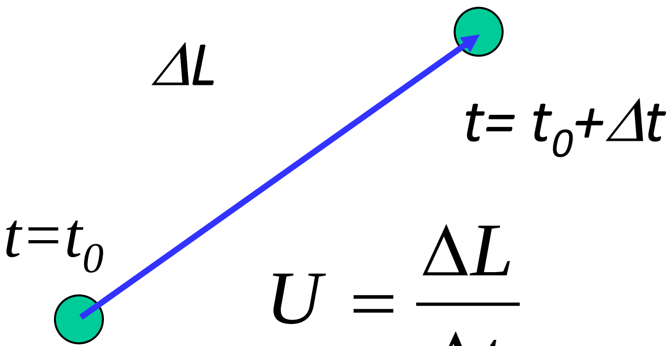
Lecture 17: Stereoscopic Particle Image Velocimetry - Part 01

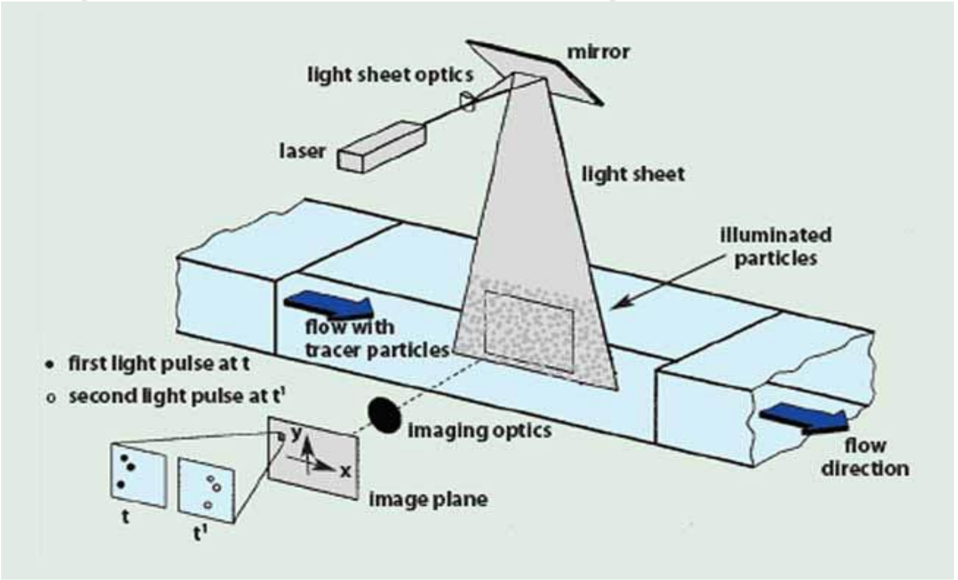
Dr. Hui Hu
Martin C. Jischke Professor in Aerospace Engineering
Dept. of Aerospace Engineering, Iowa State University
537 Bissell Road, Ames, Iowa 50011-1096, USA.
Tel: 515-294-0094 (O) / Fax: 515-294-3262 (O)
Email: huhui@iastate.edu

❑ PIV Image Processing

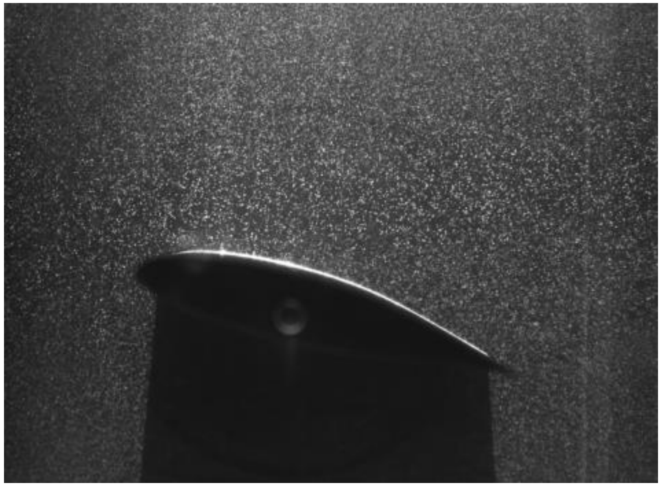
- ***Time-of-flight method:*** *to measure the displacements of the tracer particles seeded in the flow in a fixed time interval.*



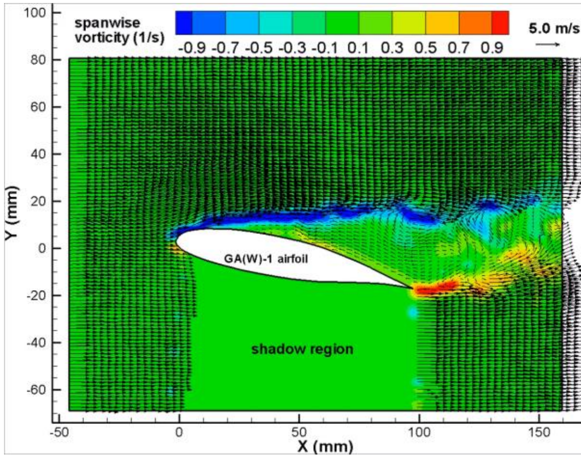
$$U = \frac{\Delta L}{\Delta t}$$



a. T=t0



b. T=t0+10μs

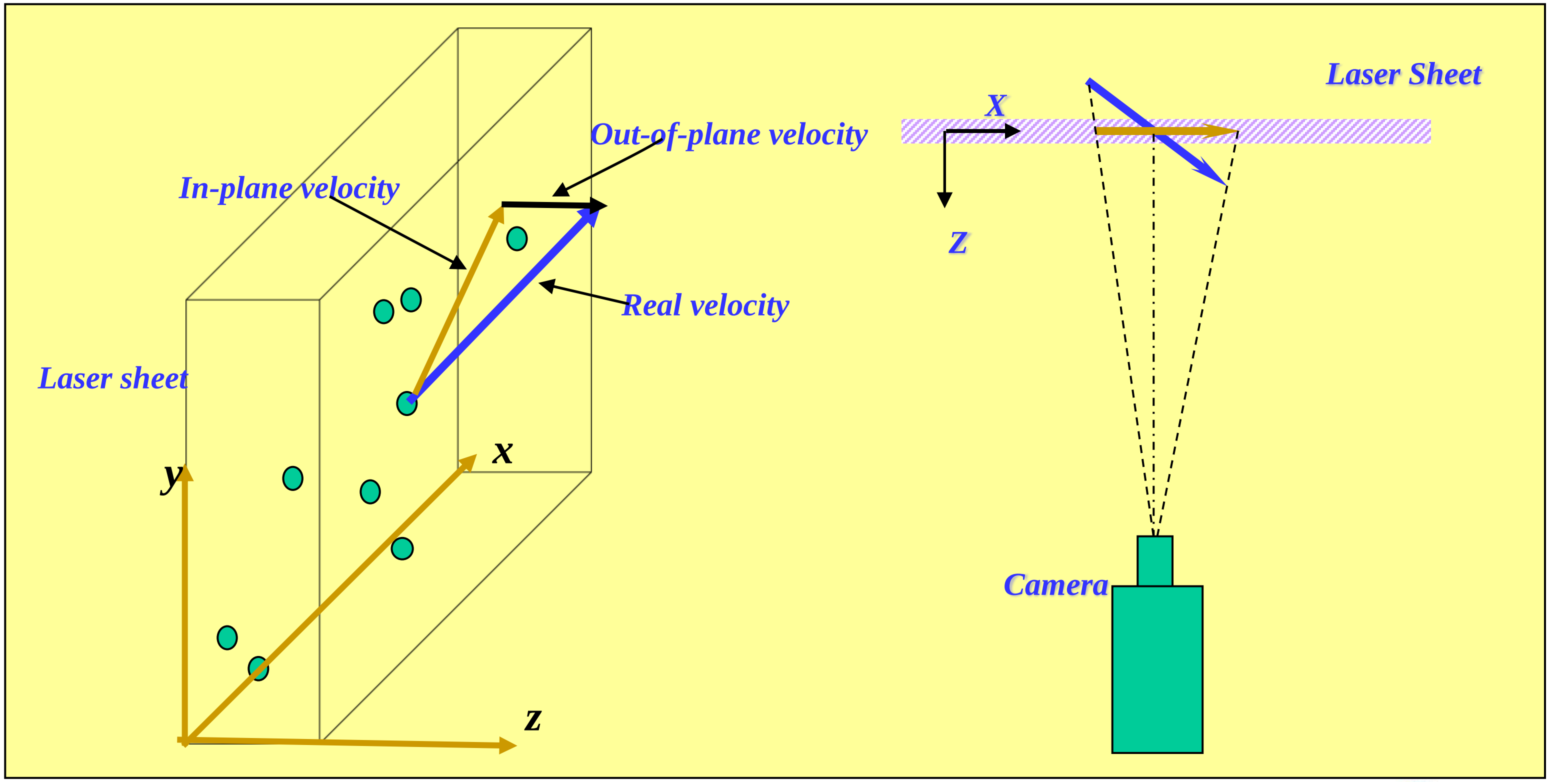


Corresponding Velocity field

Effect of the out-of-plan velocity for 2-D PIV measurements

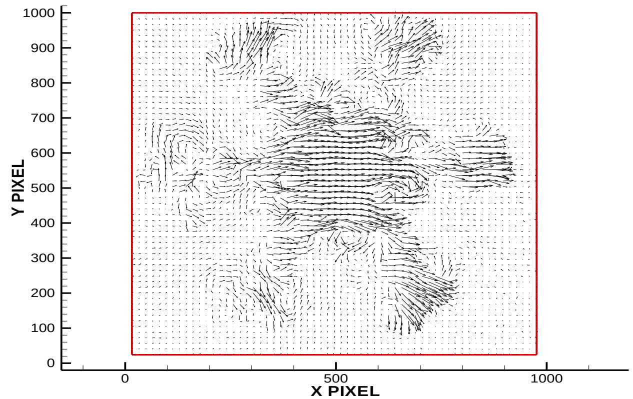
case	V_M	V_X	W_M	N	D_M	CR-U	CR-V	AVE-ERR
A	7.5	15.0	0.017	4,000	5.0	0.991	0.980	7.12%
F	7.5	15.0	0.17	4,000	5.0	0.698	0.748	13.75%
G	7.5	15.0	0.34	4,000	5.0	0.363	0.394	41.30%
H	7.5	15.0	1.70	4,000	5.0	-0.06	-0.05	132.1%

V_M: average velocity (pixel/interval)
V_X : maximum Velocity (pixel/interval)
W_M: out of plane velocity (laser width/interval)
N: tracer number
D_M: tracer average diameter (pixel)
Aver-Err: average error of PIV results without sub-pixel interpolation.

