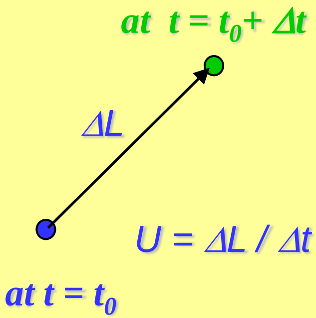
Lecture 18: Stereoscopic Particle Image Velocimetry - Part 02

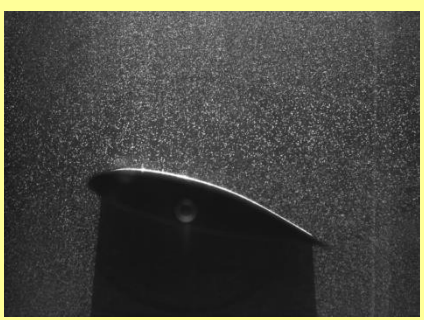
Dr. Hui Hu
Martin C. Jischke Professor in Aerospace Engineering
Dept. of Aerospace Engineering, Iowa State University
537 Bissell Road, Ames, Iowa 50011-1096, USA.
Tel: 515-294-0094 (O) / Fax: 515-294-3262 (O)
Email: huhui@iastate.edu

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

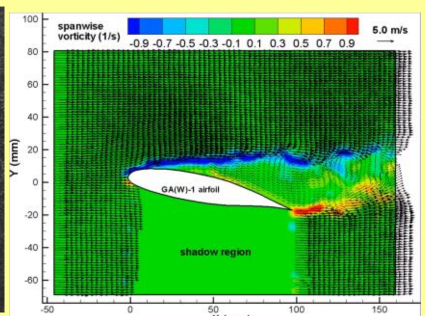
- *To* *seed fluid flows* *with small tracer* *particles* *(~μm), and assume the tracer particles moving with the same velocity as the low fluid flows.*
- *To measure the* *displacements (ΔL)* *of the tracer particles between* *known time interval (Δt).* *The local velocity of fluid flow is calculated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

A. $t=t_0$



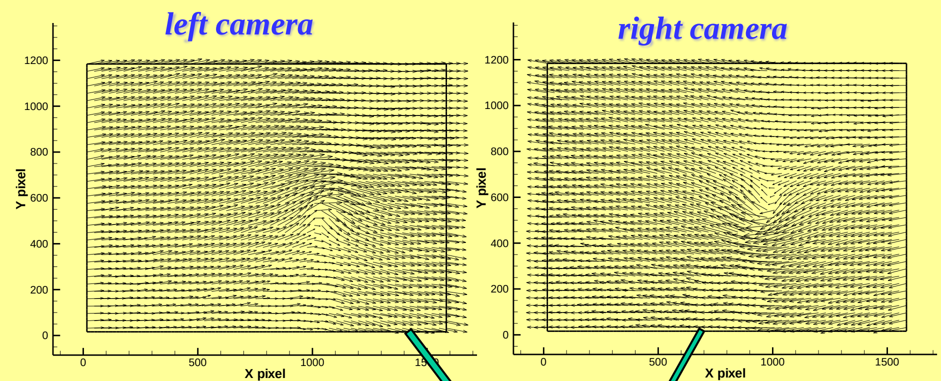


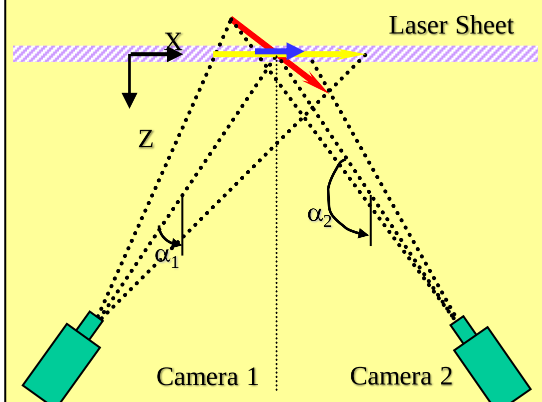
B. $t=t_0+10\mu s$

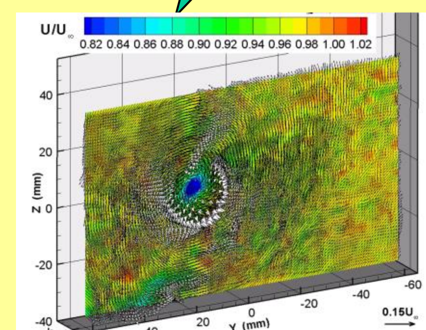


C. Derived Velocity field

Classic 2-D PIV measurement







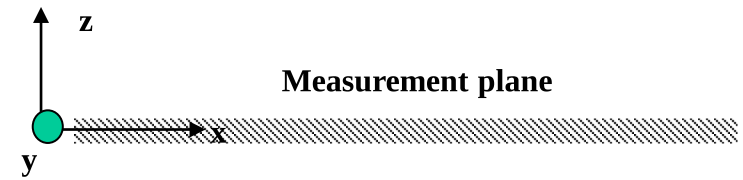
Stereoscopic PIV measurement

Dual-plane Stereoscopic PIV System!? Why???

- ***Vorticity vector is defined as the curl of the velocity vector :***

$$\varpi_z = \frac{\partial v}{\partial x} - \frac{\partial u}{\partial y};$$

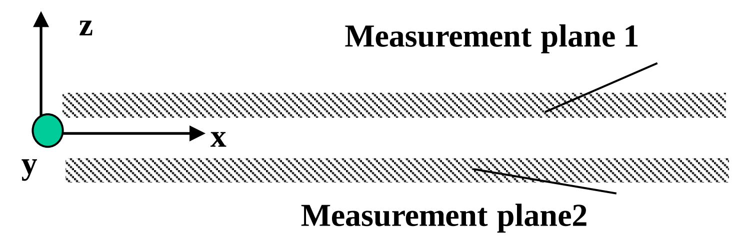
$$\varpi_x = \frac{\partial w}{\partial y} - \frac{\partial v}{\partial z}; \qquad \varpi_y = \frac{\partial u}{\partial z} - \frac{\partial w}{\partial x}$$



"Classical" PIV or SPIV systems can only provide measurement results in one single plane instantaneously

- ***Simultaneous measurements of velocity vectors (three-components) at least at two spatially separated planes are need in order to get all three-components of vorticity vectors.***

- ***Development of a Dual-plane Stereoscopic PIV system to achieve the stereoscopic PIV measurements at two parallel planes simultaneously.***

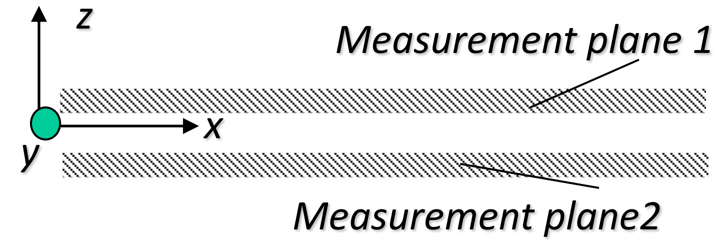


Dual-plane Stereoscopic PIV system can achieve stereoscopic PIV measurements at two parallel planes simultaneously

- ***Hu H, Saga T, Kobayashi T, Taniguchi N, Yashuki M,*** *"Dual-plane Stereoscopic Particle Image Velocimetry: System Setup and Its Application on a Lobed Jet Mixing Flow" Experiments in Fluids, Vol. 31, No. 3, pp277-293, 2001*

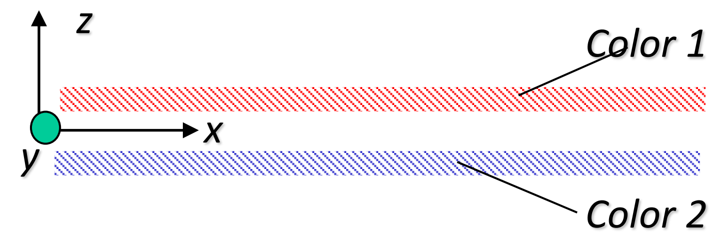
Dual-plane Stereoscopic PIV System!? How???

- Key point for the simultaneous stereoscopic PIV measurements at two parallel planes is to achieve scattering light separation.



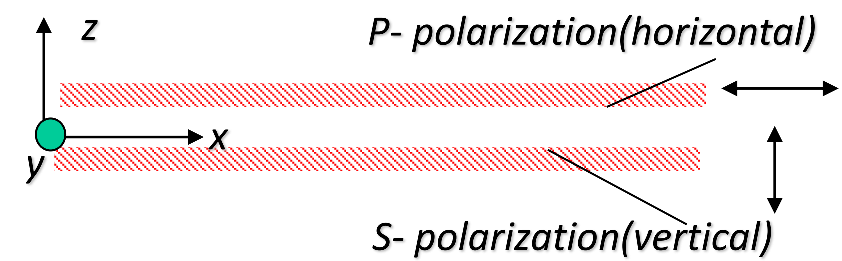
The scattering light signals from two measurement planes will be mixed without special consideration

- Color (wavelength) separation method.



Color (wavelength) separation method

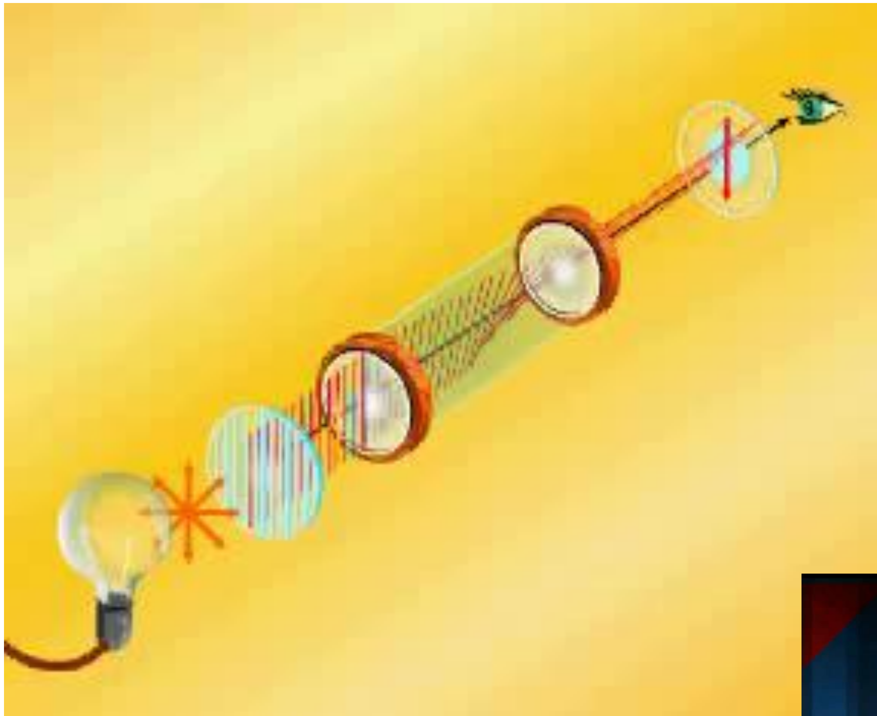
- Polarization separation method.
- The polarization of Mie scattering light is conservative in air.

