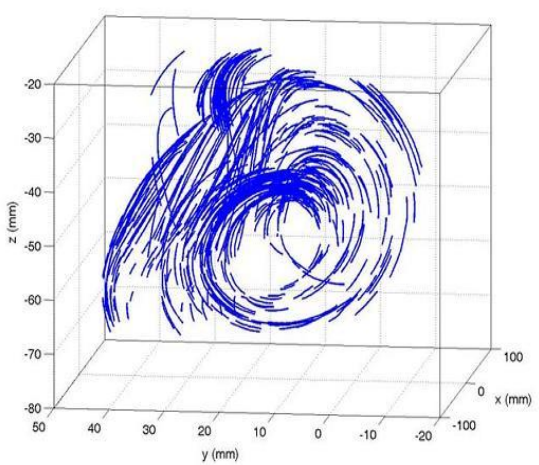


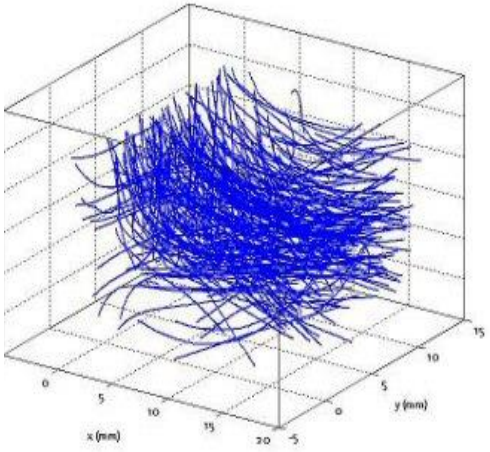
(Suzuki, Kasagi, 2000)

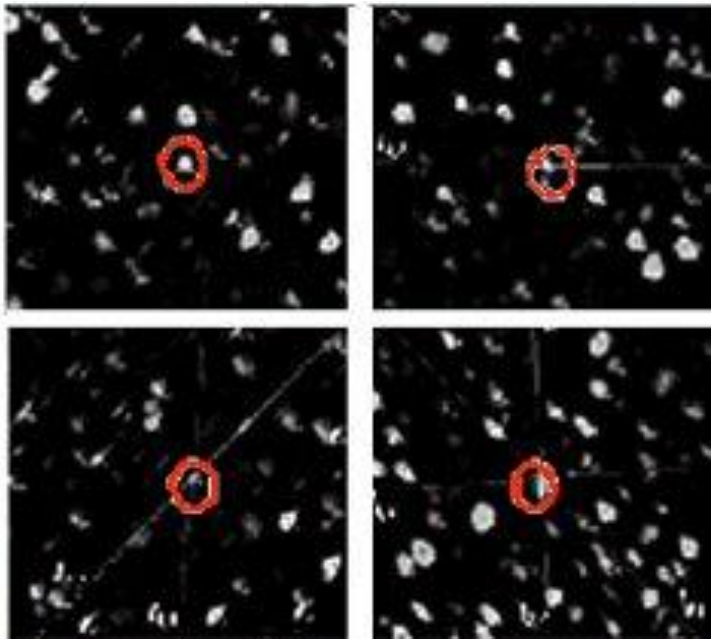
- *3D-PTV measurement result of the flow over a riblet surface*