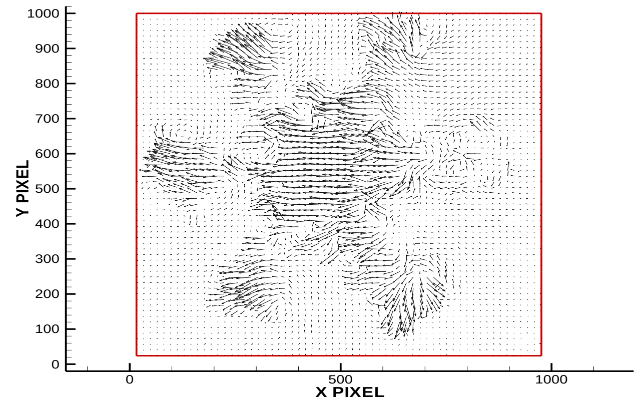


Stereoscopic Imaging Technique

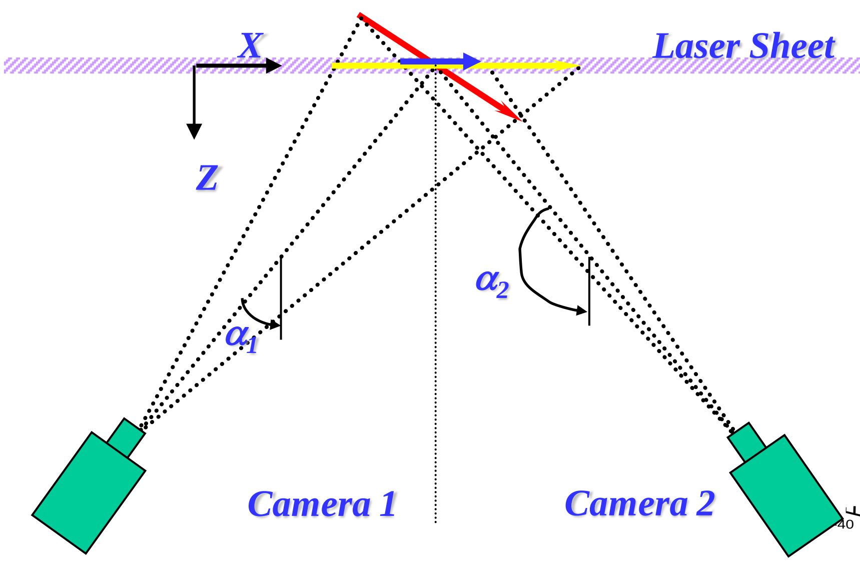
Stereoscopic PIV technique

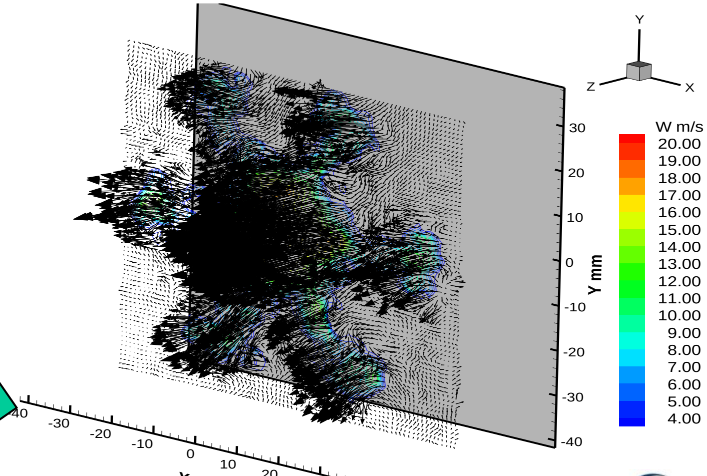


Displacement vectors in left camera



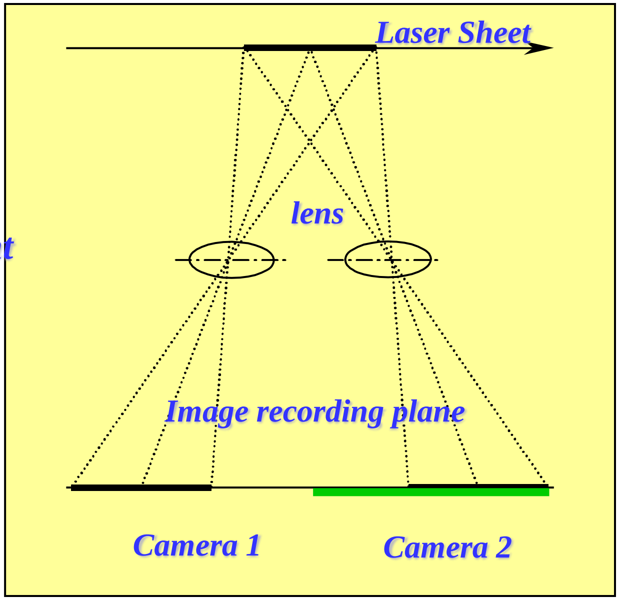
Displacement vectors in right camera

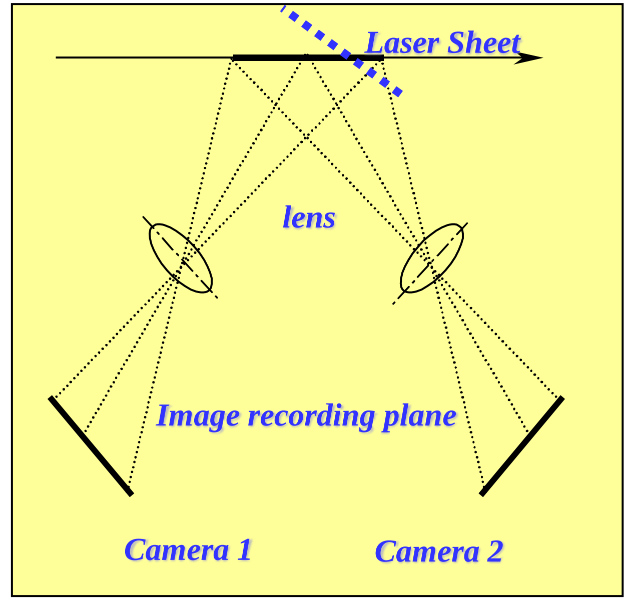




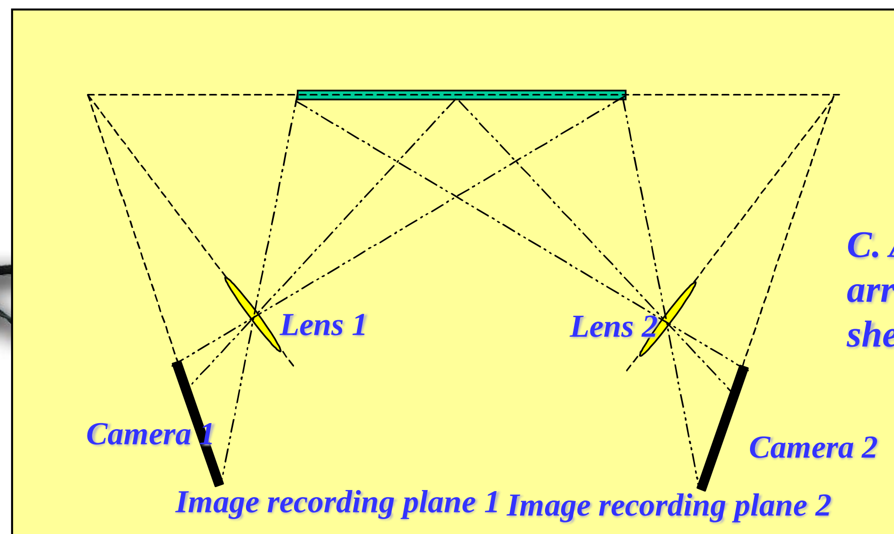
Stereoscopic PIV technique

a. lens translation arrangement



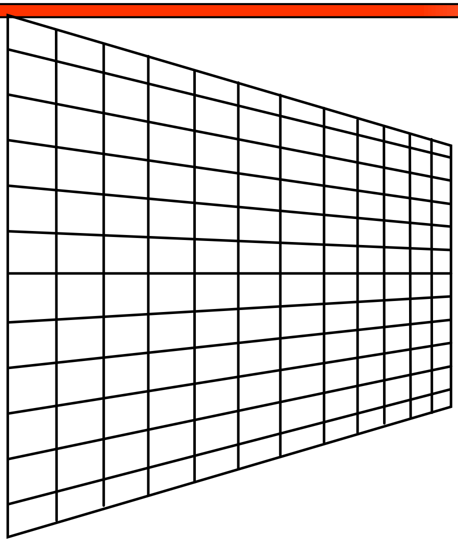


b. angle displacement arrangement

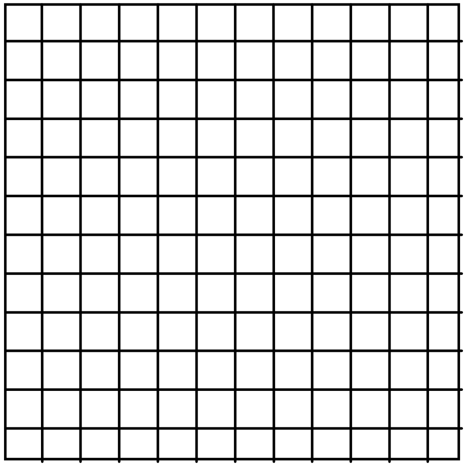


C. Angle displacement arrangement with sheimpflug condition

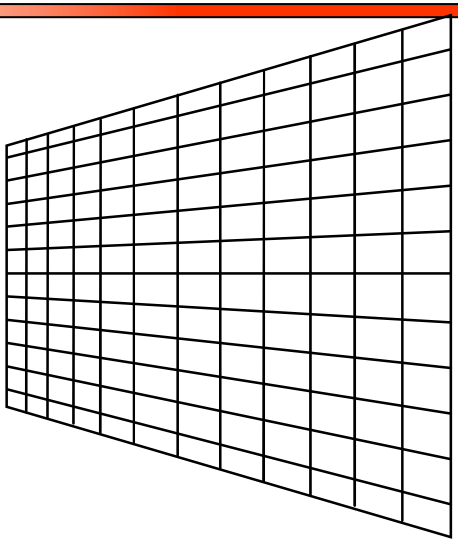
Stereoscopic PIV technique



a. image of left camera

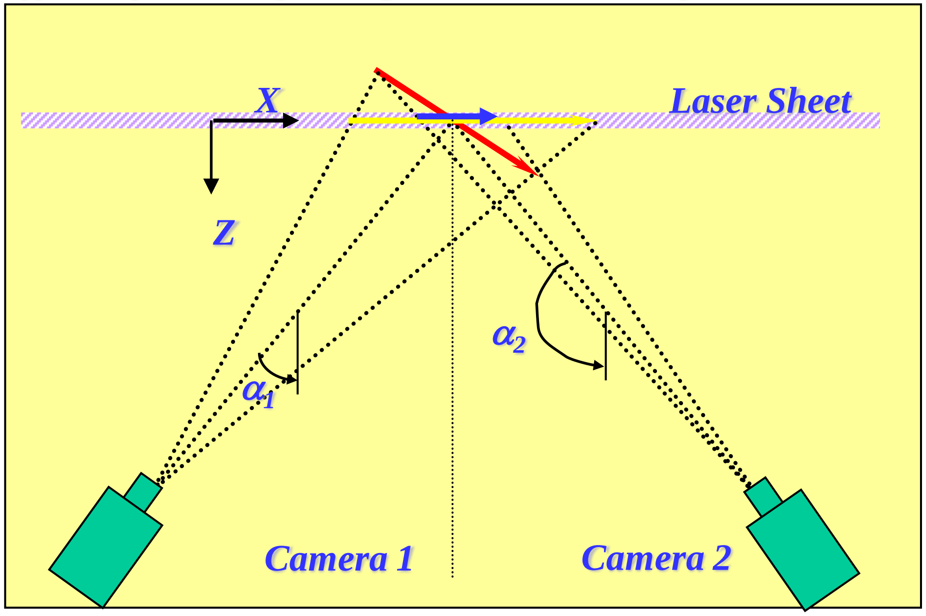


b. rectangular grid in the object plane



c. image of left camera

The perspective effect of the angle displacement arrangement



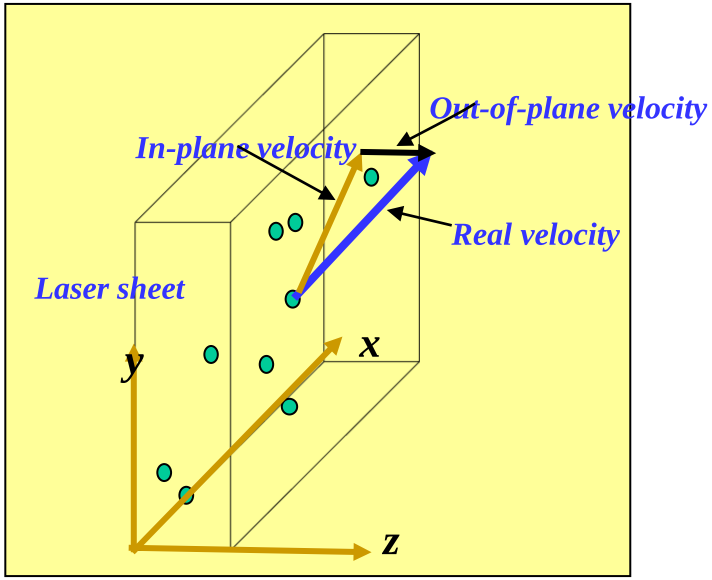