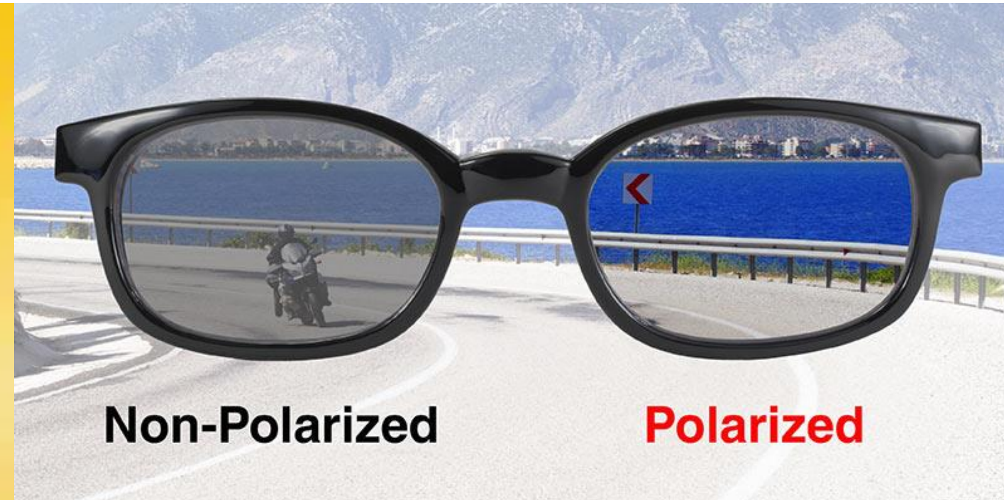


polarization separation method

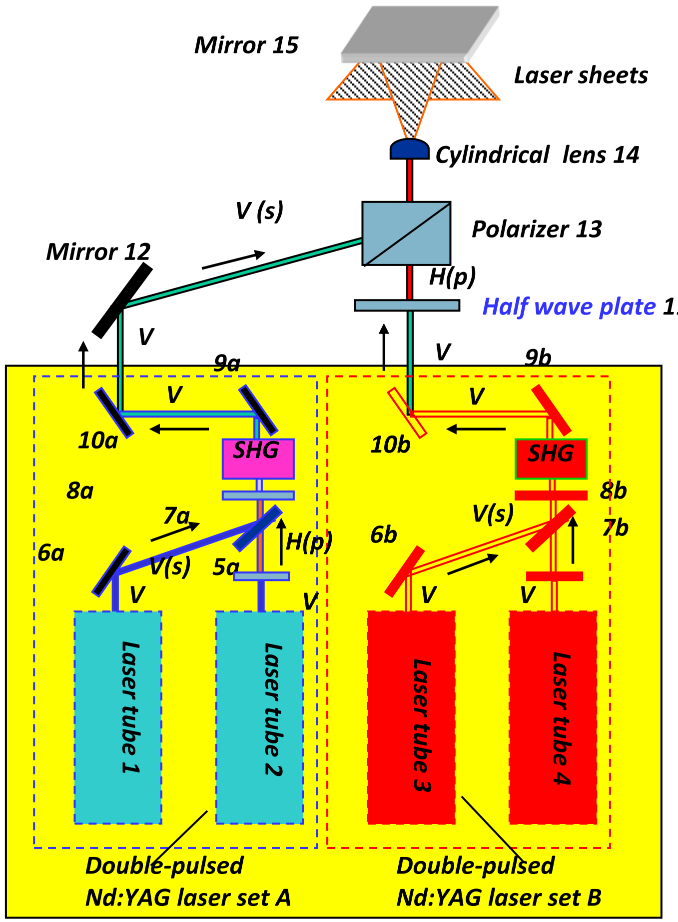
- Hu H, Saga T, Kobayashi T, Taniguchi N, Yashuki M, "Dual-plane Stereoscopic Particle Image Velocimetry: System Setup and Its Application on a Lobed Jet Mixing Flow" Experiments in Fluids, Vol. 31, No. 3, pp277-293, 2001