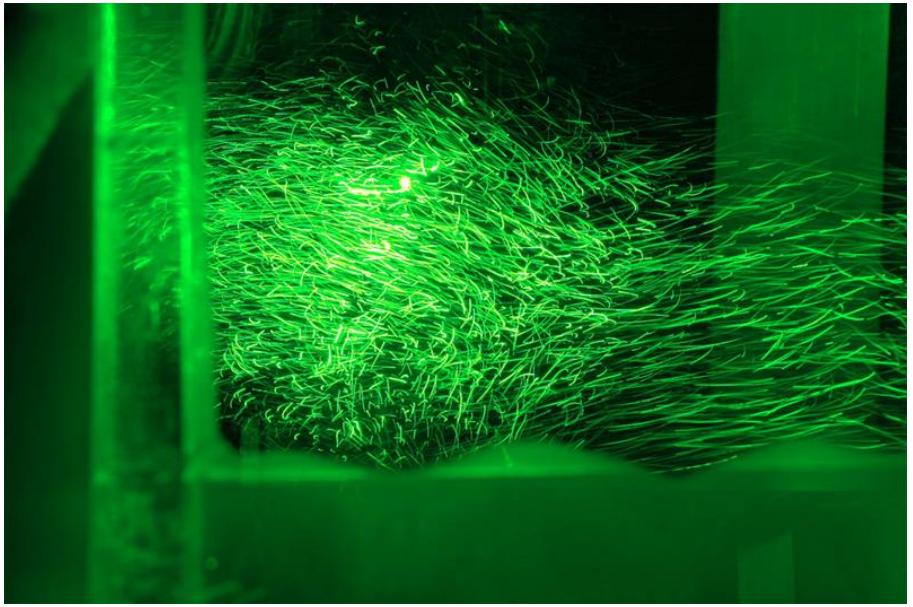
3-D PTV





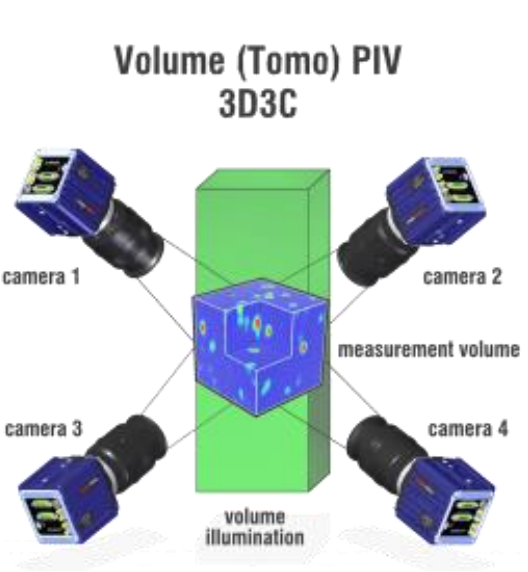


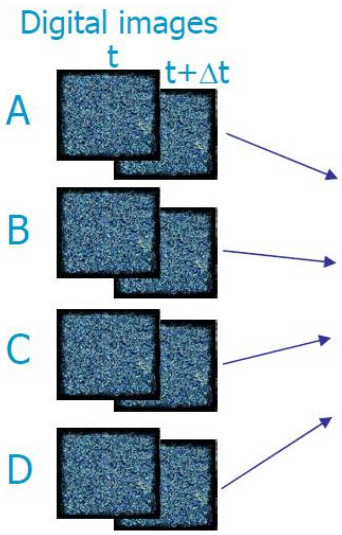


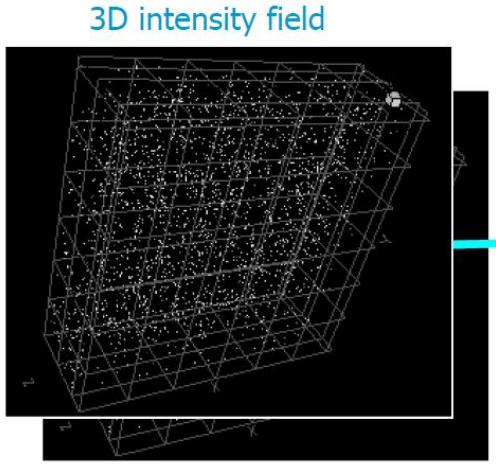


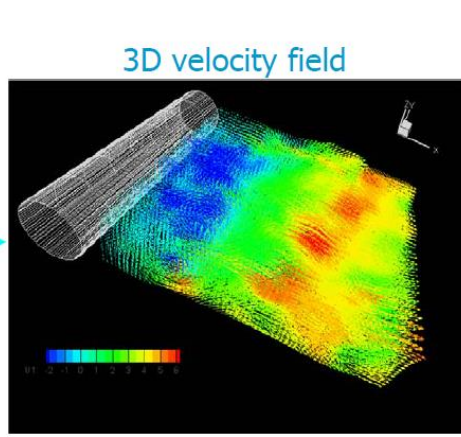
(Willneff, ETH Zurich. 2003)

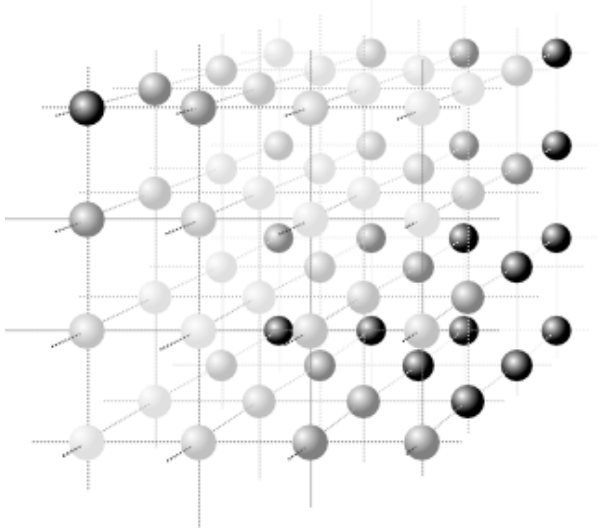
Tomographic PIV Technique

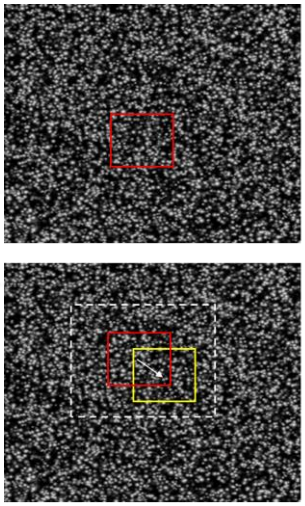




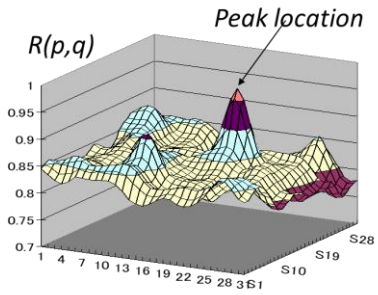


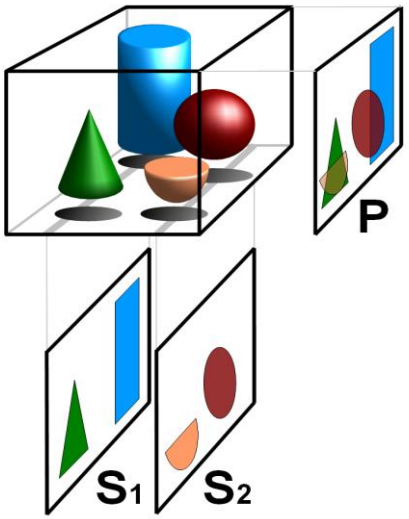






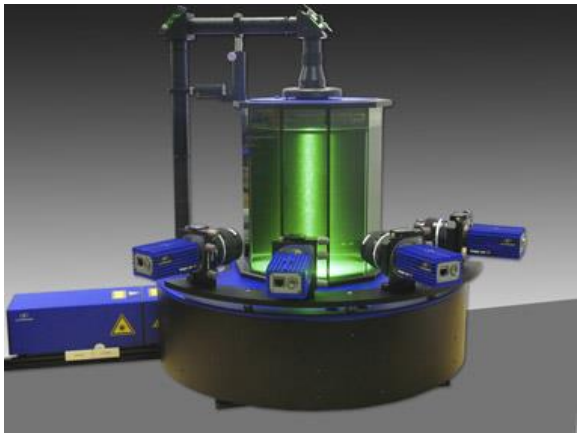
$$R(p,q)=\frac{\int(f(x,y)-\bar{f})(g(x,y)-\bar{g})dv}{\sqrt{\int(f(x,y)-\bar{f})^2 dv \int(g(x,y)-\bar{g})^2 dv}}$$

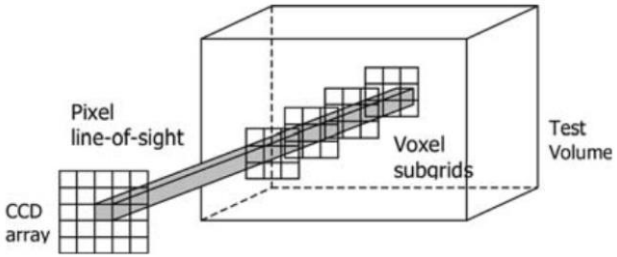




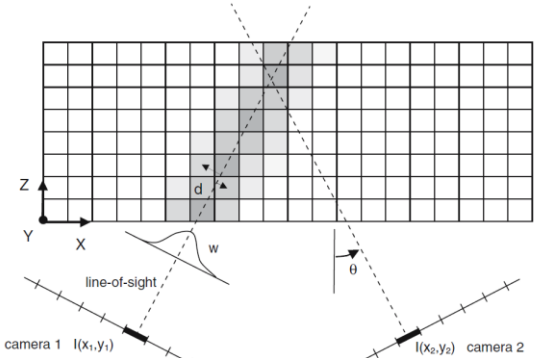
- *Pixel-based correction for 2D PIV*
- *Voxel-based correction for tomographic PIV*