Mapping Function for Stereo PIV

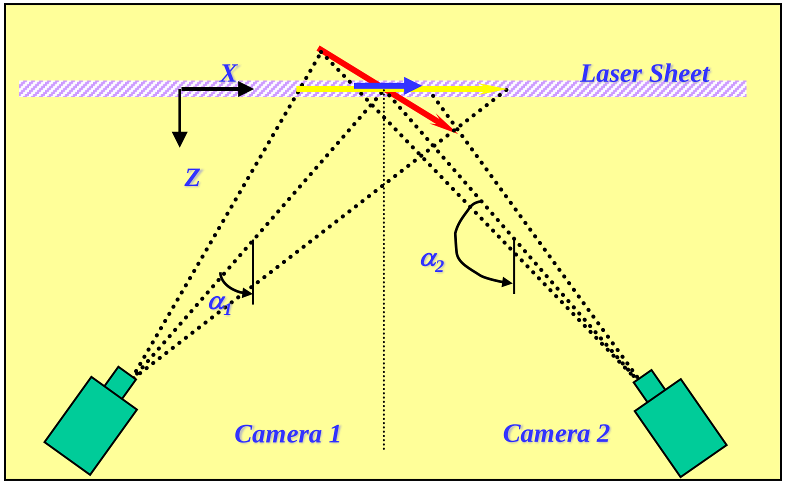
$$X^{(c)} = F^{(c)}(x_i)$$

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

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

$$\overline{\Delta X_i^{(c)}} \cong (\nabla F)\overline{\Delta x}$$

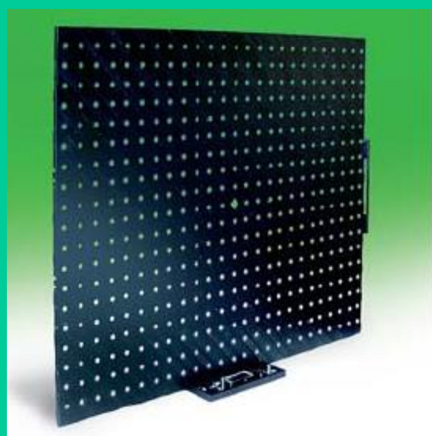


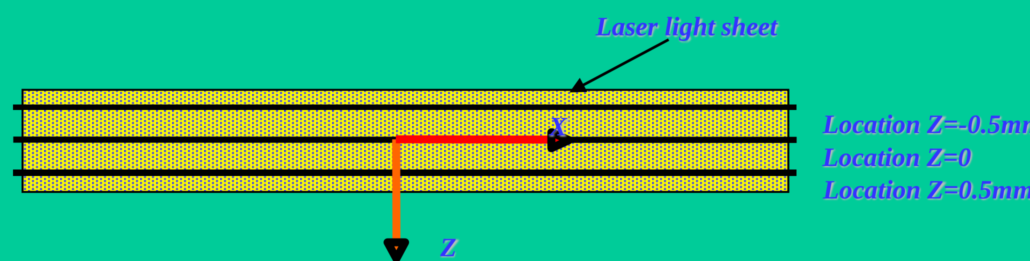


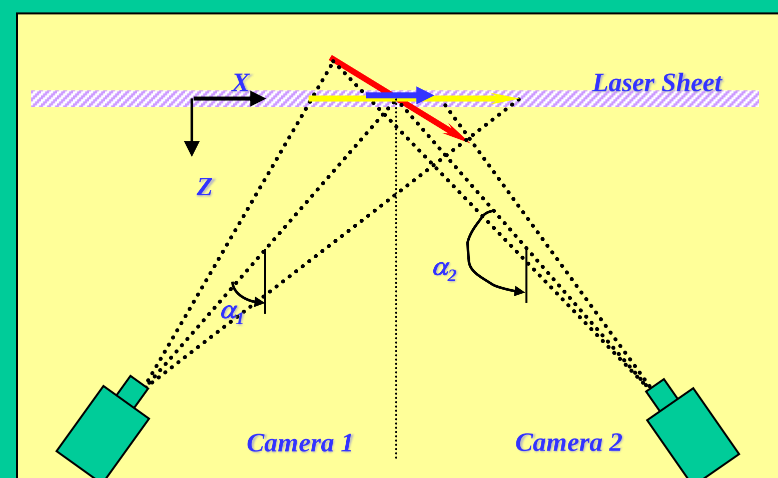
Mapping Function for Stereo PIV

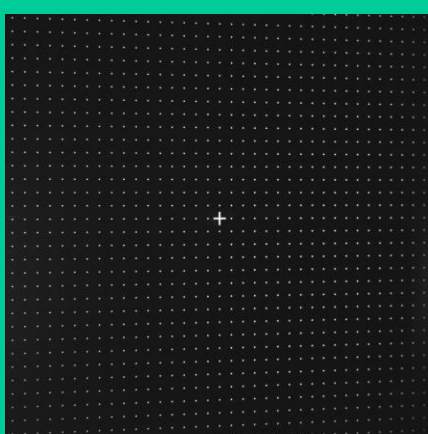
$$X^{(c)} = F^{(c)}(x_i)$$

$$\begin{aligned} F(x,y,z) = {} & a_0 + a_1x + a_2y + a_3z + a_4x^2 + a_5xy + a_6y^2 + a_7xz + a_8yz + a_9z^2 + a_{10}x^3 + a_{11}x^2y + a_{12}xy^2 \\ & + a_{13}y^3 + a_{14}x^2z + a_{15}xyz + a_{16}y^2z + a_{17}xz^2 + a_{18}yz^2 + a_{19}x^4 + a_{20}x^3y + a_{21}x^2z^2 + a_{22}x^1y^3 \\ & + a_{23}y^4 + a_{24}x^3z + a_{25}x^2yz + a_{26}xy^2z + a_{27}y^3z + a_{28}x^2z^2 + a_{29}xyz^2 + a_{30}y^2z^2 \end{aligned}$$