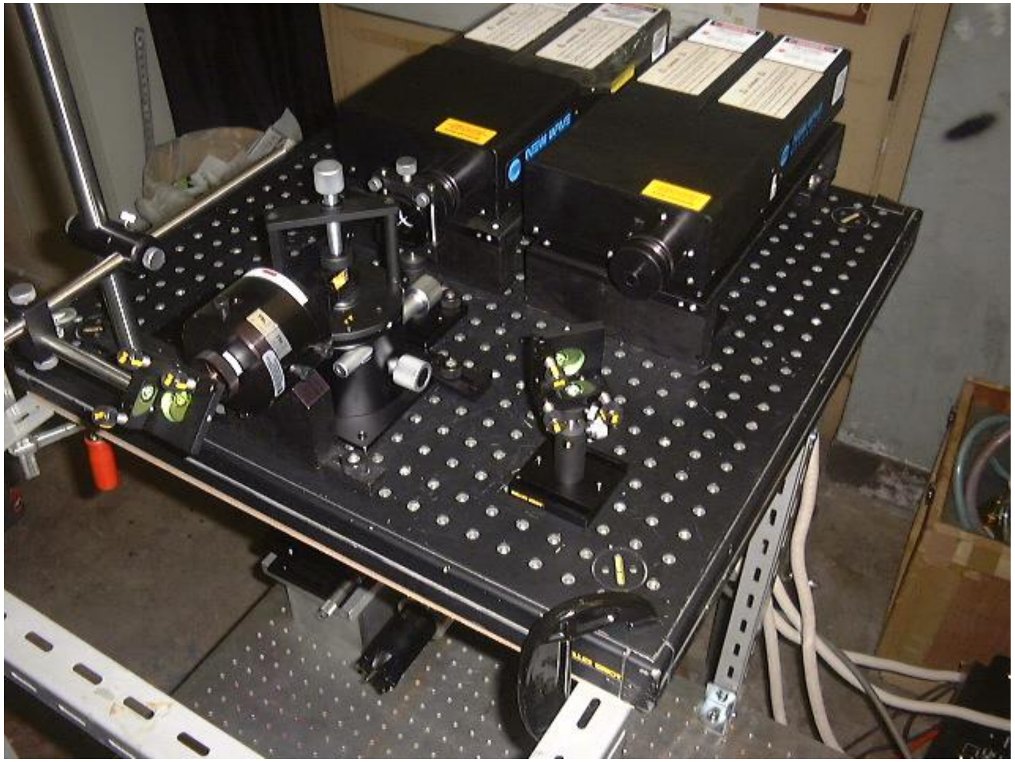
Polarization of light





Optical Set-up for Dual-plane SPIV Illumination

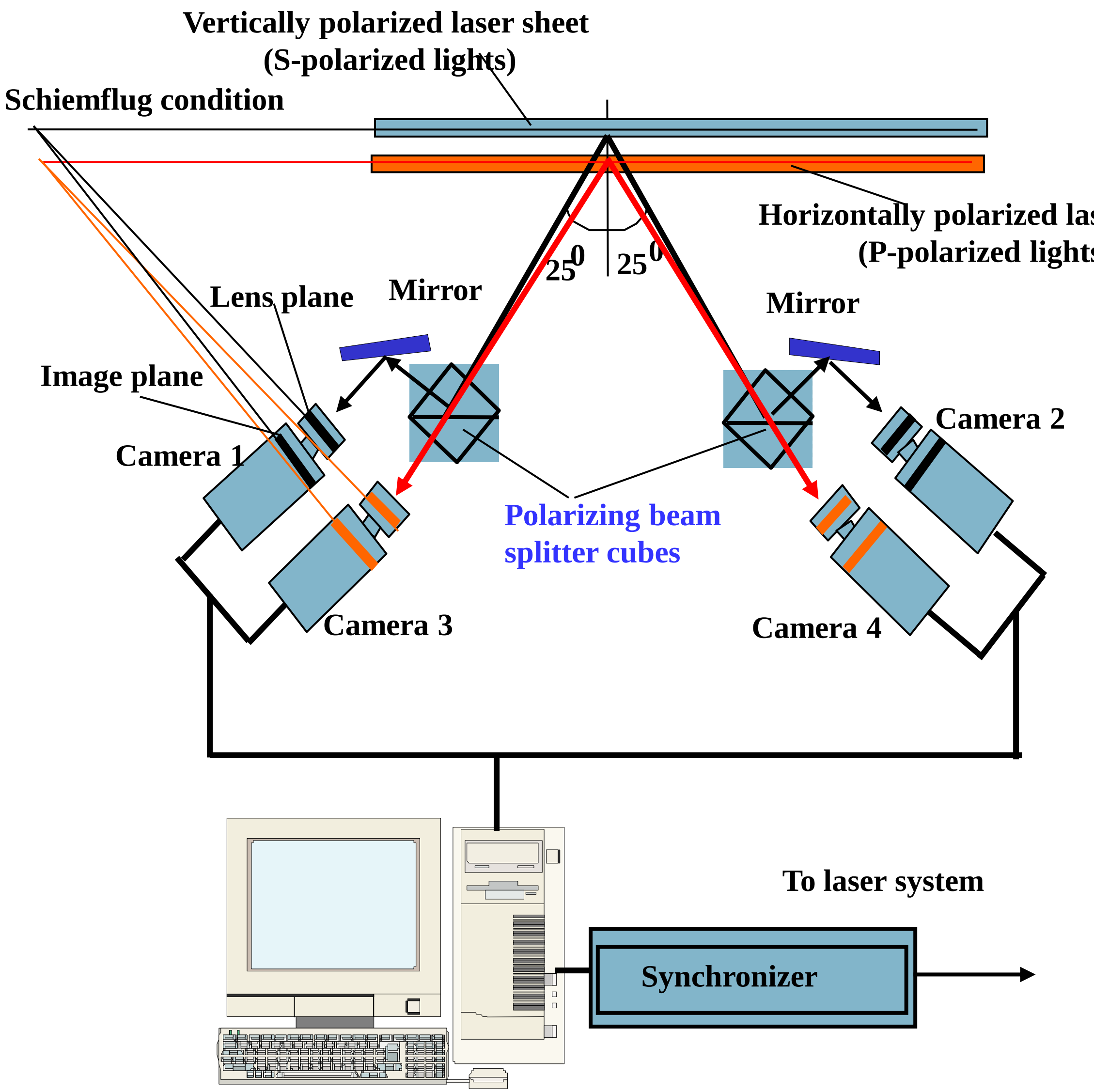


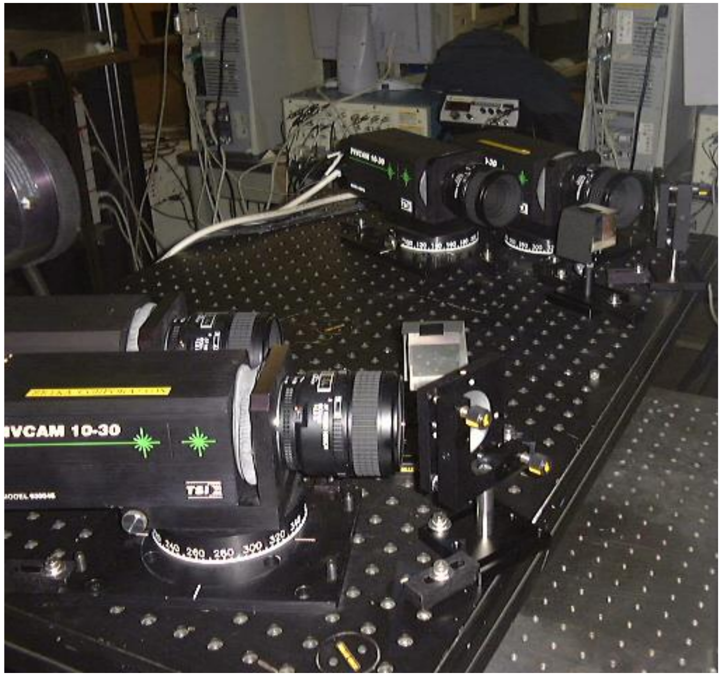


1 to 4 :	*laser tube*	*5,8,11:*	*half wave plate*
6,9, 10,15:	*mirror*	*7,13:*	*polarizer*
14:	*cylinder lens*		

- ***Hu H, Saga T, Kobayashi T, Taniguchi N, Yashuki M,*** *"Dual-plane Stereoscopic Particle Image Velocimetry: System Setup and Its Application on a Lobed Jet Mixing Flow" Experiments in Fluids, Vol. 31, No. 3, pp277-293, 2001*

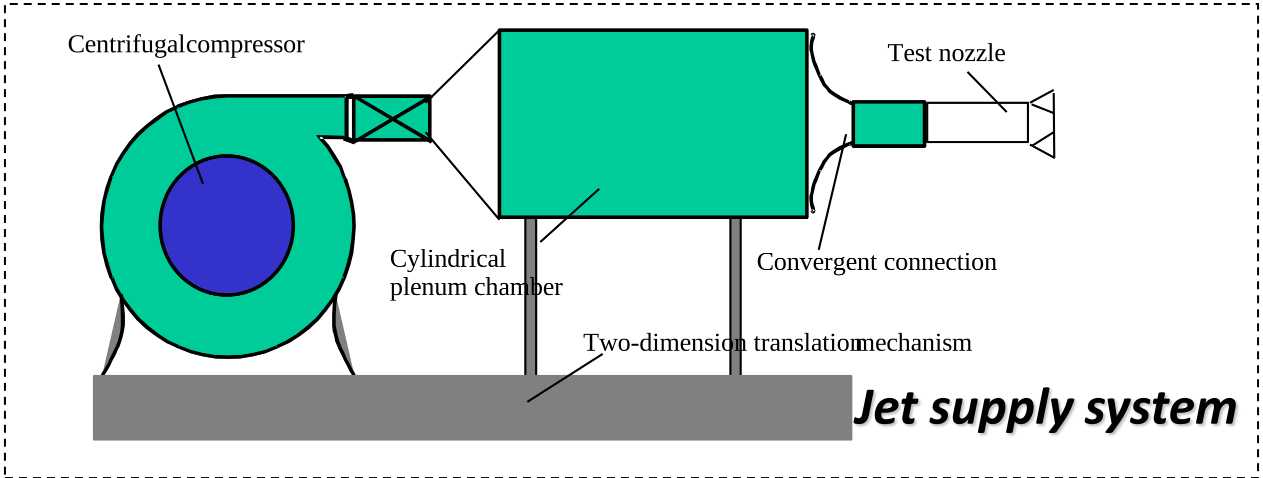
Set-up for Dual-plane SPIV Image Recording





- *__Hu H__, Saga T, Kobayashi T, Taniguchi N, Yashuki M, "Dual-plane Stereoscopic Particle Image Velocimetry: System Setup and Its Application on a Lobed Jet Mixing Flow" Experiments in Fluids, Vol. 31, No. 3, pp277-293, 2001*

Experimental Set-up

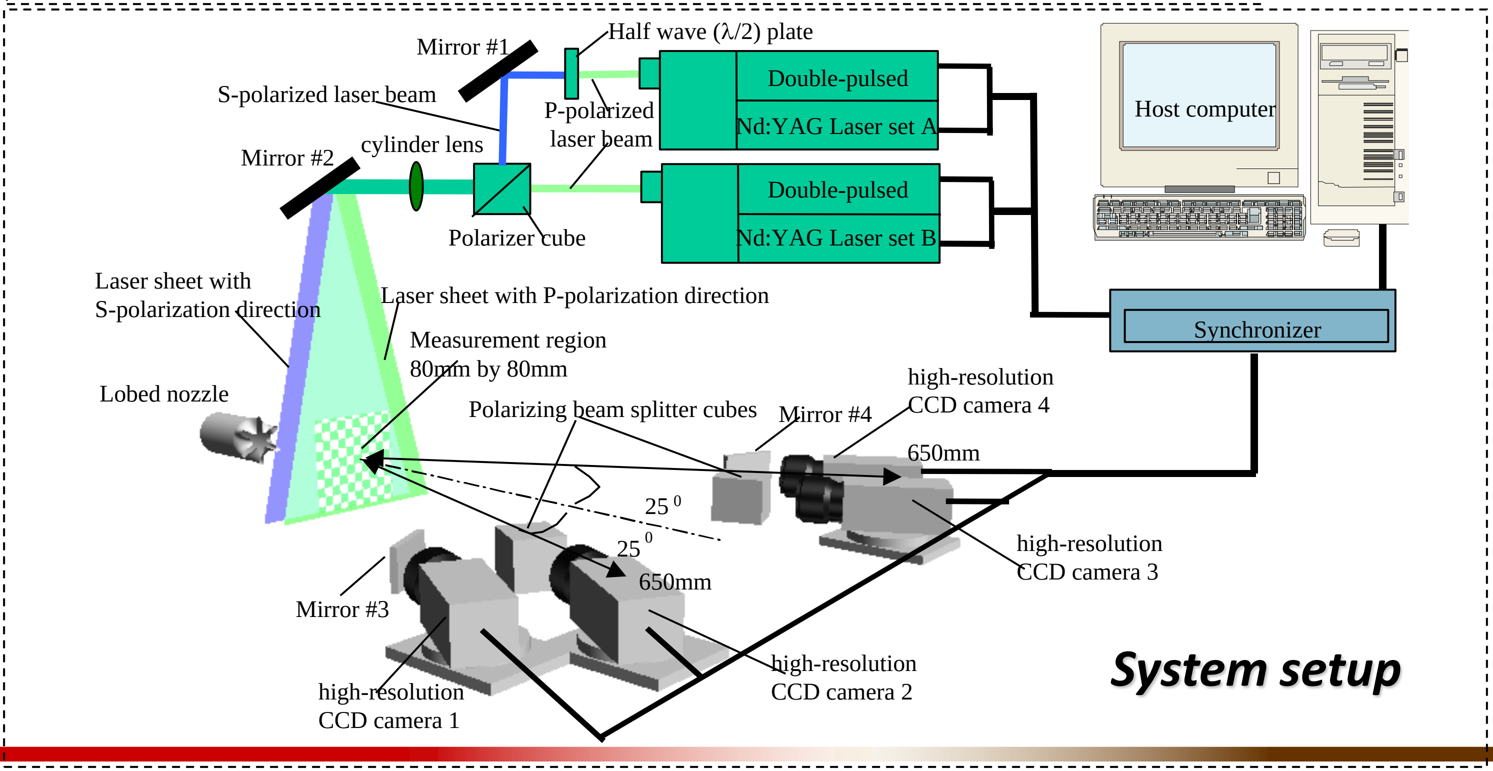


Flow condition :