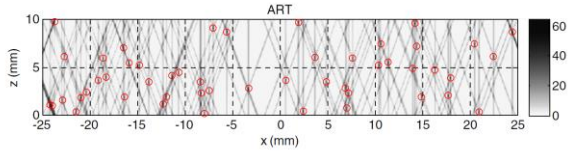
Tomographic PIV Technique

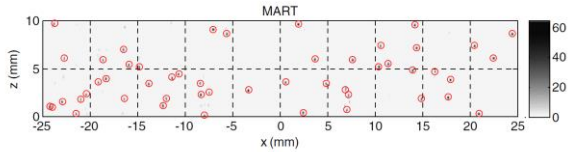


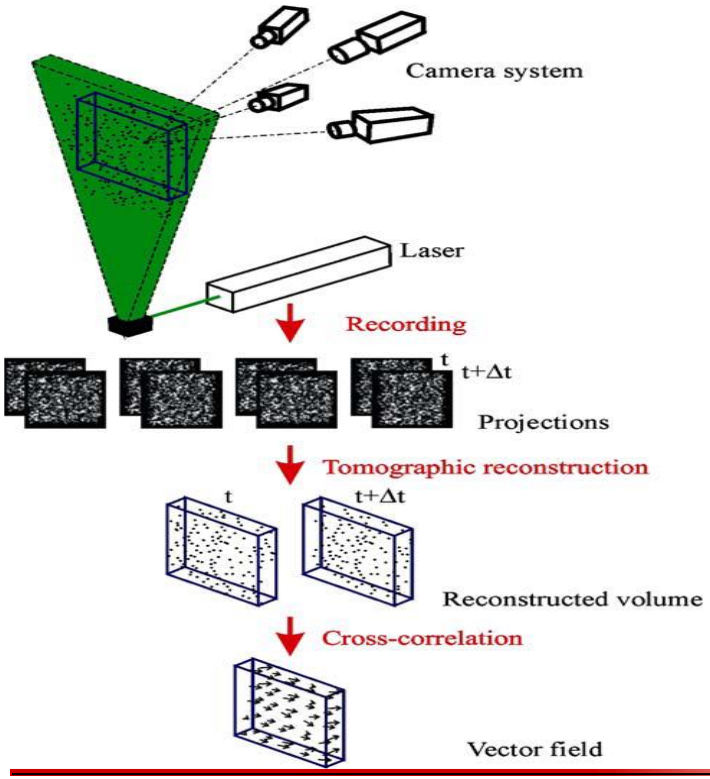


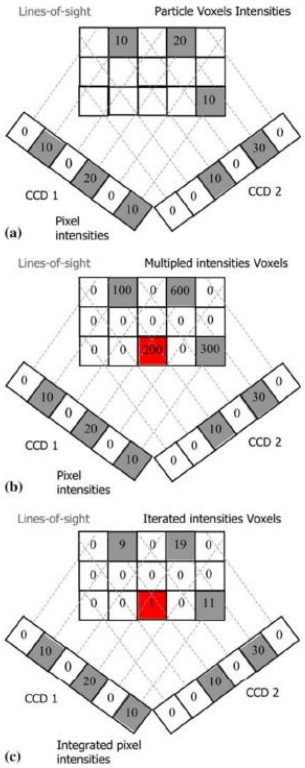
$$\sum_{j \in N_i} w_{i,j}\, E(X_j, Y_j, Z_j) = I(x_i, y_i),$$