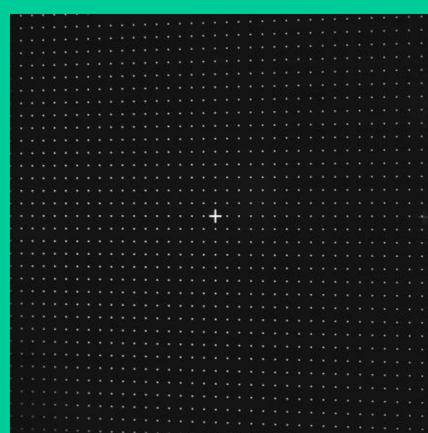






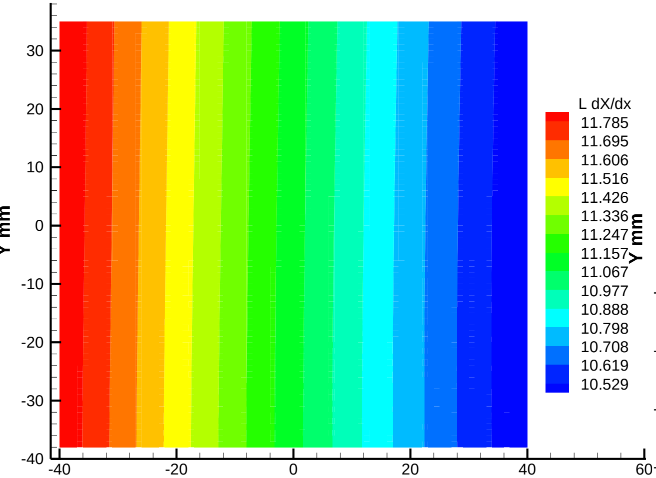


a. image from the left camera

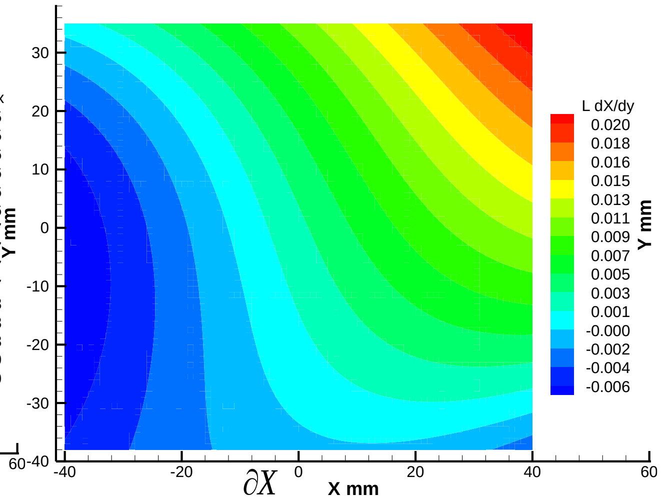


b. image from the right camera

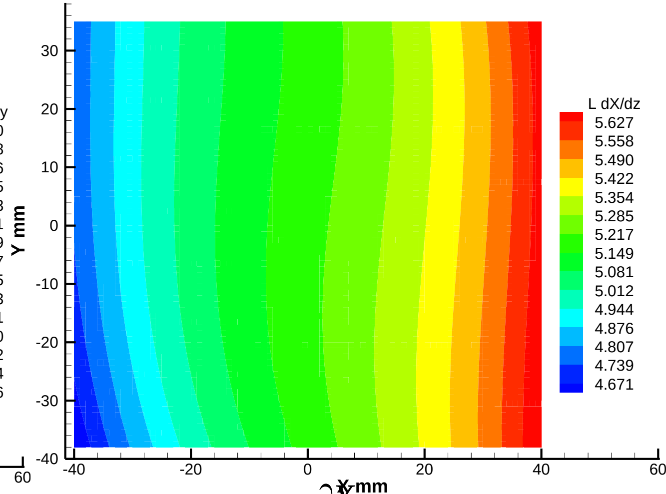
Mapping function



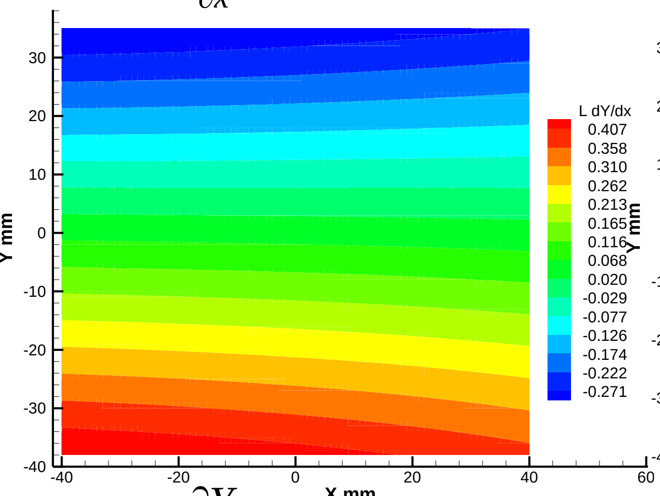
$$\frac{\partial X}{\partial x}$$



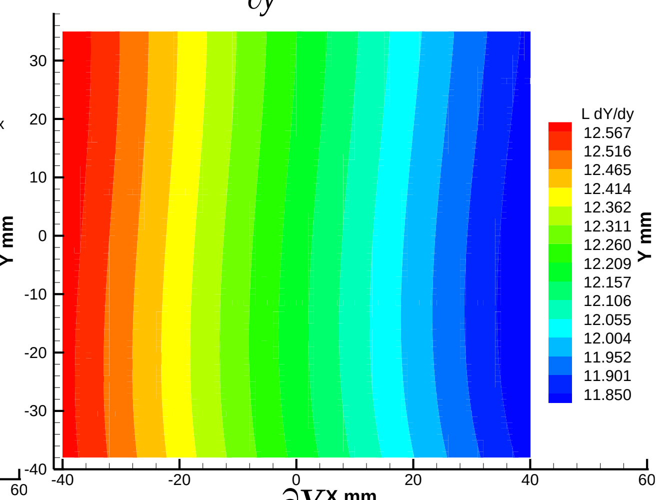
$$\frac{\partial X}{\partial y}$$



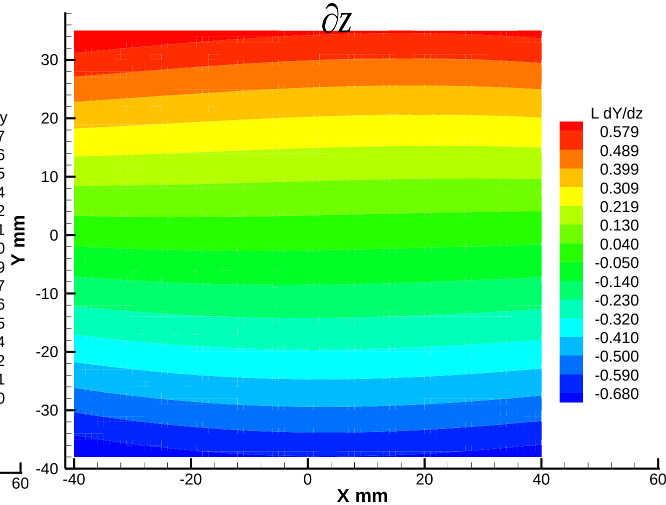
$$\frac{\partial X}{\partial z}$$



$$\frac{\partial Y}{\partial x}$$



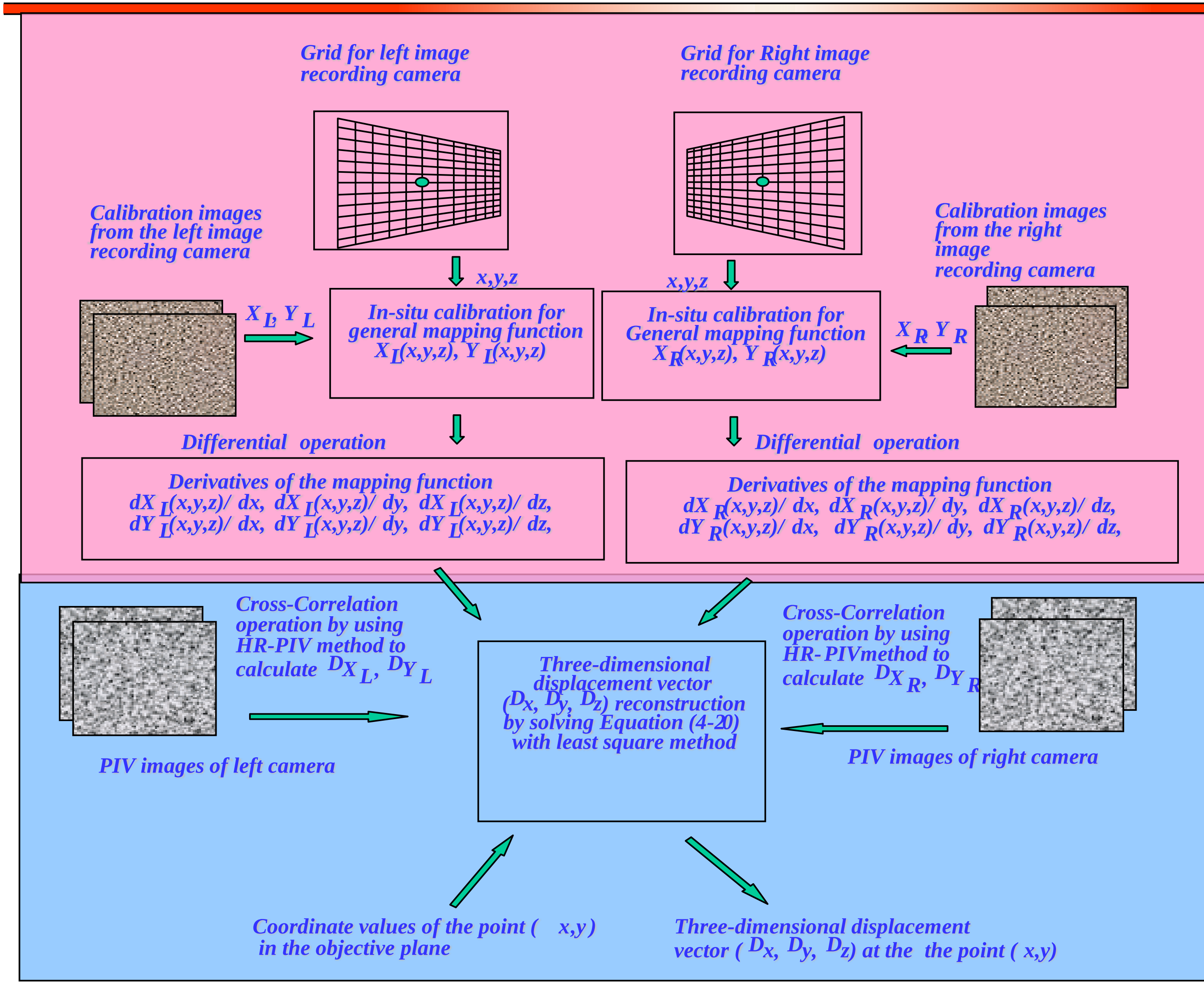
$$\frac{\partial Y}{\partial y}$$



$$\frac{\partial Y}{\partial z}$$

The derivatives of the mapping function for the left camera

Flow Chart for Stereo PIV measurements



In-situ calibration to determine the mapping function

To reconstruct the 3-component of the velocity vector using the mapping function