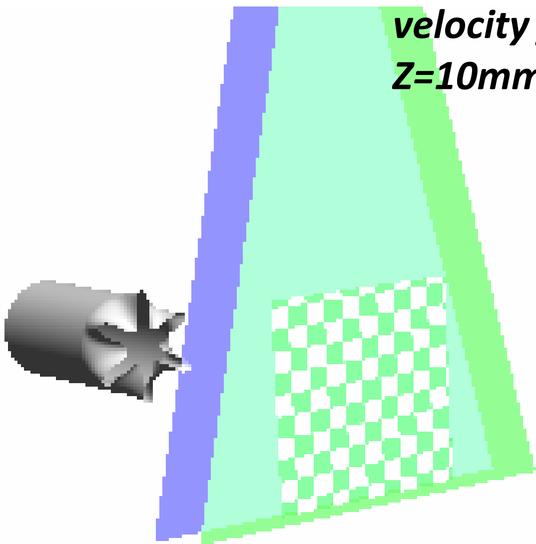
$U_{jet} = 20$ m/s

$D = 40$ mm

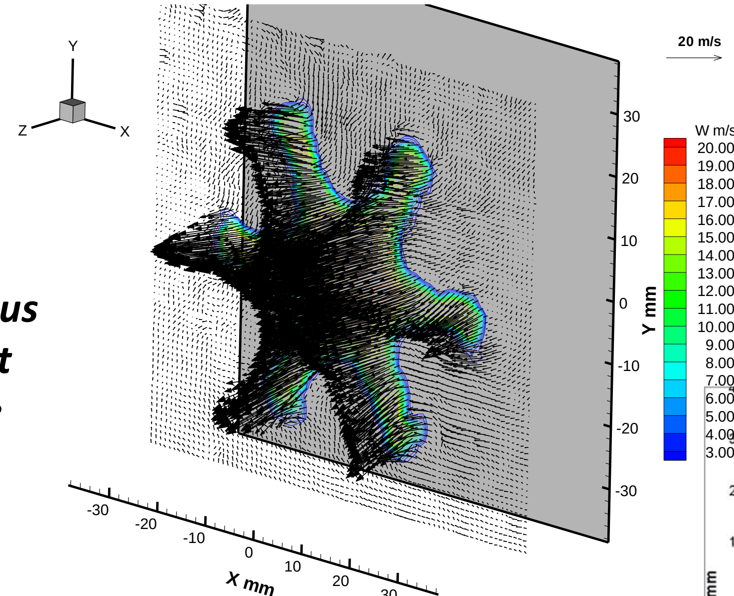
$Re = 60{,}000$

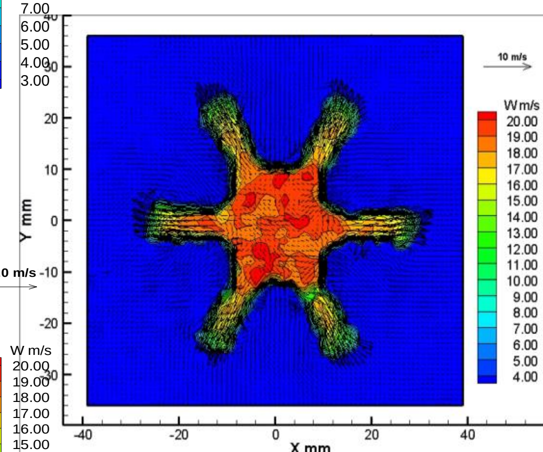


The Simultaneous Measurement Results of the Dual-plane Stereoscopic PIV System at Two Parallel Planes

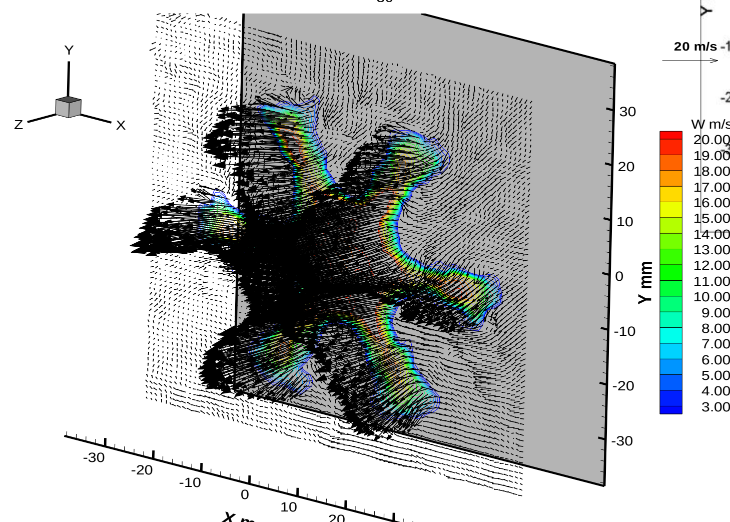


A. Instantaneous velocity field at Z=10mm plane



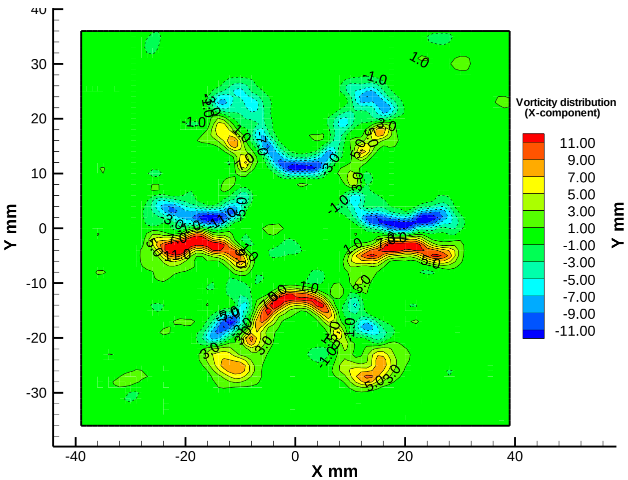


B. the simultaneous velocity field at Z=12mm plane

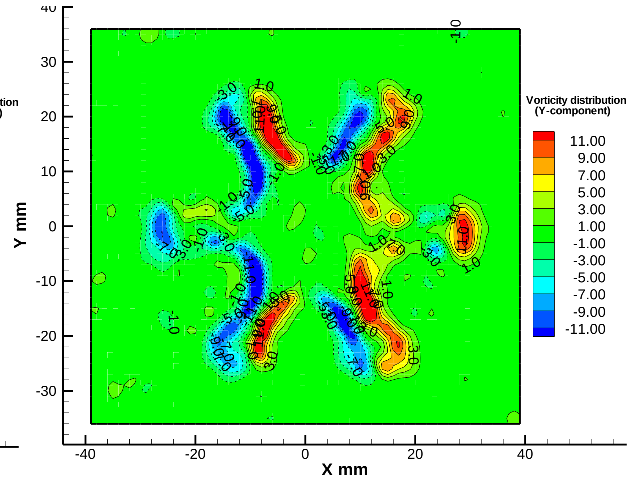


- ***<u>Hu H</u>, Saga T, Kobayashi T, Taniguchi N, Yashuki M,*** *"Dual-plane Stereoscopic Particle Image Velocimetry: System Setup and Its Application on a Lobed Jet Mixing Flow" Experiments in Fluids, Vol. 31, No. 3, pp277-293, 2001*

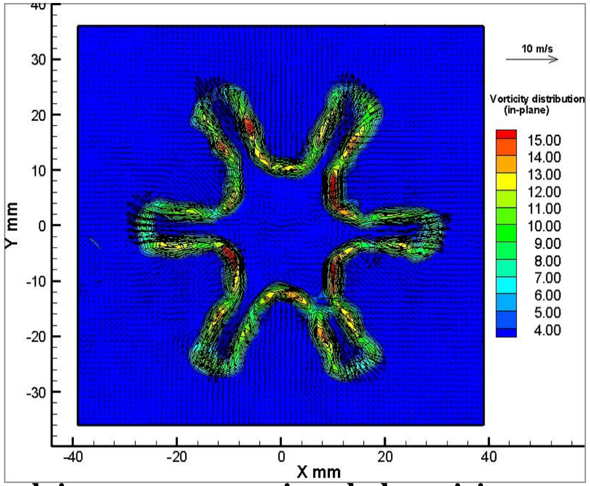
Distributions of Three Components of Vorticity Vectors