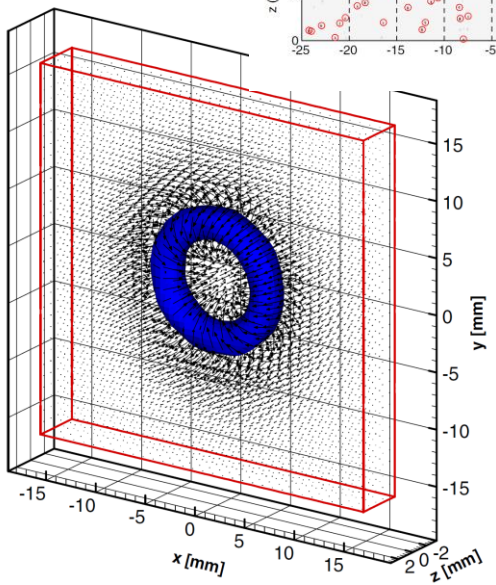


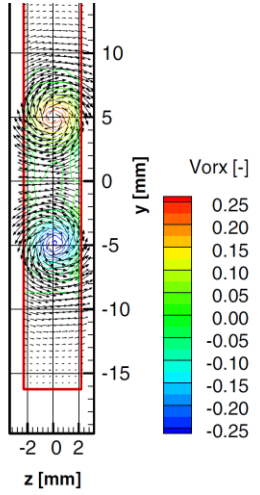




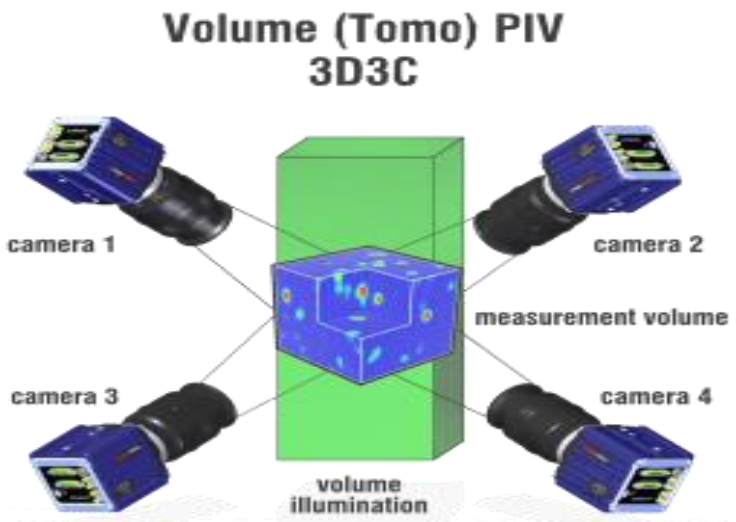


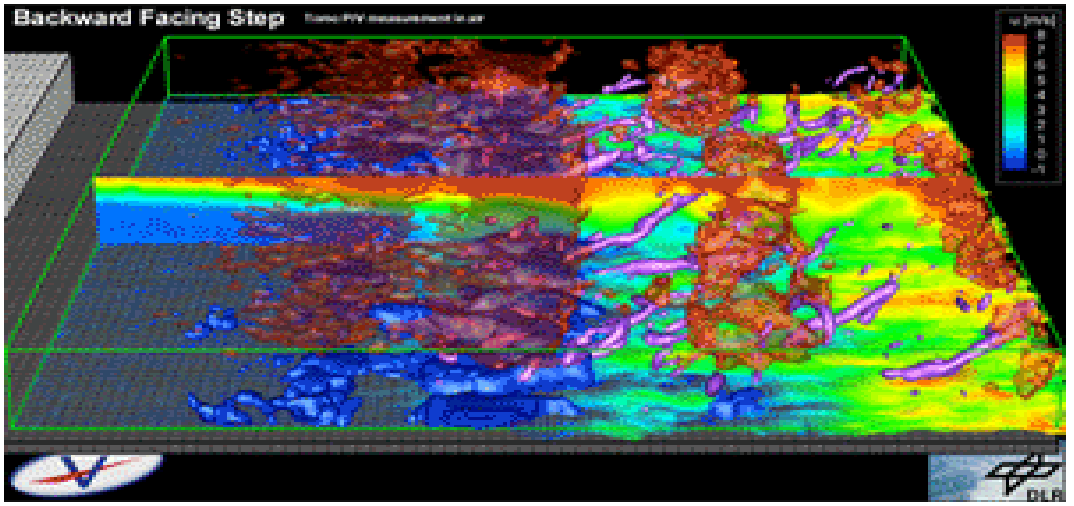




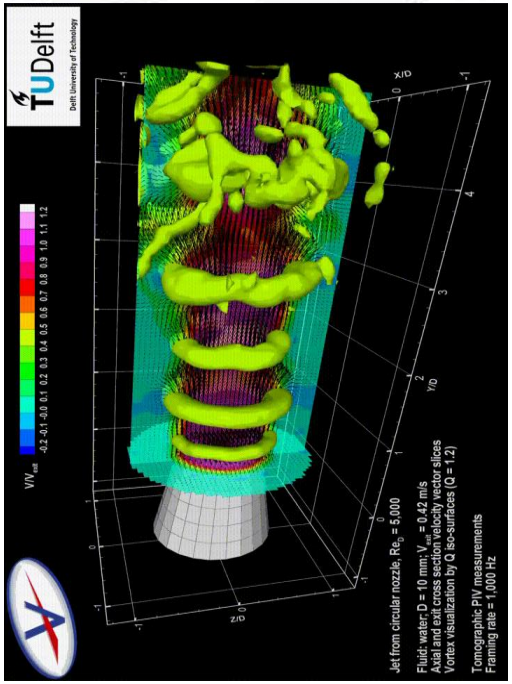


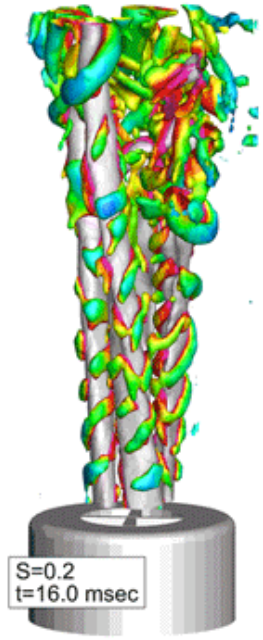
Tomographic PIV Technique

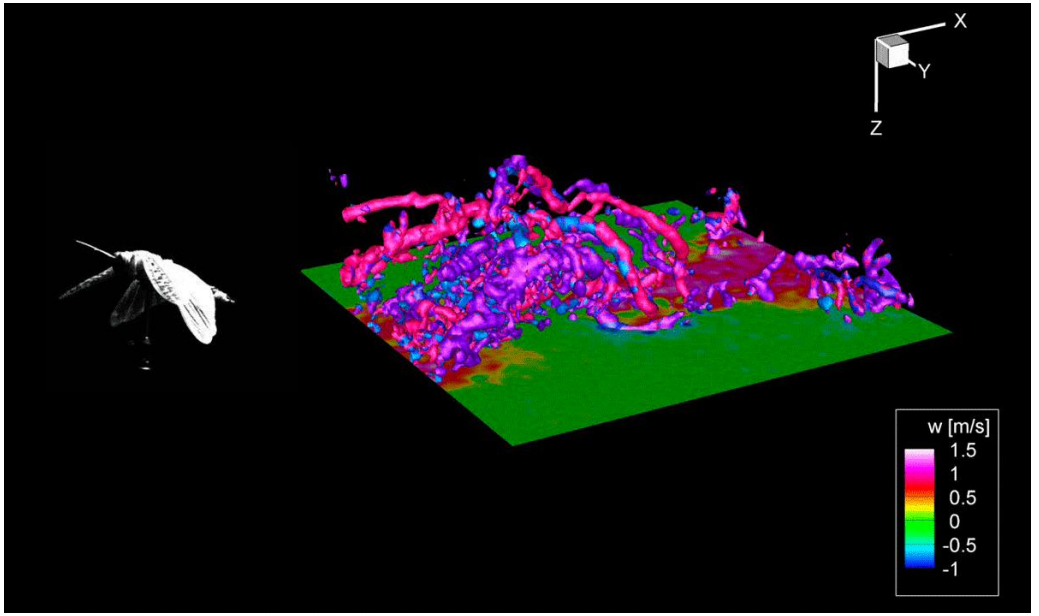




http://www.lavision.de/en/

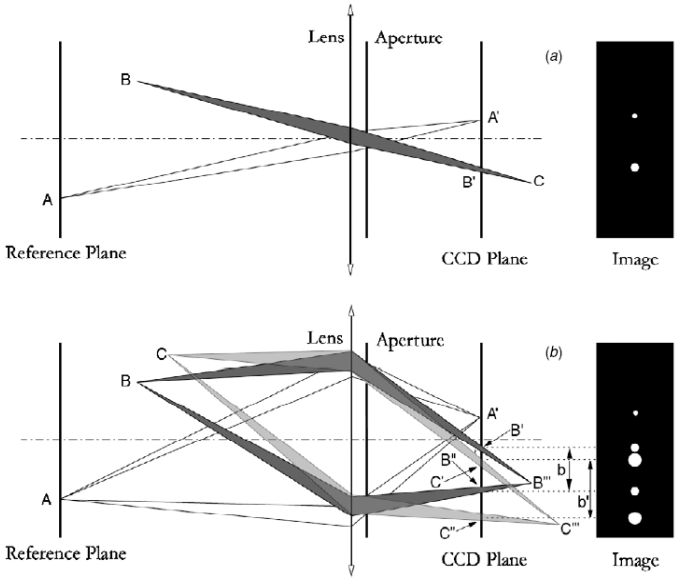


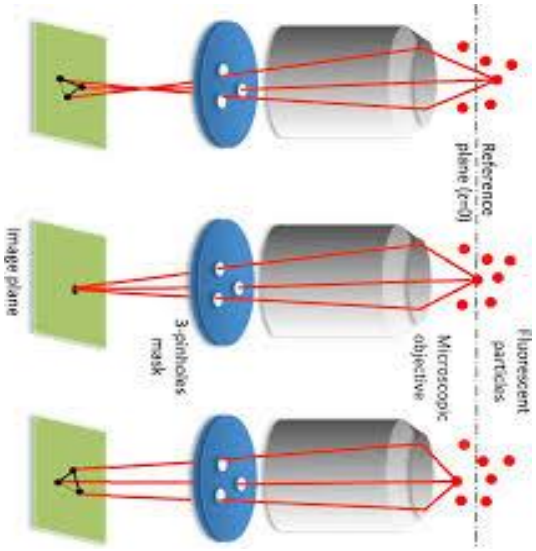




Defocusing Digital Particle Image Velocimetry (DDPIV)