Concept of Lobed Mixer/Nozzle

Aero-engine:

*enhance mixing between hot high-speed flow exhaust from **core-engine** with cold low-speed bypass flow*

- ***civilian airplanes:***

reduce jet noise during take-off and landing

thrust augmentation

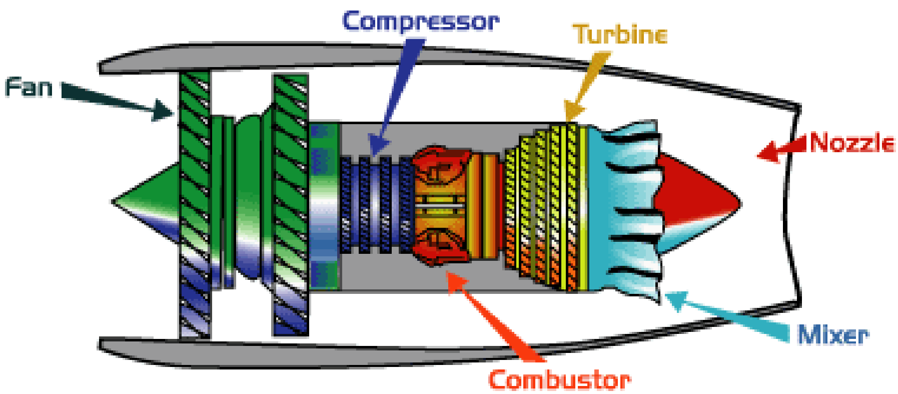
- ***Military airplanes:***

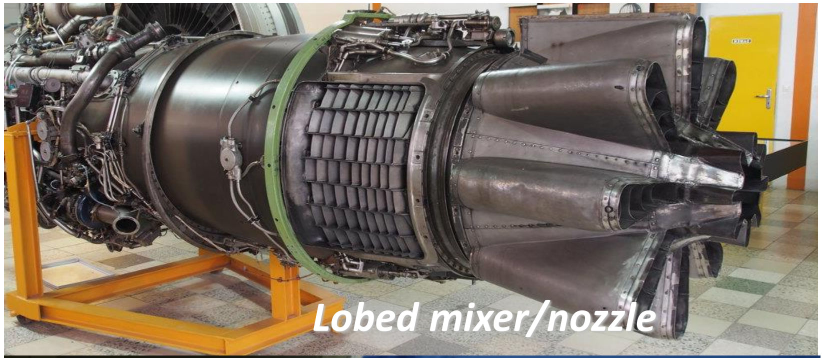
reduce the length of the hot plume, therefore, reduce the infrared emission signals to improve its survivability from the attack of infrared guided missiles.

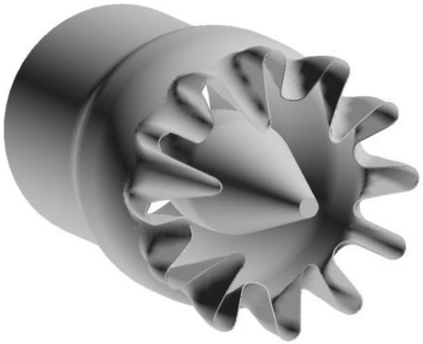
Combustion:

enhance mixing between the fuel with air in the combustion chamber

- *improve combustion efficiency*
- *suppression pollutant formation*



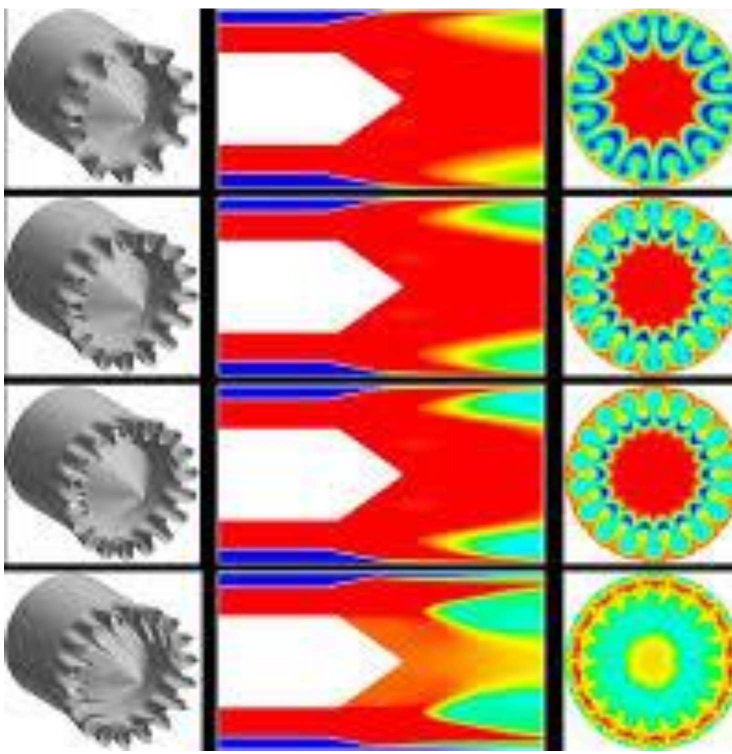


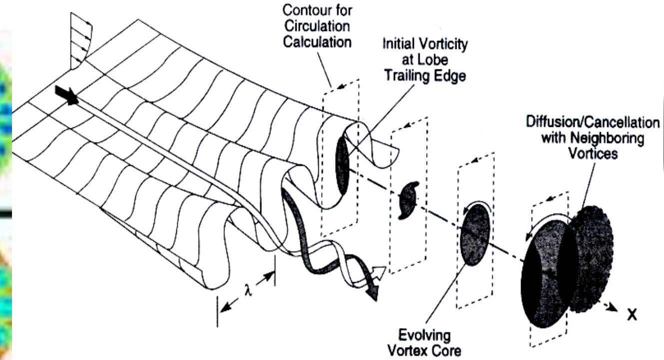


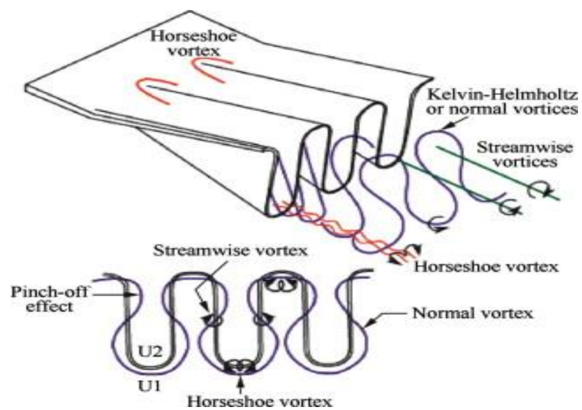
Vortex Structures Downstream a Lobed Mixer/Nozzle