a. instantaneous vorticity ϖ_x

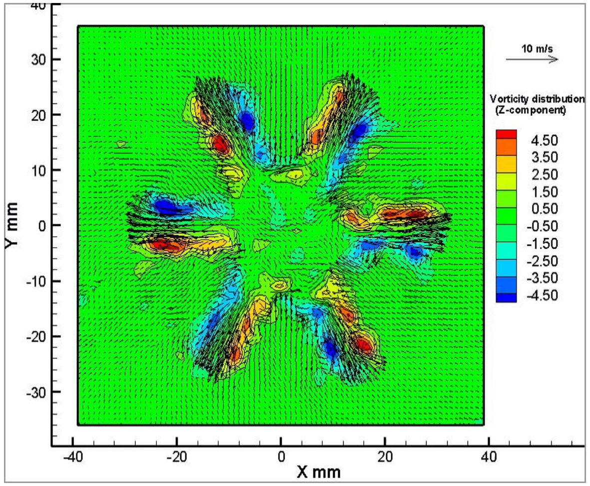


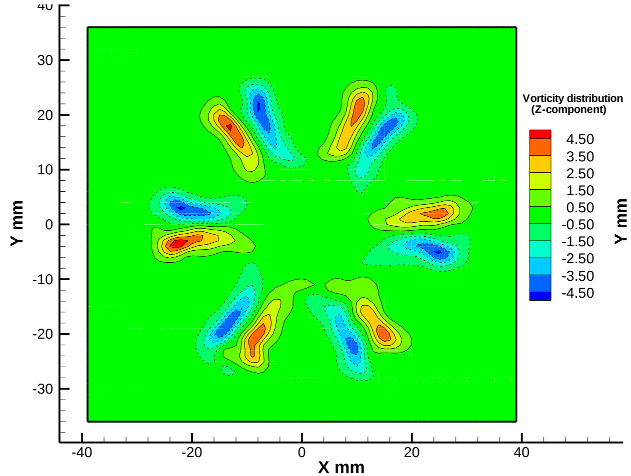
b. instantaneous vorticity ϖ_y



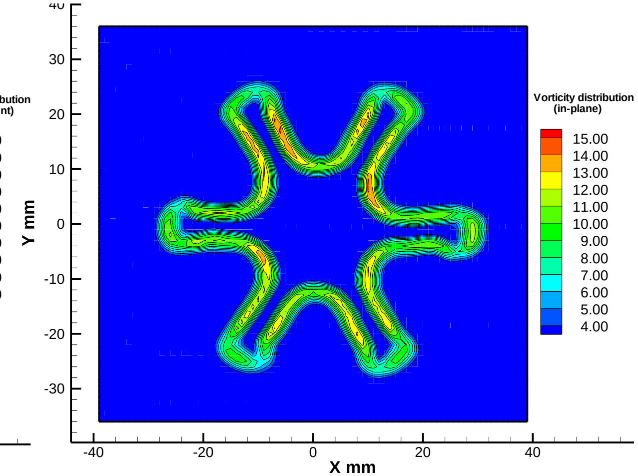
d. instantaneous azimuthal vorticity

$$\varpi_{in-plane} = \sqrt{\varpi_x^{\ 2} + \varpi_y^{\ 2}}$$





e. ensemble-averaged streamwise vorticity ϖ_z

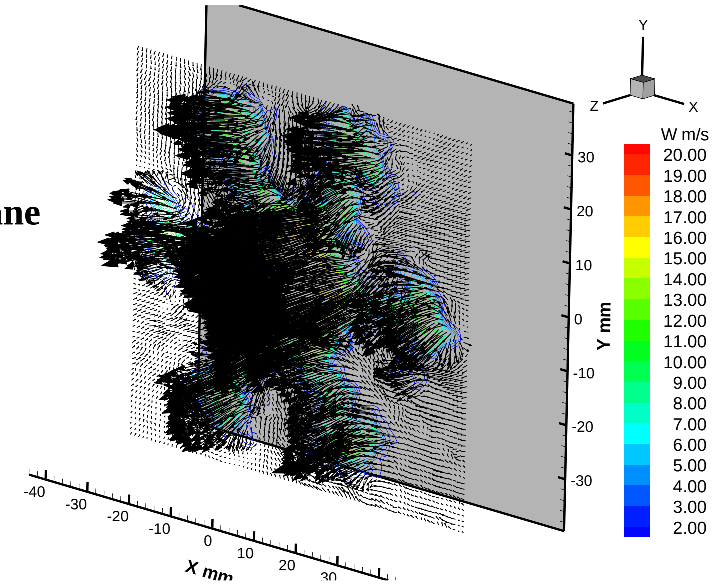


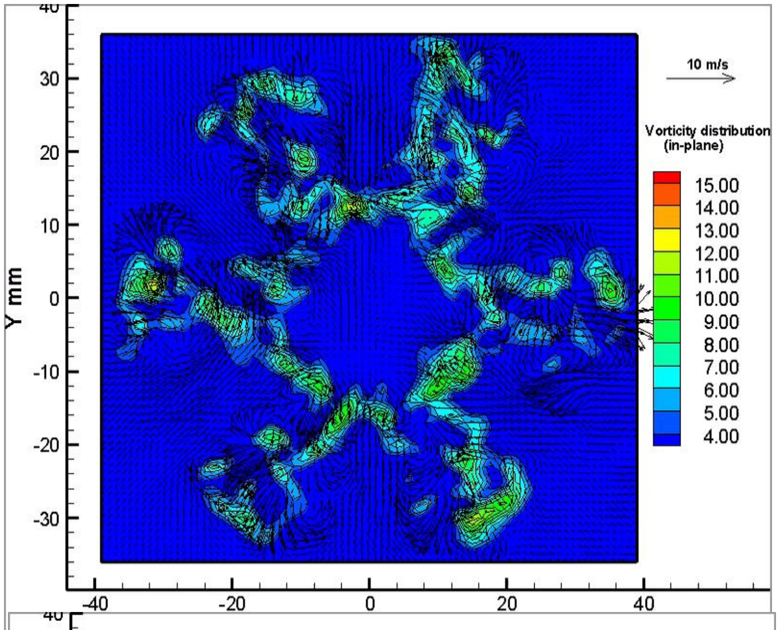
f. ensemble-averaged azimuthal vorticity $\varpi_{in-plane} = \sqrt{\varpi_x^{\ 2} + \varpi_y^{\ 2}}$

- Hu H, Saga T, Kobayashi T, Taniguchi N, Yashuki M, "Dual-plane Stereoscopic Particle Image Velocimetry: System Setup and Its Application on a Lobed Jet Mixing Flow" Experiments in Fluids, Vol. 31, No. 3, pp277-293, 2001

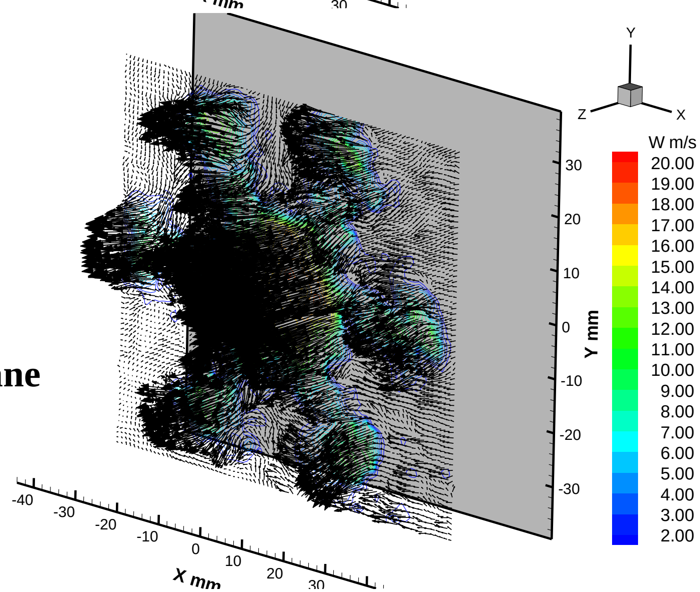
Measurement Results of the Dual-plane Stereoscopic PIV System

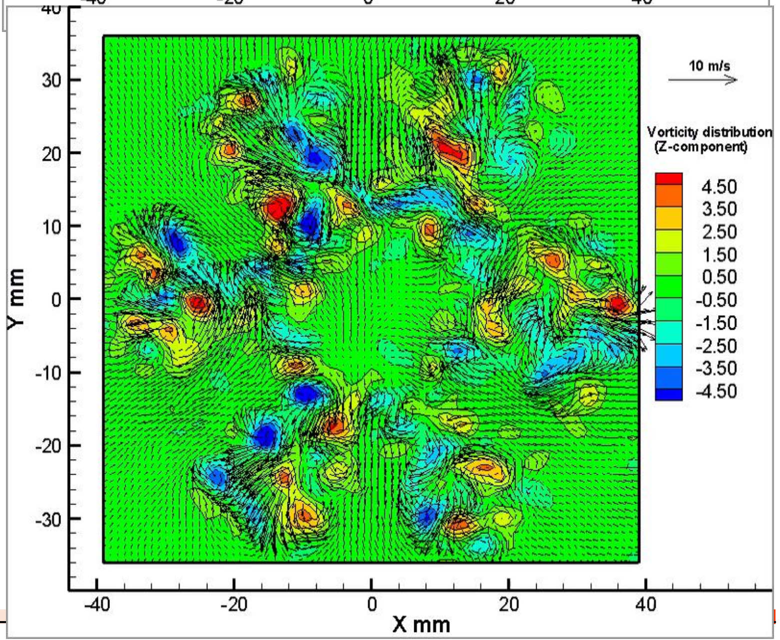
Z=40mm plane



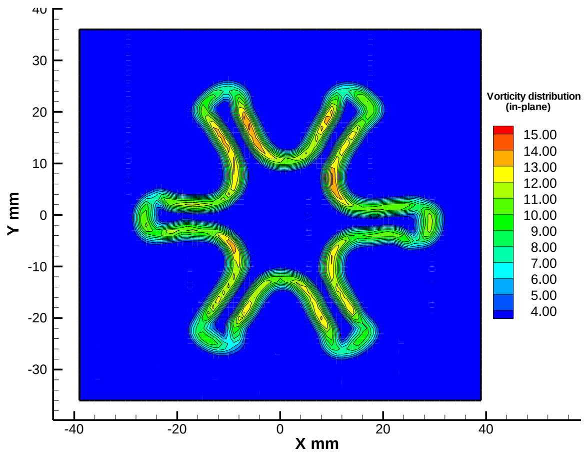


Z=42mm plane

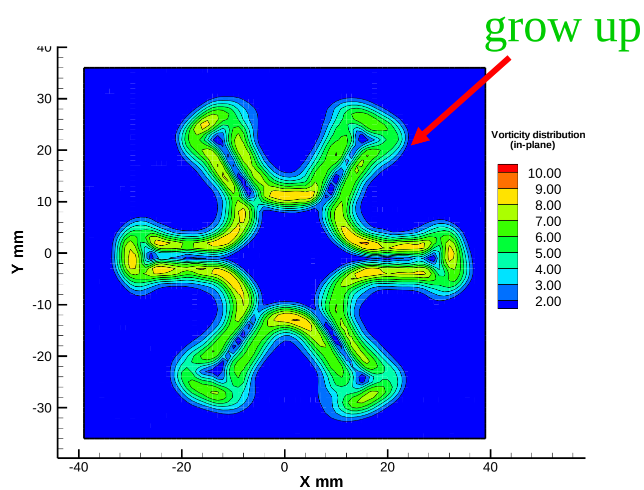




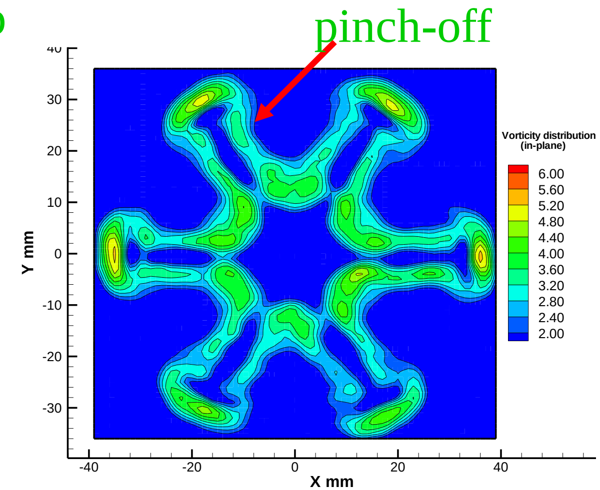
Evolution of Spanwise Kelvin-Helmholtz Vortex Structures



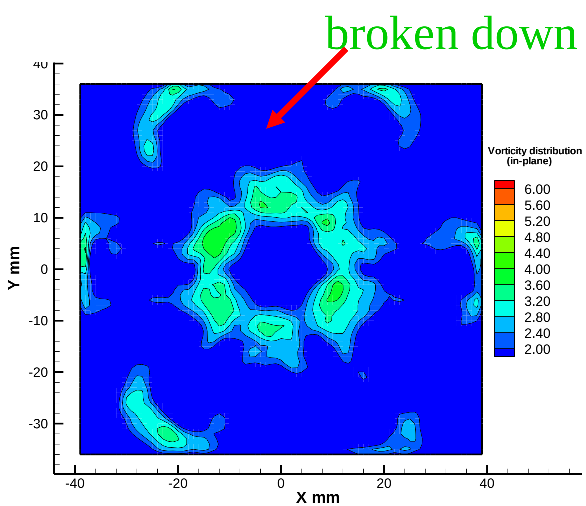
a. Z=10mm cross plane (Z/D=0.25)