Defocusing concept





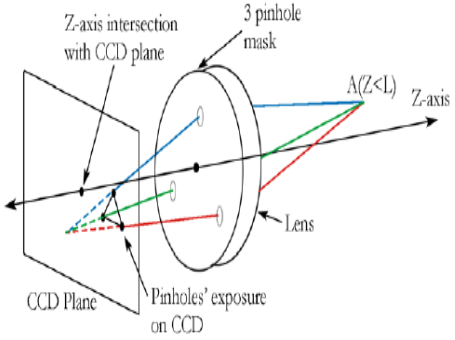
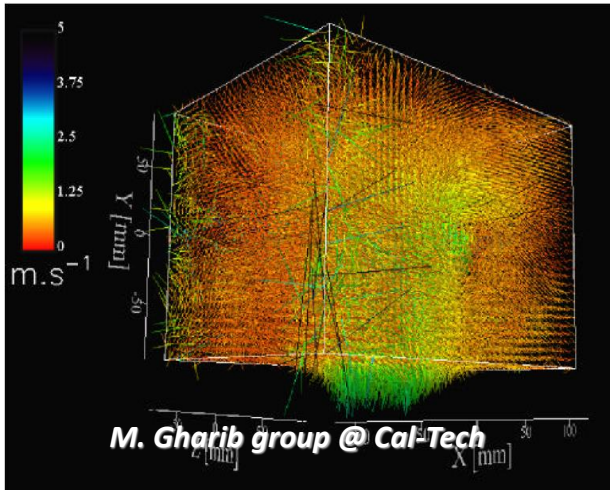
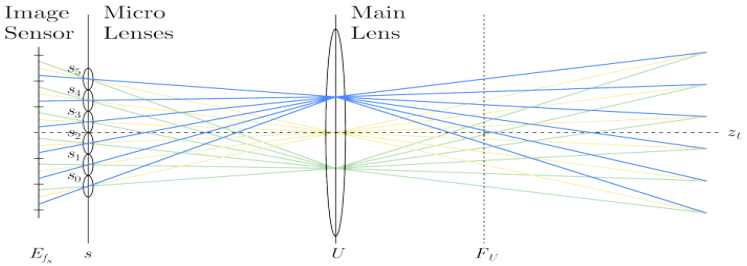


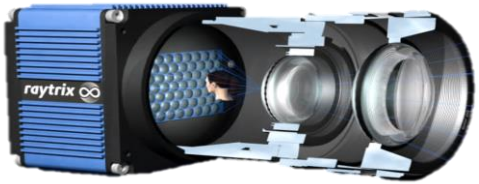
Figure 3. DDPIV using a three-pinhole mask (adapted from Pereira *et al* (2000)).

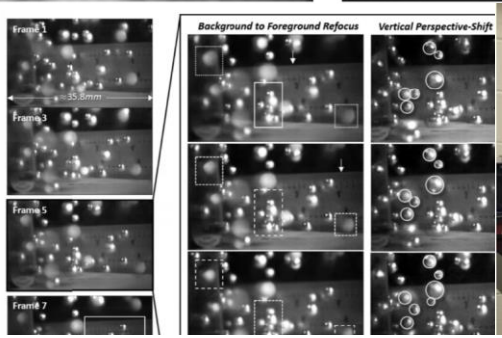


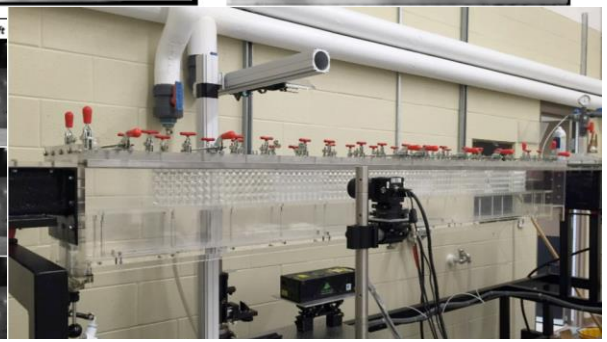
Plenoptic PIV technique

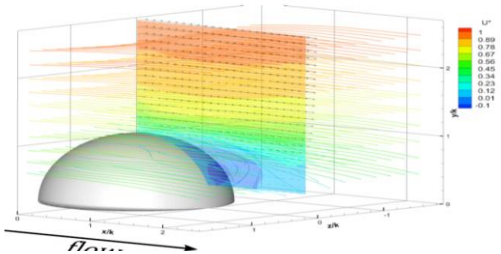
- ***Plenoptic or light-field Camera***

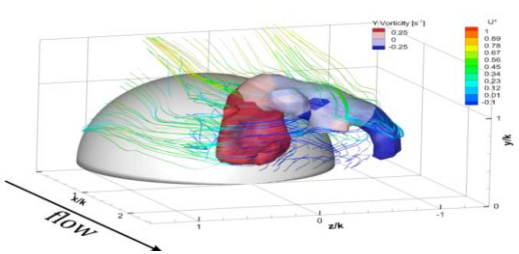


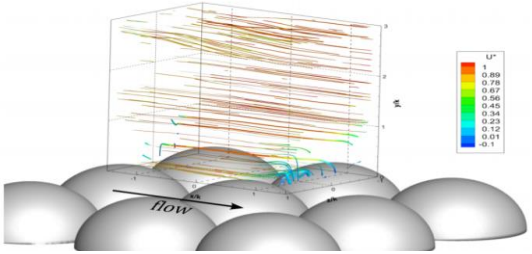


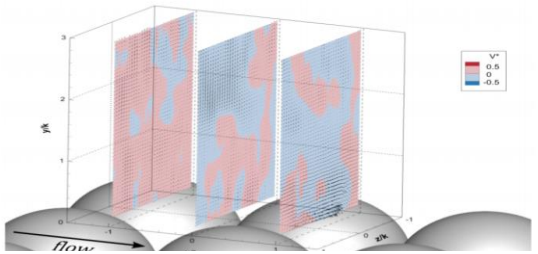








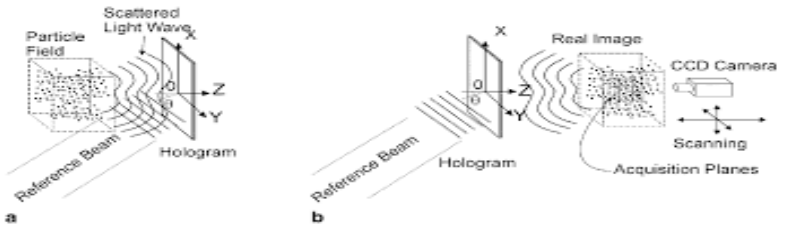


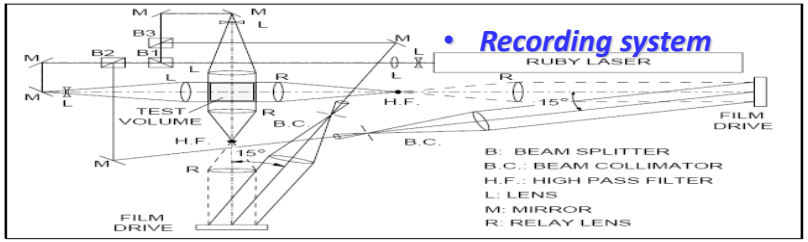


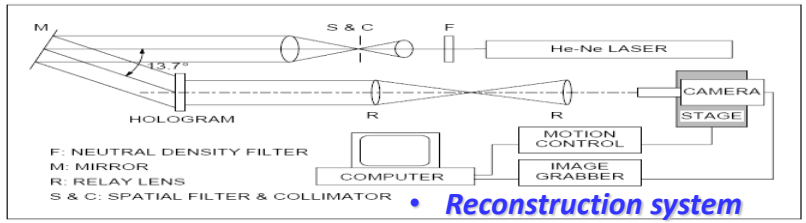
- *Johnson, K., Thurow, B., Kim, T., Blois, G., Christensen, K."Three Dimensional Plenoptic PIV Measurements of a Turbulent Boundary Layer Overlying Rough and Permeable Surfaces," 18th International Symposium on Applications of Laser and Imaging Techniques to Fluid Mechanics, Lisbon, Portugal. July 2016*