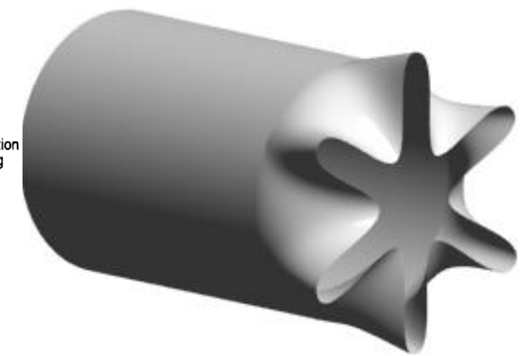
Two kinds of vortex structures are considered to play important roles for the mixing enhancement in a lobed mixing flow:

- ***Azimuthal (spanwise) vortex structures** due to the Kelvin-Helmholtz instability at the interface between two streams.*
- ***Large-scale streamwise vortices** generated by the special geometry of the lobed trailing edge*



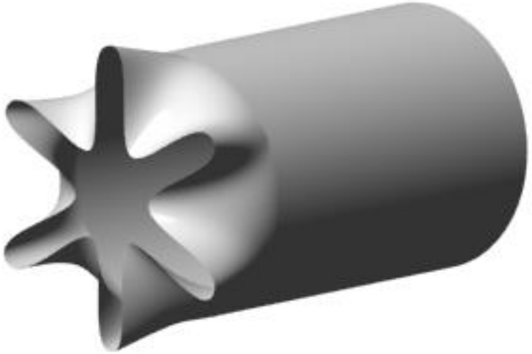


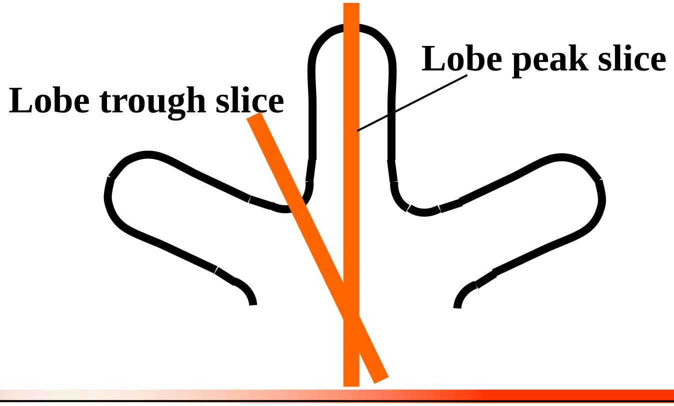




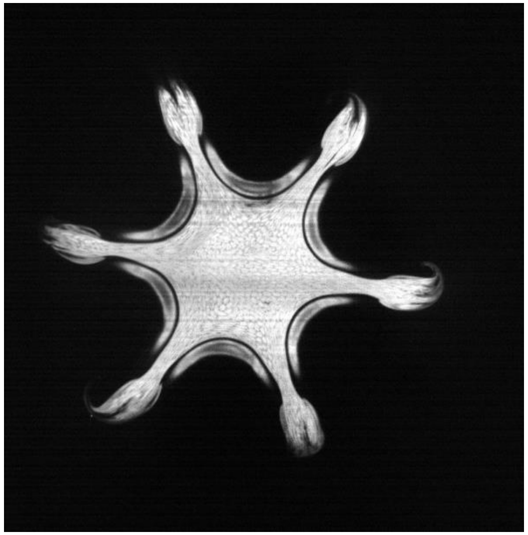
The lobed nozzle used in the present study

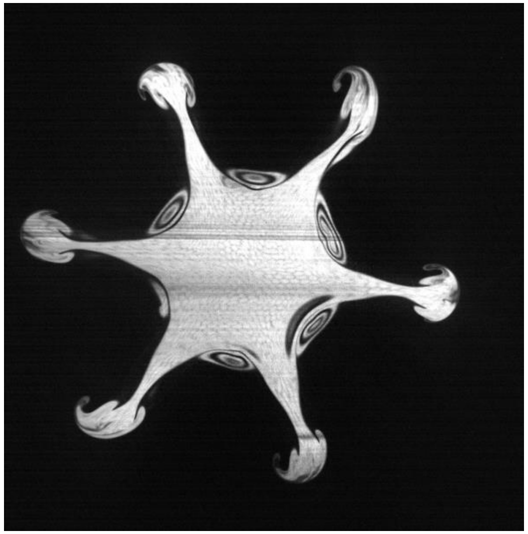
Laser Induced Fluorescence (LIF) Flow Visualization (Axial Slices, Re=6,000)

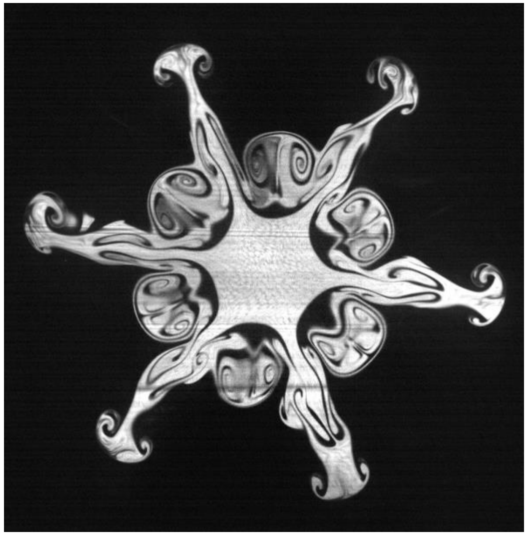


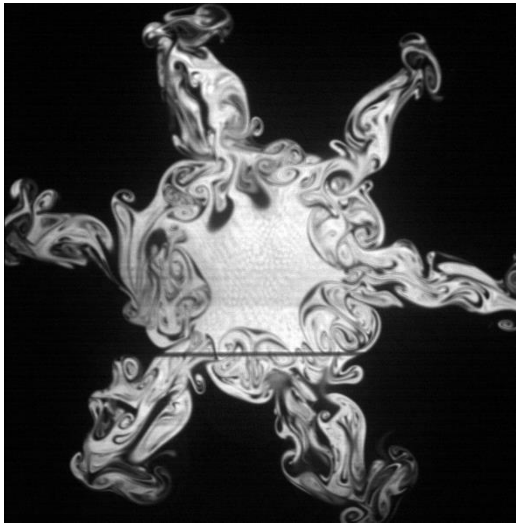


Laser Induced Fluorescence (LIF) Flow Visualization
(Cross Sections, Re=3,000)