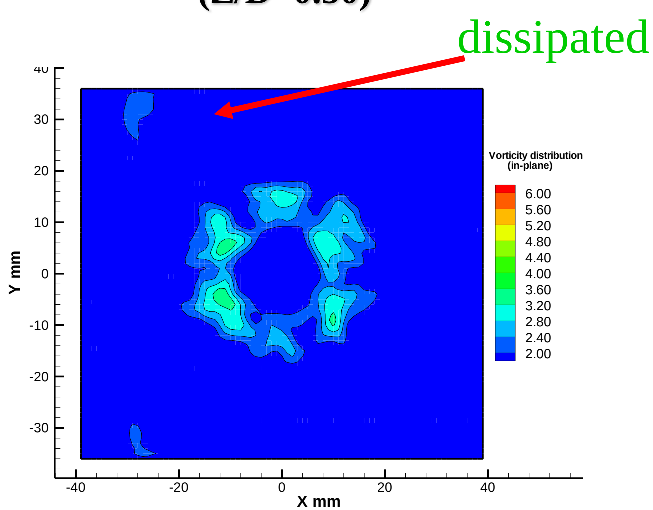
b. Z=20mm cross plane (Z/D=0.50)



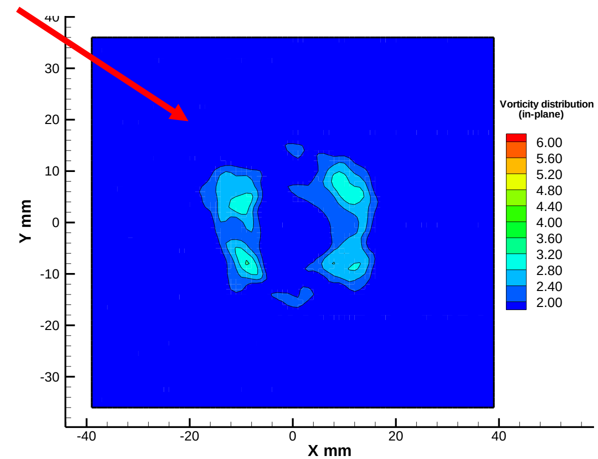
c. Z=40mm cross plane (Z/D=1.0)



d. Z=60mm cross plane (Z/D=1.5)

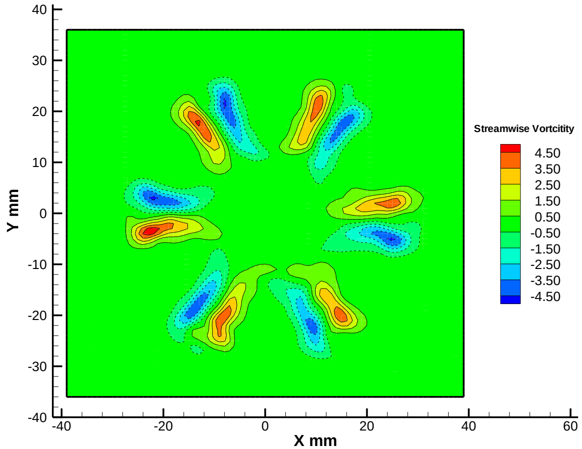


e. Z=80mm cross plane (Z/D=2.0)

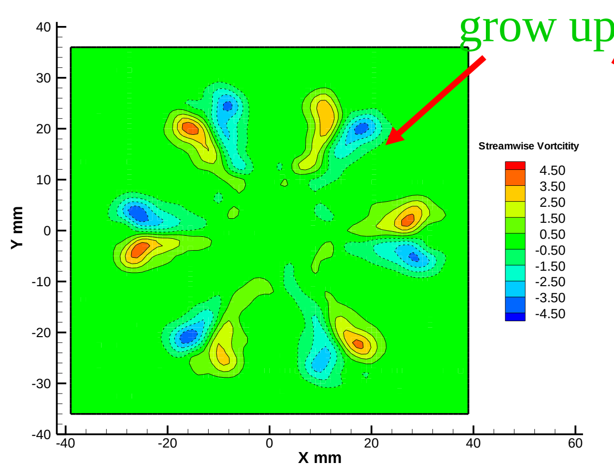


f. Z=120mm cross plane (Z/D=3.0)

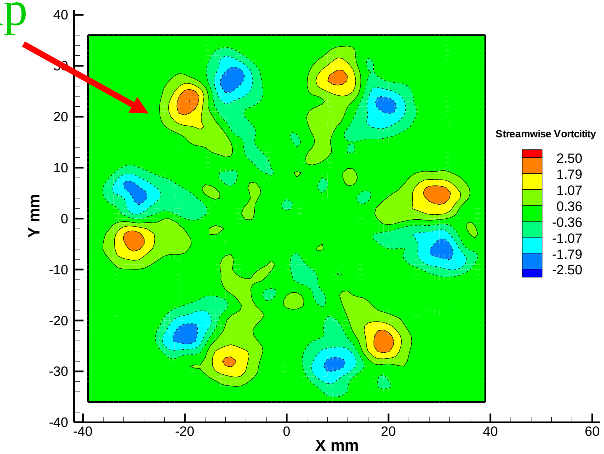
Evolution of Large-scale Streamwise Vortex Structures



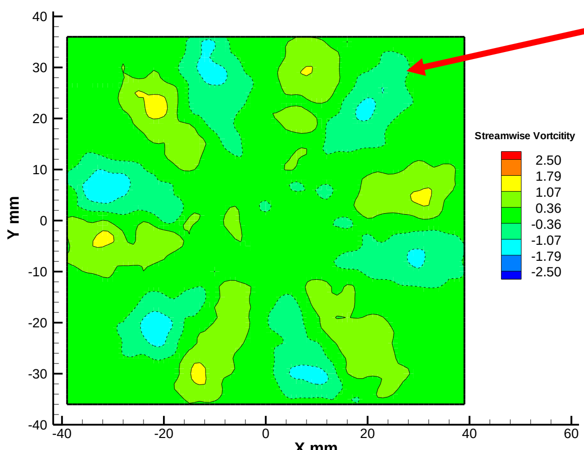
a. Z=10mm cross plane (Z/D=0.25)



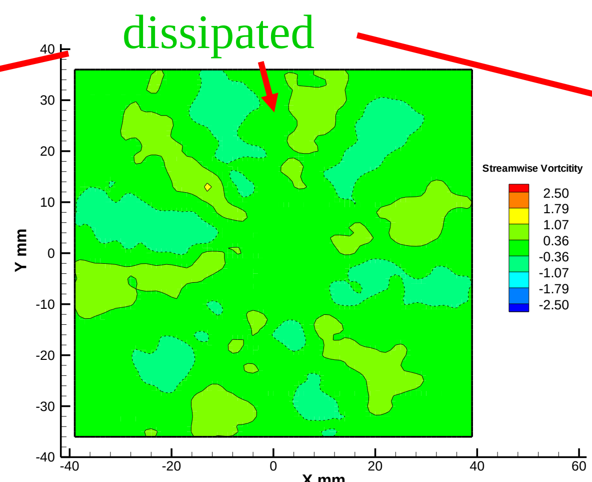
b. Z=20mm cross plane (Z/D=0.50)



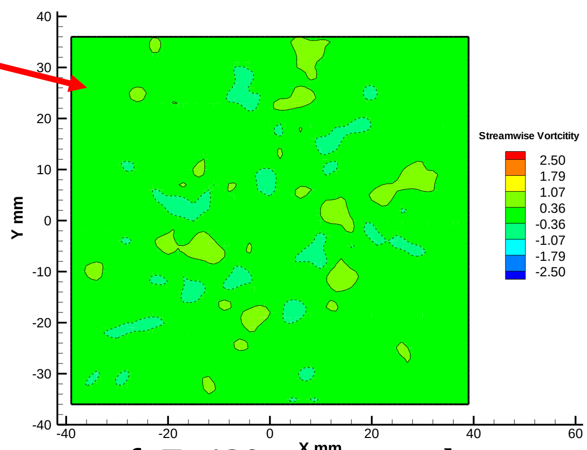
c. Z=40mm cross plane (Z/D=1.0)



d. Z=60mm cross plane (Z/D=1.5)



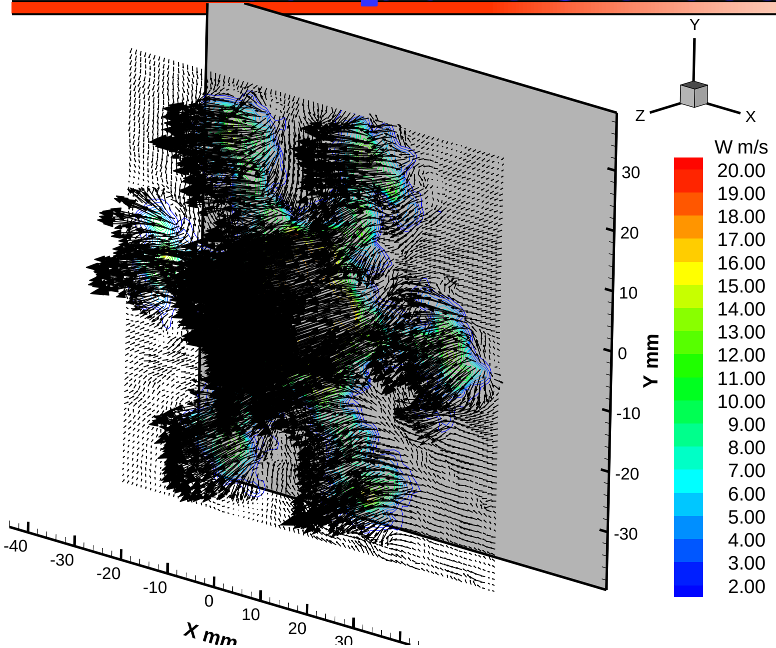
e. Z=80mm cross plane (Z/D=2.0)



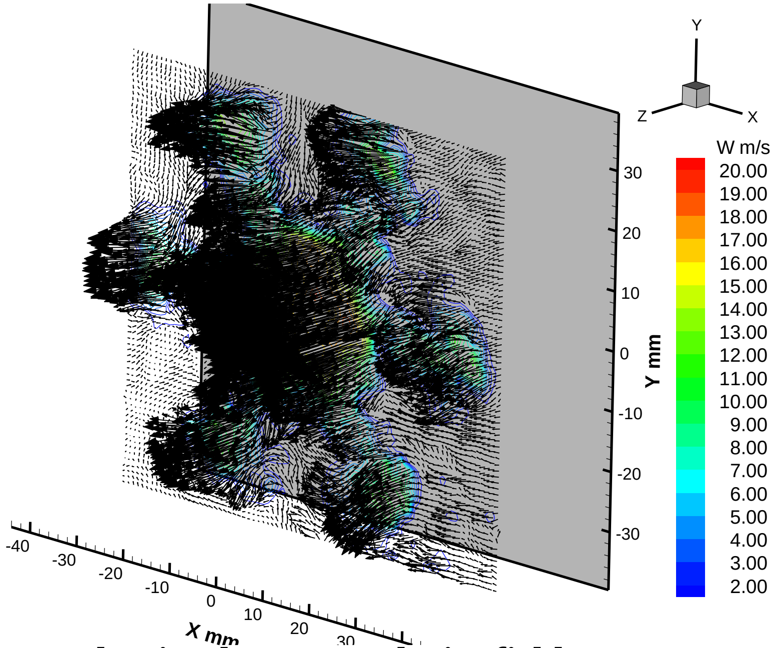
f. Z=120mm cross plane (Z/D=3.0)