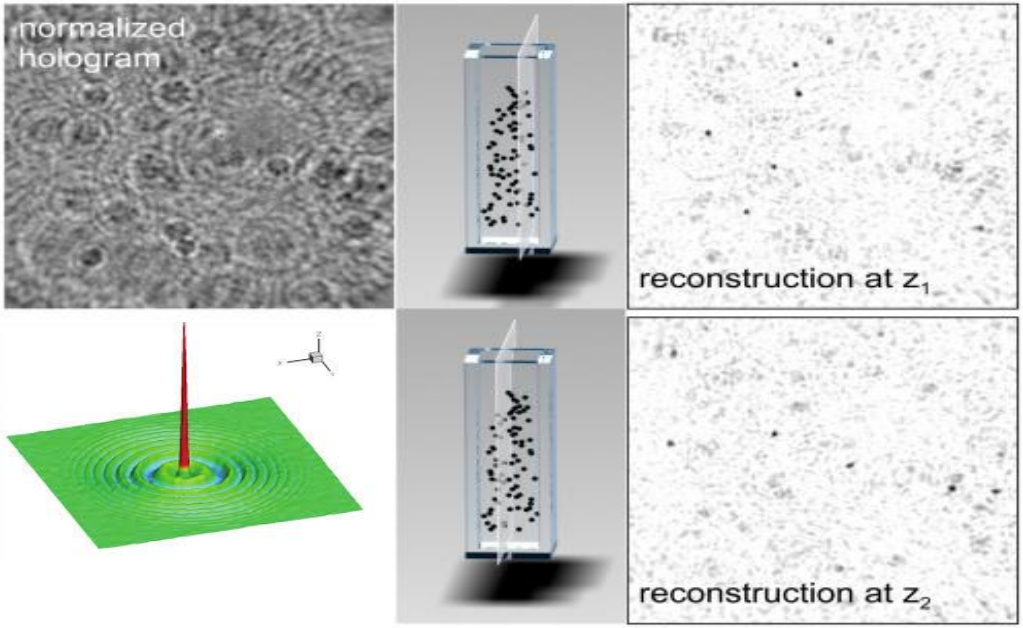
Holographic PIV (HPIV) technique

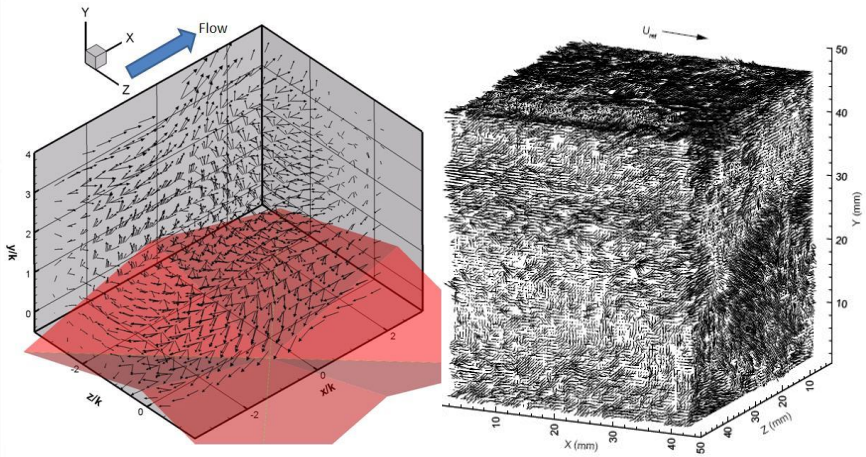
https://www.youtube.com/watch?v=0ics3RVSn9w