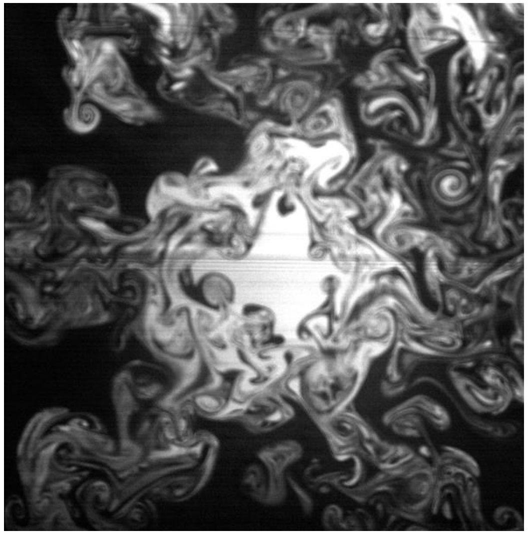

X/D=0.25


X/D=0.5

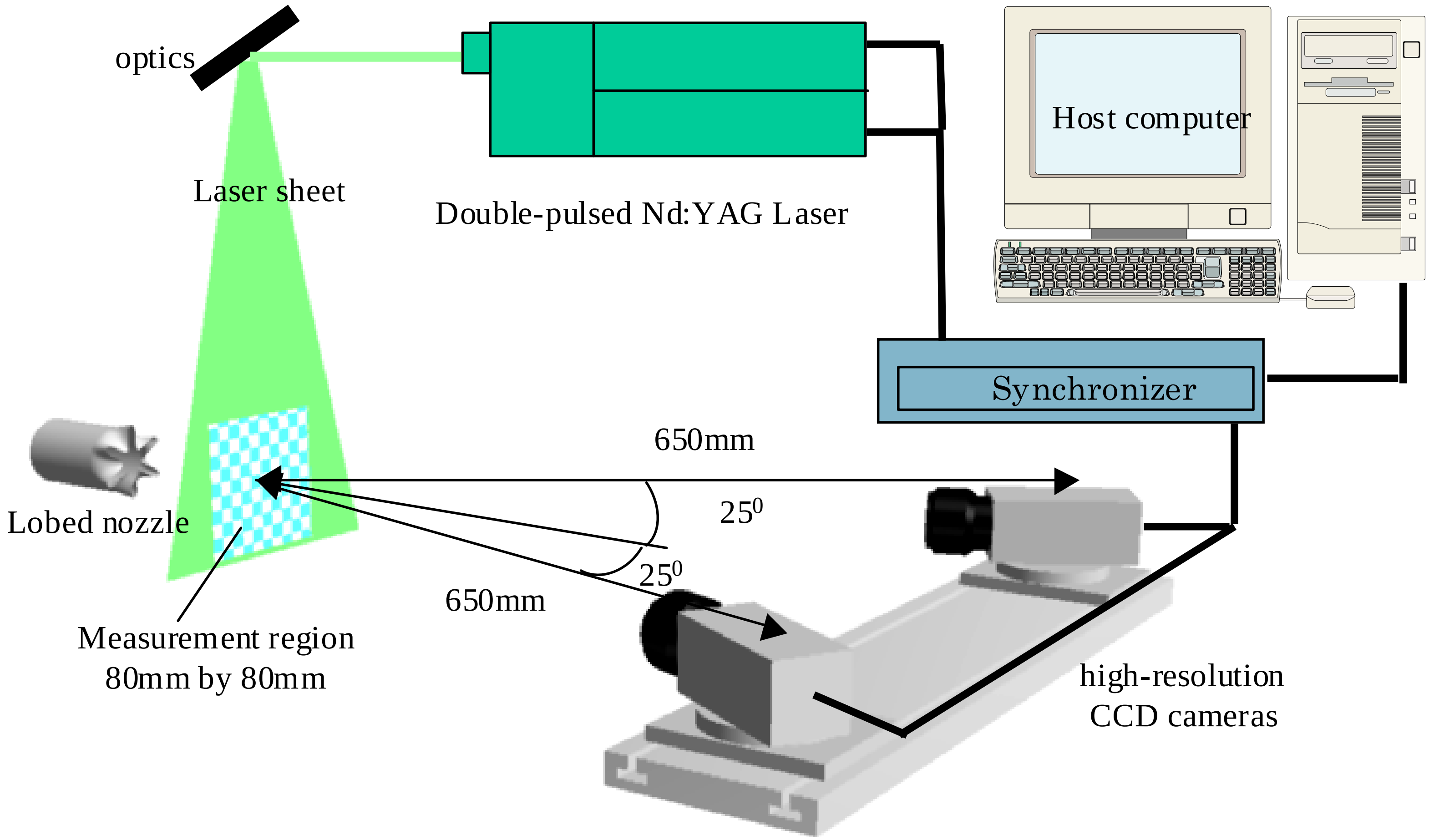

X/D=0.75


X/D=1.0


X/D=1.5

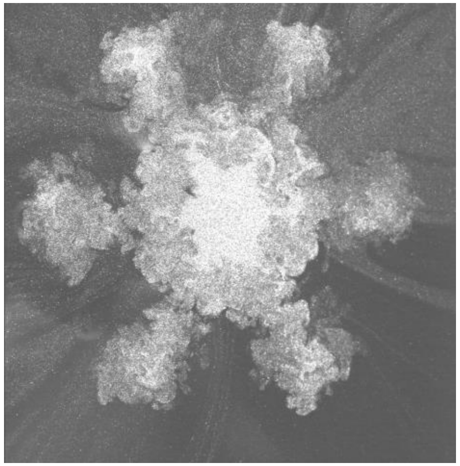

X/D=2.0

Stereoscopic PIV system

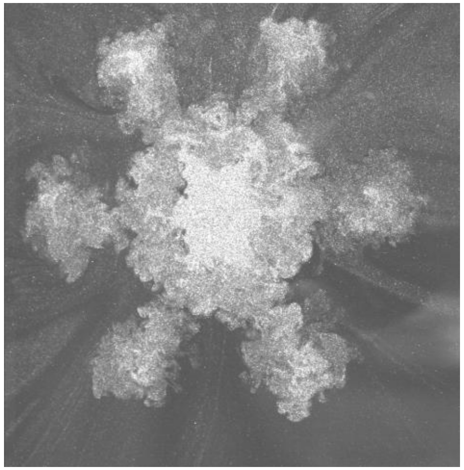


- ***<u>Hu H</u>*, *Saga T, Kobayashi T, Taniguchi N***, *"A Study on a Lobed Jet Mixing Flow by Using Stereoscopic PIV Technique". Physics of Fluids, Vol.13, No. 11, pp3425-3441, 2001*

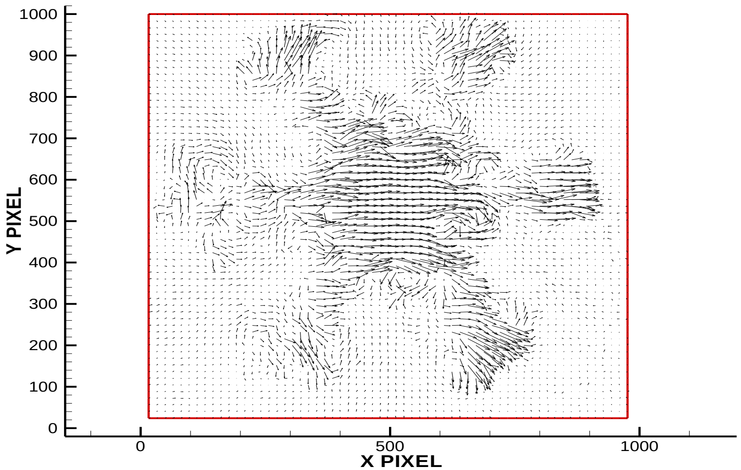
Stereoscopic PIV technique



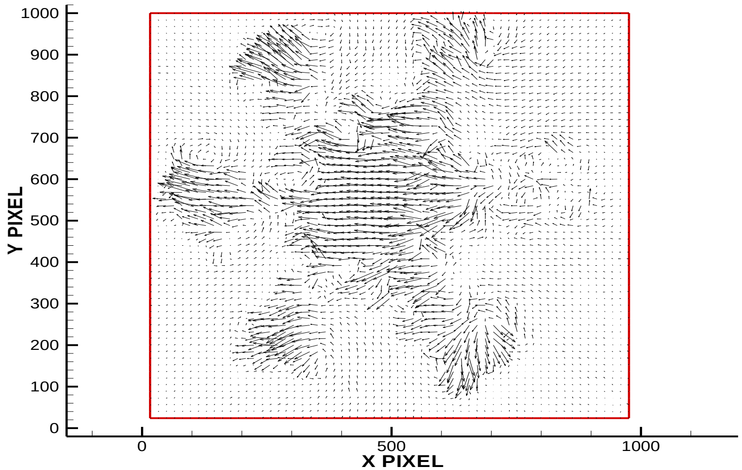
a. PIV image from the left camera



b. PIV image from the right camera



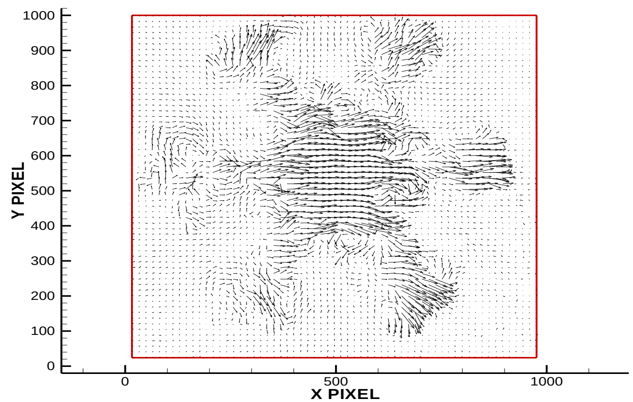
Displacement vectors in left camera



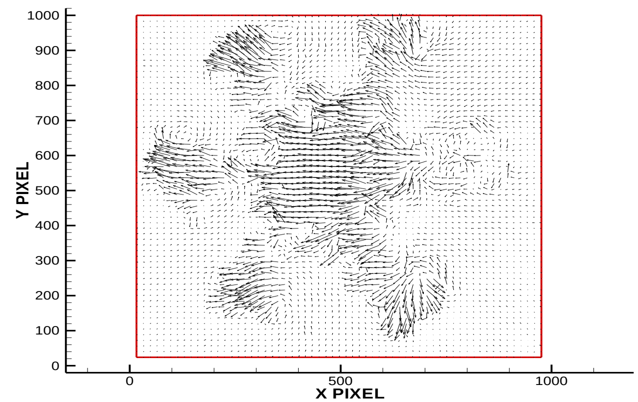
Displacement vectors in right camera

- ***<u>Hu H</u>*, *Saga T, Kobayashi T, Taniguchi N***, *"A Study on a Lobed Jet Mixing Flow by Using Stereoscopic PIV Technique". Physics of Fluids, Vol.13, No. 11, pp3425-3441, 2001*