- *Hu H, Saga T, Kobayashi T, Taniguchi N, Yashuki M, "Dual-plane Stereoscopic Particle Image Velocimetry: System Setup and Its Application on a Lobed Jet Mixing Flow" Experiments in Fluids, Vol. 31, No. 3, pp277-293, 2001*

The Simultaneous Measurement Results of the Dual-plane Stereoscopic PIV at two separate planes



A. Instantaneous velocity field at Z=40mm plane



B. the simultaneous velocity field at Z=42mm plane

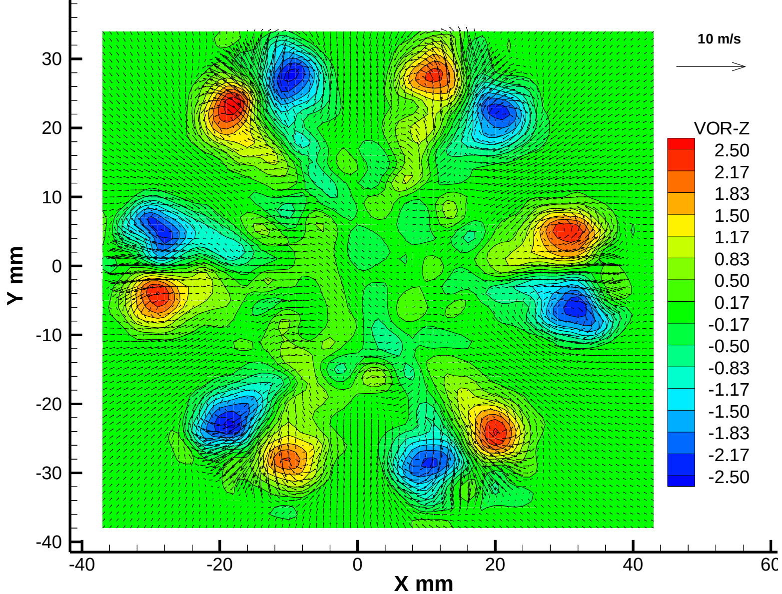
All three components of vorticity vectors:

$$\varpi_x = \frac{D}{U_0}\left(\frac{\partial w}{\partial y} - \frac{\partial v}{\partial z}\right); \varpi_y = \frac{D}{U_0}\left(\frac{\partial u}{\partial z} - \frac{\partial w}{\partial x}\right); \varpi_z = \frac{D}{U_0}\left(\frac{\partial v}{\partial x} - \frac{\partial u}{\partial y}\right)$$

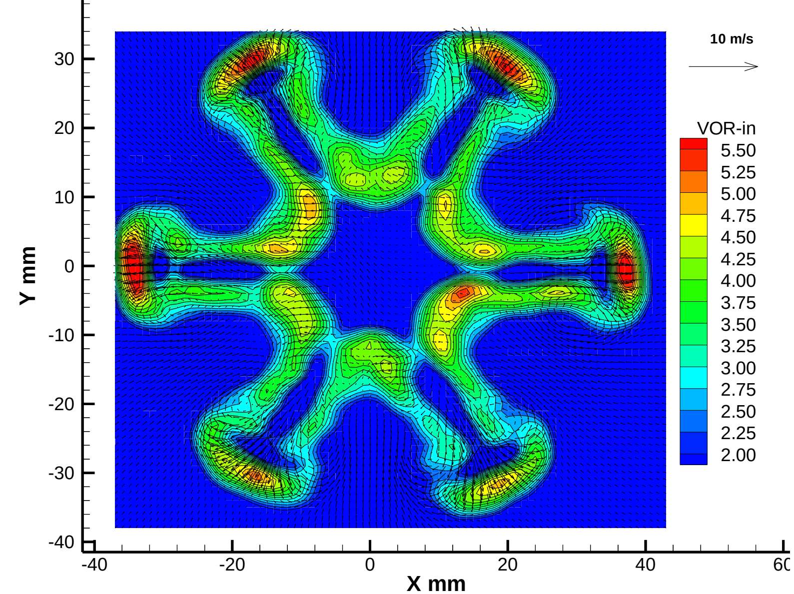
Cross correlation coefficient of flow variables at $Z=Z_1$ and $Z=Z_2$ planes:

$$Cross - R(u', v', w') = \frac{1}{N}\sum_{t}^{t=N}(u'(x,y,z_1,t) \bullet u'(x,y,z_2,t) + v'(x,y,z_1,t) \bullet v'(x,y,z_2,t) + w'(x,y,z_1,t) \bullet w'(x,y,z_2,t))$$

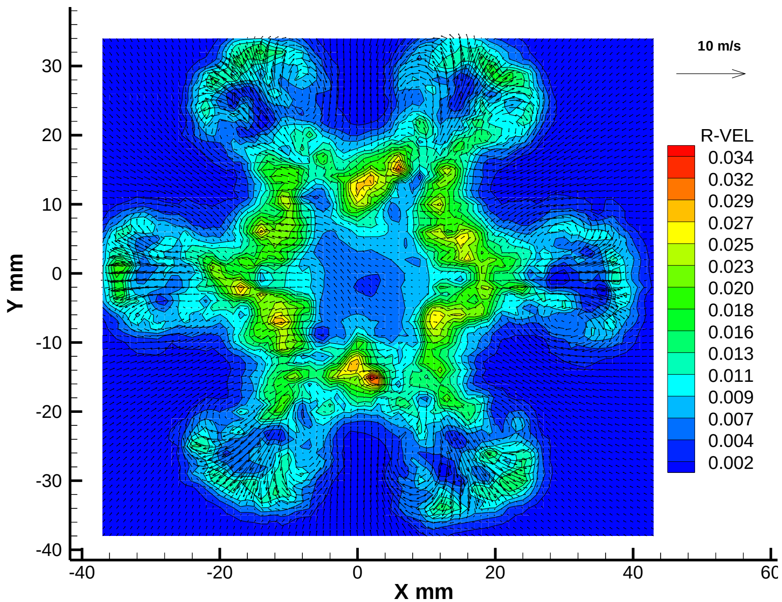
$$Cross - R(\varpi_z) = \frac{1}{N}\sum_{t=1}^{t=N}\varpi_z(x,y,z_1,t) \bullet \varpi_z(x,y,z_2,t)$$



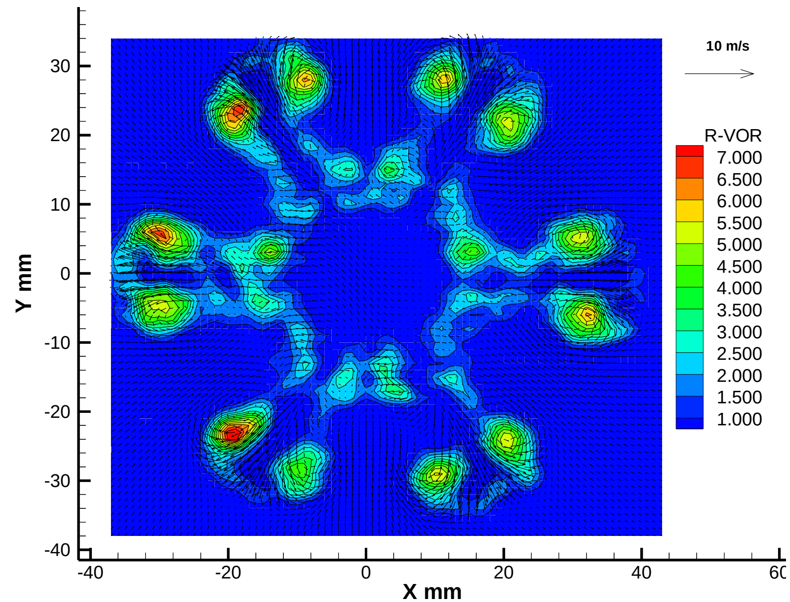
A. ensemble averaged streamwise vorticity



B. ensemble averaged in-plane vorticity



C. cross-correlation coefficeints of turbulent velocity



D. cross-correlation coefficeints of streamwise vorticity

In the Z=40 mm cross plane of the lobed jet flow

The auto-correlation coefficients measurement with two illuminating laser sheets overlapped at the same plane

- ***The temporal resolution of conventional PIV systems is limited to the framing rate of the cameras used for PIV image recording. Such limitation is much more serious for the PIV systems with high-resolution digital cameras. For example, the frame rate of a 1K by 1K pixel camera is always about 15Hz and much lower for the cameras with higher resolution. Therefore, a conventional PIV system is typically insufficient to record time sequences in rapidly evolving or turbulent flows. Therefore, only time-averaged quantities, such as the mean velocity and Reynolds stress, can be obtained to characterize the flow unsteadiness.***