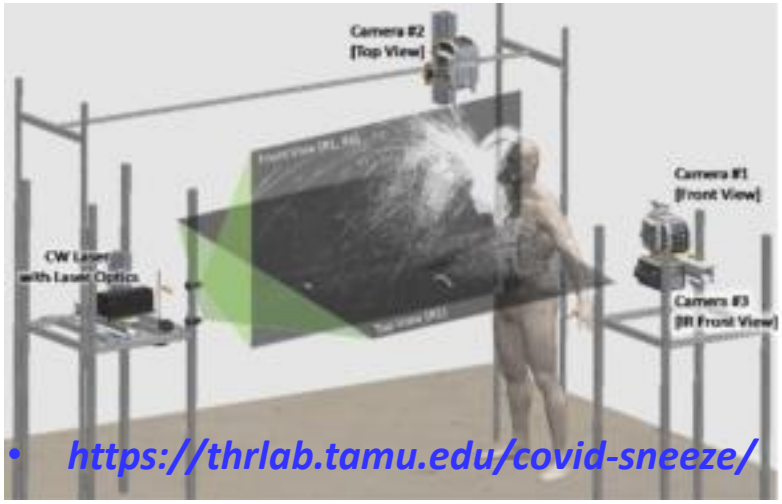




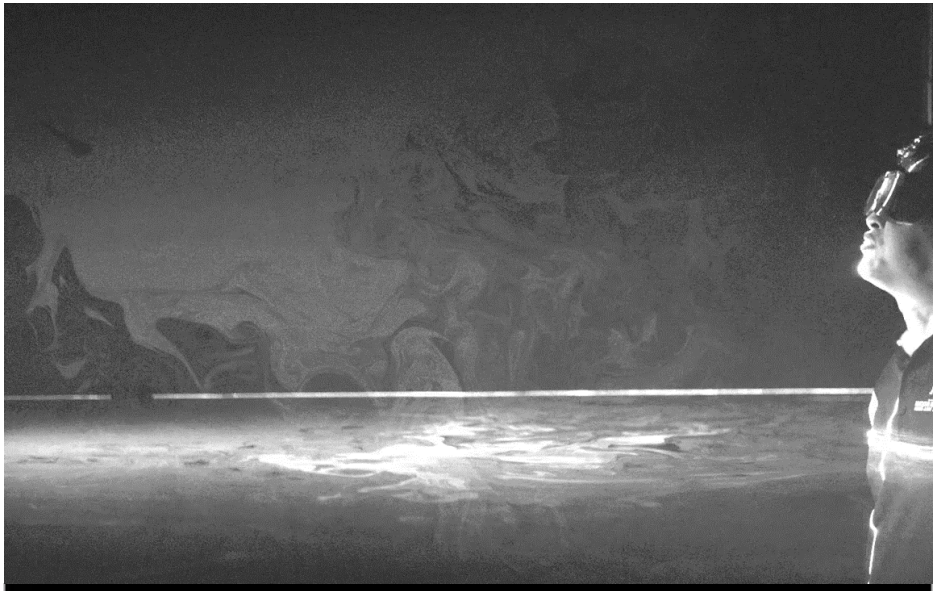


PIV Application Examples

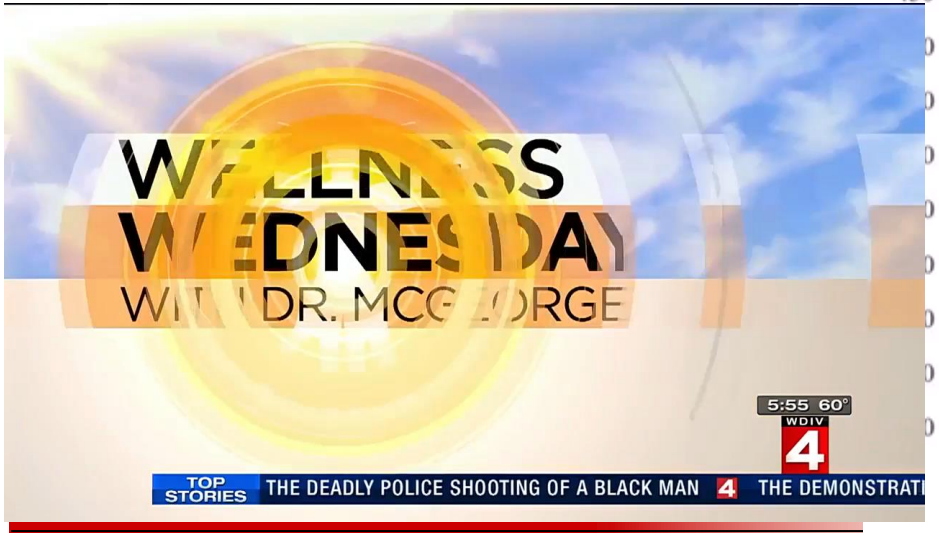
- *A supportive COVID-19 study: Experimental Investigation on a Human Sneeze*



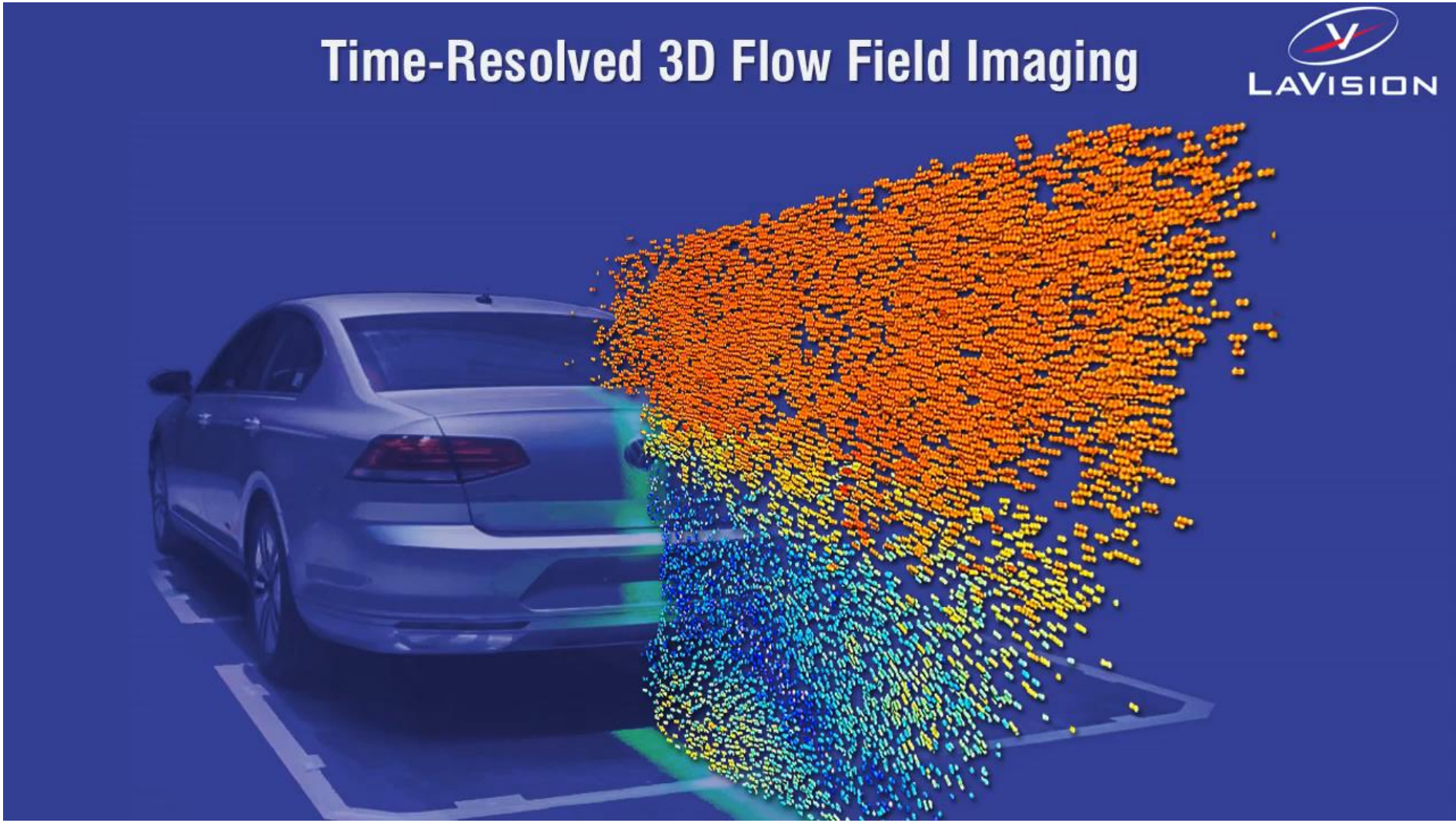
- *https://thrlab.tamu.edu/covid-sneeze/*



- *https://www.youtube.com/watch?v=9-ui6uFhUx0*

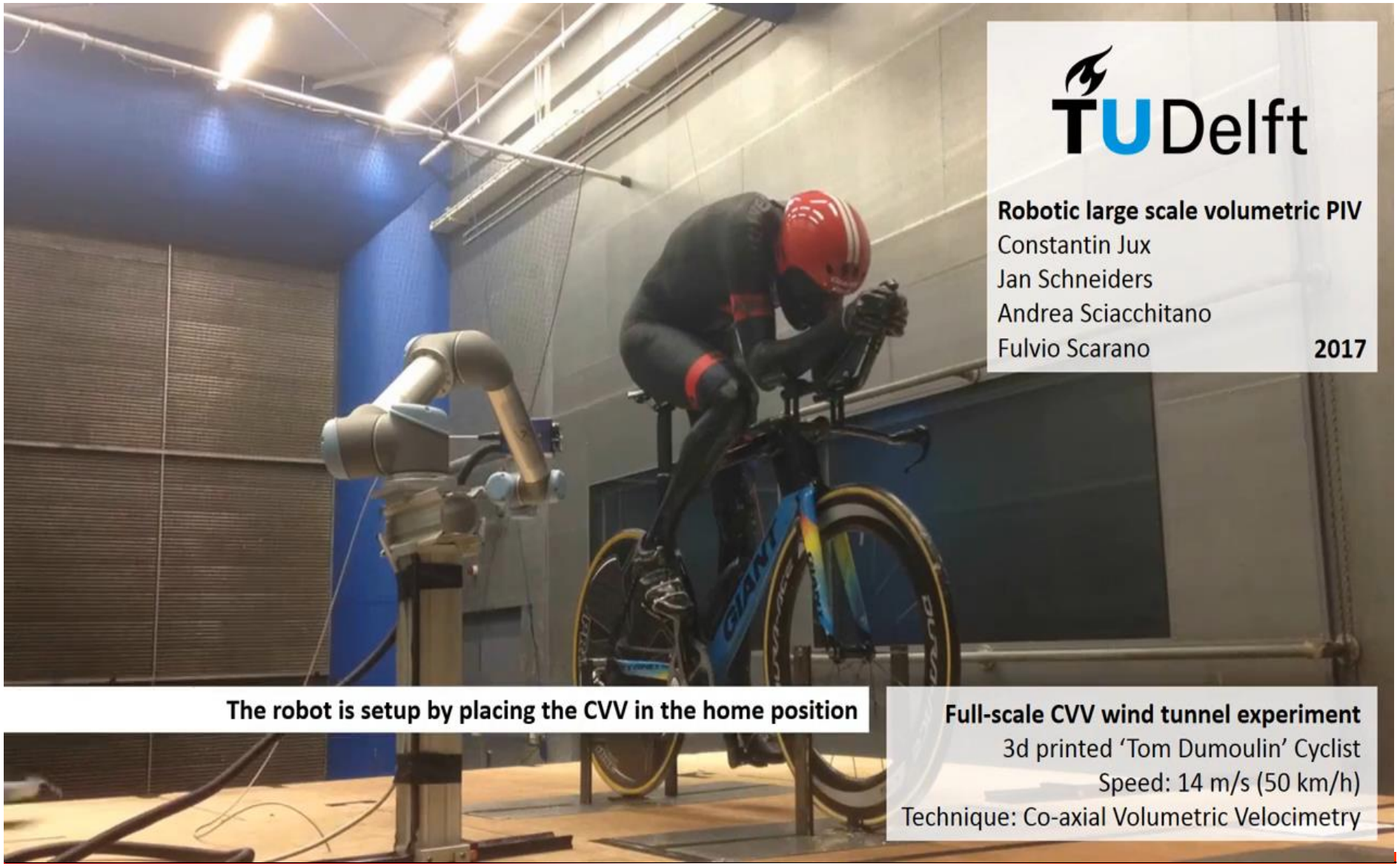


PIV Application Examples

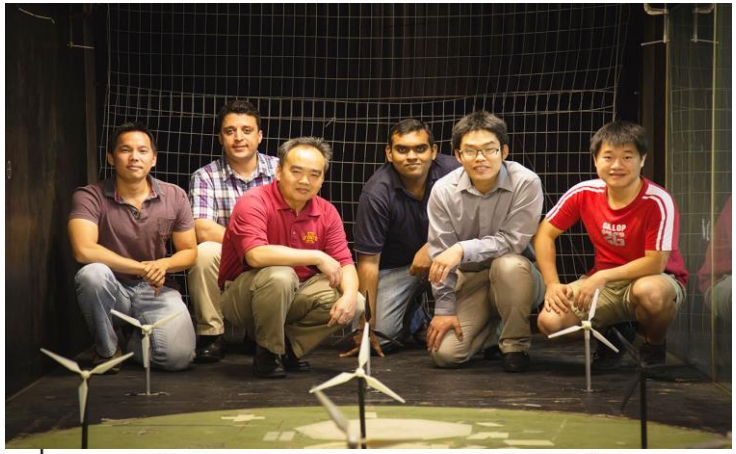


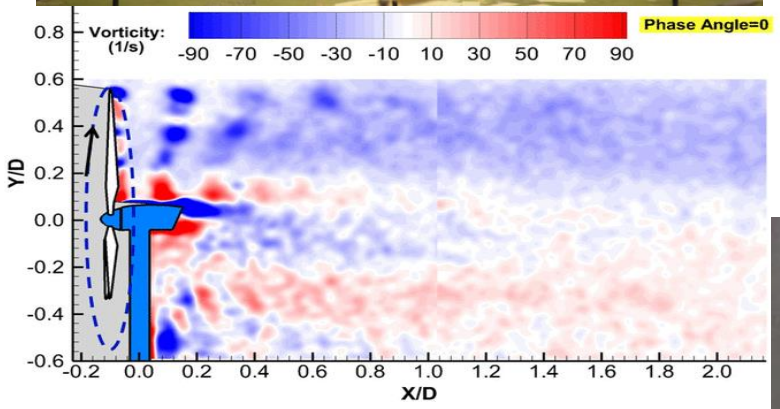
PIV Application Examples

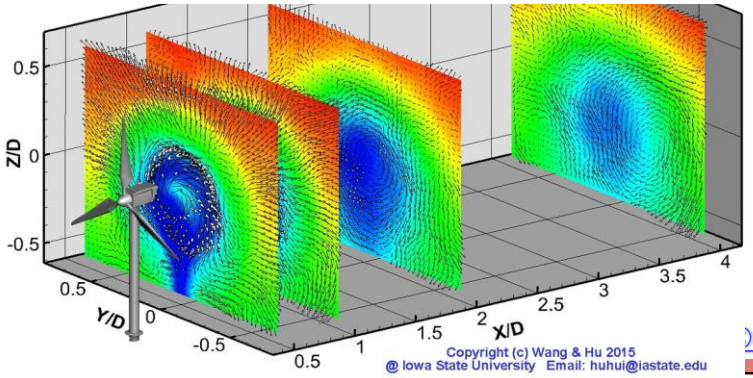
https://www.youtube.com/watch?v=yn-H9DEXsHg



PIV Application Examples







- *Hong, J., Toloui, M., Chamorro, L. P., Guala, M., Howard, K., Riley, S.. & Sotiropoulos, F. (2014). Natural snowfall reveals large-scale flow structures in the wake of a 2.5-MW wind turbine. Nature Communications,*