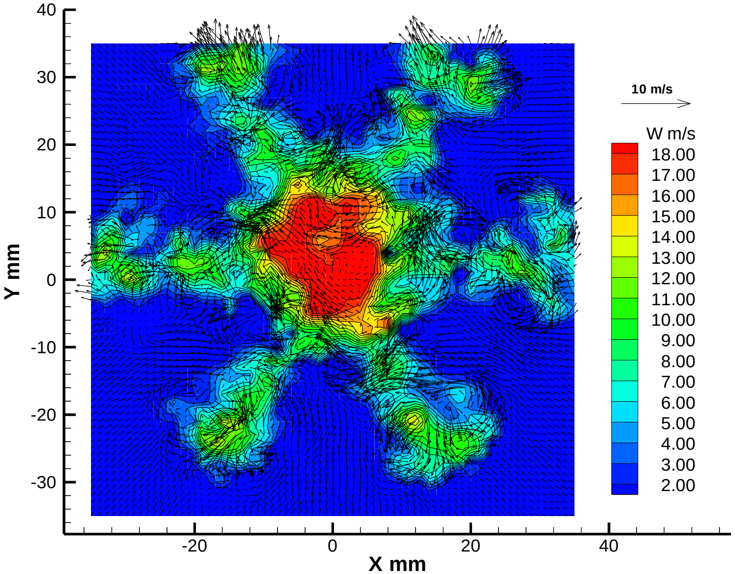
- ***The limitation of the slow framing rate of image recording camera can be over-passed by the present dual-plane stereoscopic PIV system. By adjusting the two illuminating laser sheets overlapped at the same plane, the flow field can be measured synchronously at variable separation times up to μs order.***

$$Auto-R(X)=\frac{1}{N}\sum_{n=0}^{N-1}X_n(x,y,z,t)\bullet X_n(x,y,z,t+\tau)$$

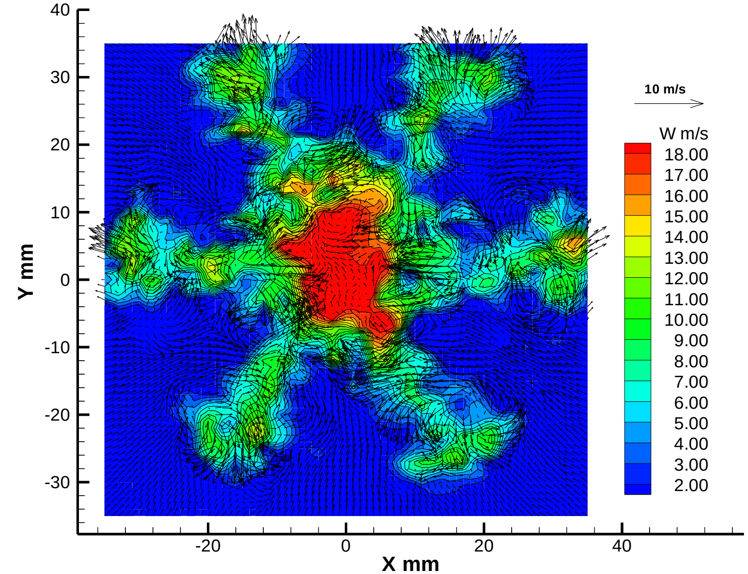
- ***Hu H, Saga T, Kobayashi T, Taniguchi N, Yashuki M,*** *"Dual-plane Stereoscopic Particle Image Velocimetry: System Setup and Its Application on a Lobed Jet Mixing Flow" Experiments in Fluids, Vol. 31, No. 3, pp277-293, 2001*

The Measurement Results of the Dual-plane Stereoscopic PIV system

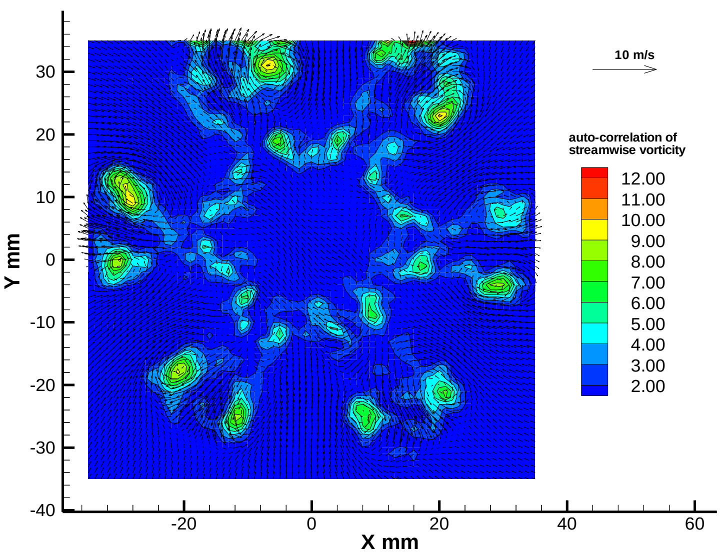
(the two illuminating laser sheets overlapped at the same Z=40mm plane with 0.1ms time delay)



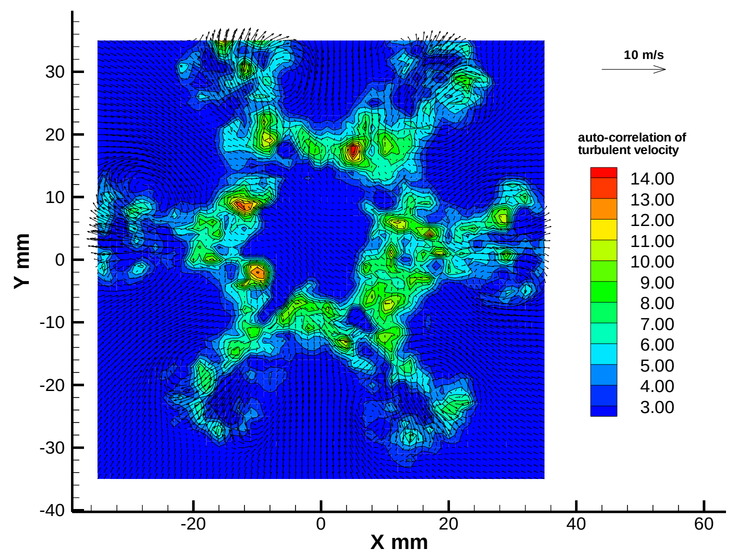
A. instantaneous velocity field at time t=T0



B.instantaneous velocity field at time t=T0+0.1ms



c. auto-correlation of the streamwsie vorticity

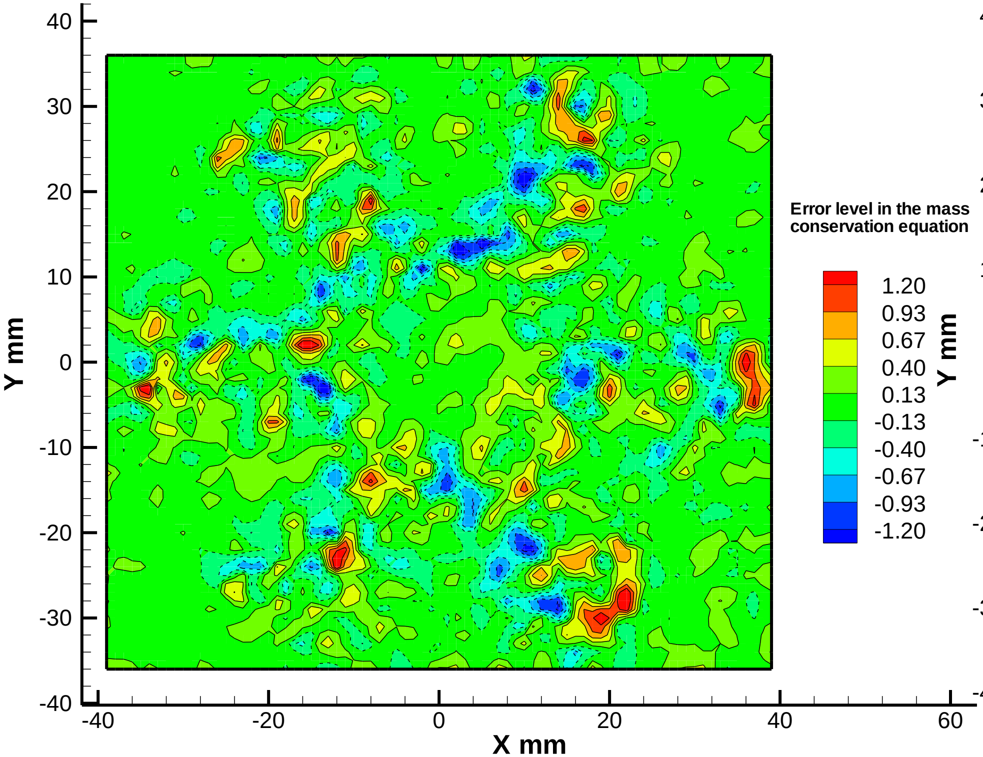


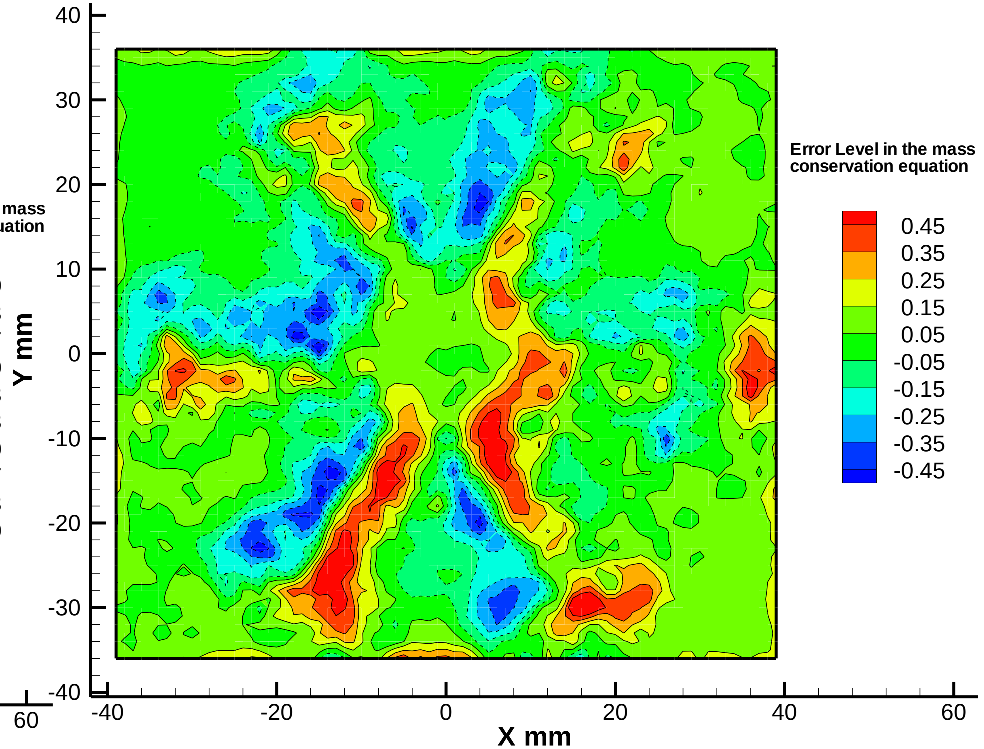
d. auto-correlation coefficents of the turbulent velocity

Mass Conservation Equation

$$Q = \frac{D}{U_0}\left(\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z}\right)$$

Z=40mm cross plane





Instantaneous distribution
(averaged value Q=0.35)
(equivalent error velocity $\Delta w/U_0$=1.75%)

ensemble-averaged distribution
(averaged value Q=0.13)
(equivalent error velocity $\Delta w/U_0$=0.65%)