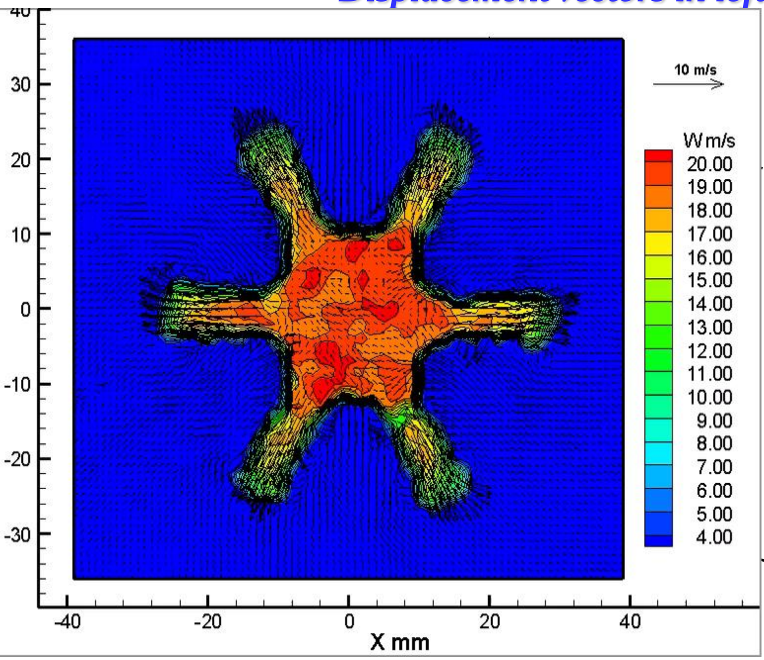
Stereoscopic PIV technique

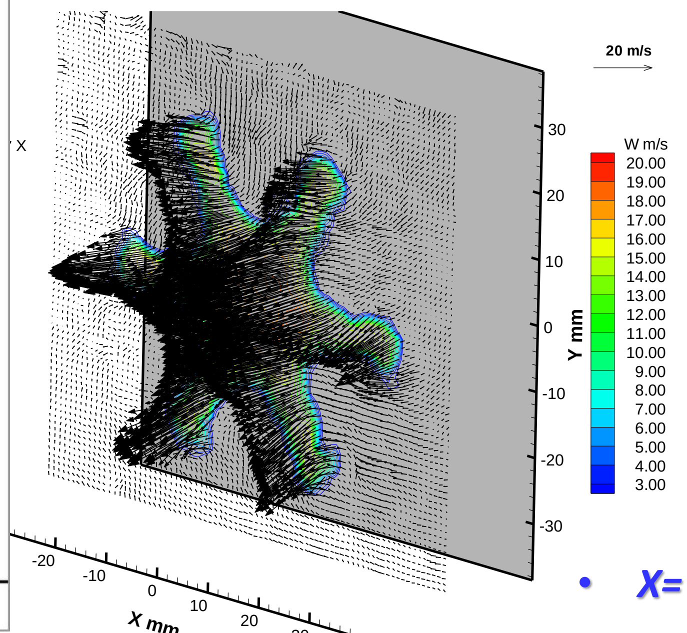


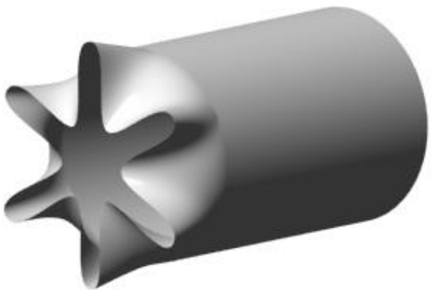
Displacement vectors in left camera



Displacement vectors in right camera



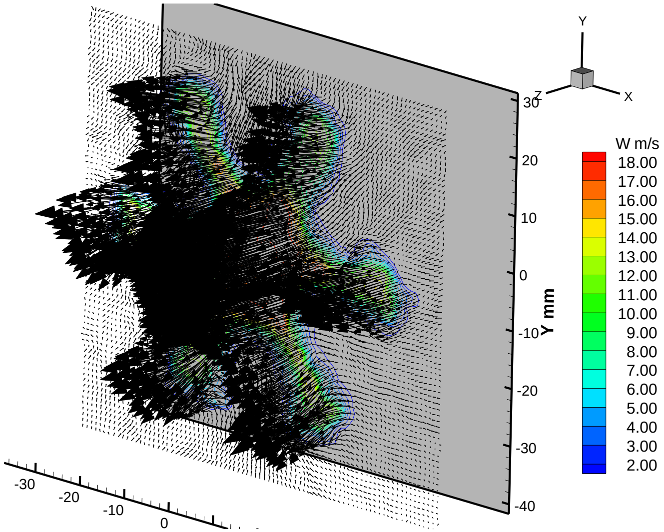




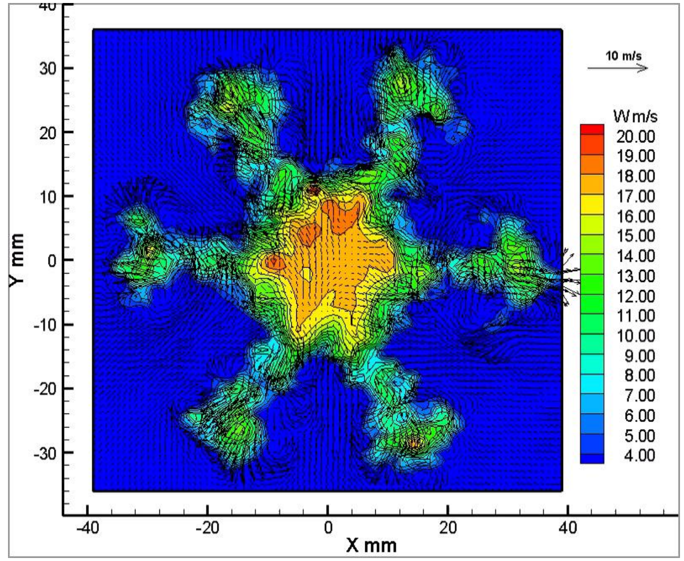
- ***X= 10 mm downstream***

- ***<u>Hu H</u>, Saga T, Kobayashi T, Taniguchi N***, *"A Study on a Lobed Jet Mixing Flow by Using Stereoscopic PIV Technique". Physics of Fluids, Vol.13, No. 11, pp3425-3441, 2001*

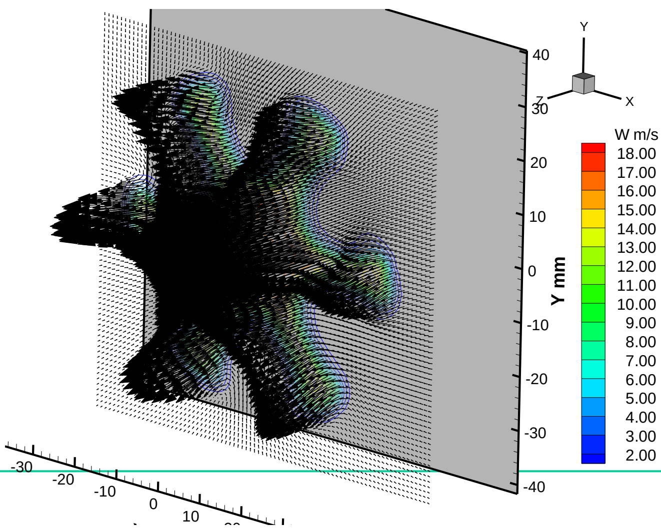
Measurements Results

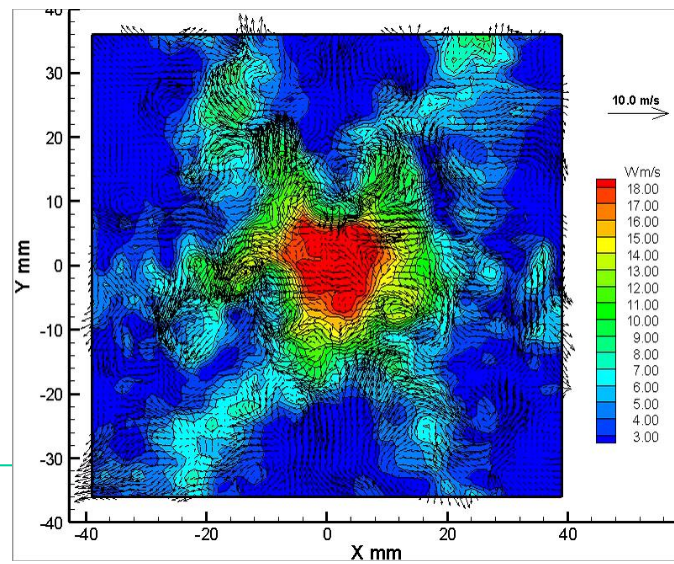


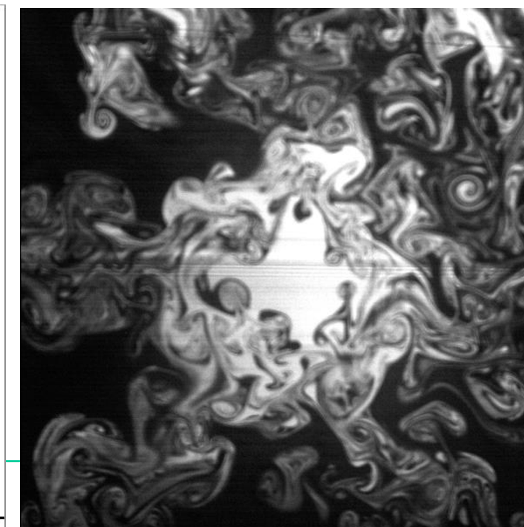
a. instantaneous velocity



• X= 40 mm downstream



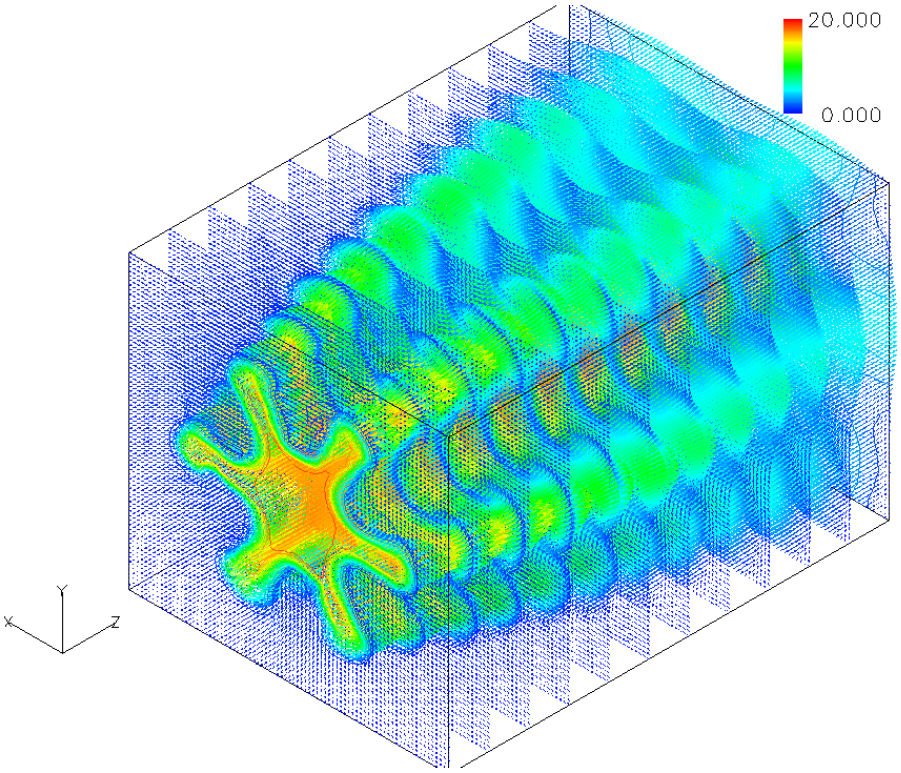




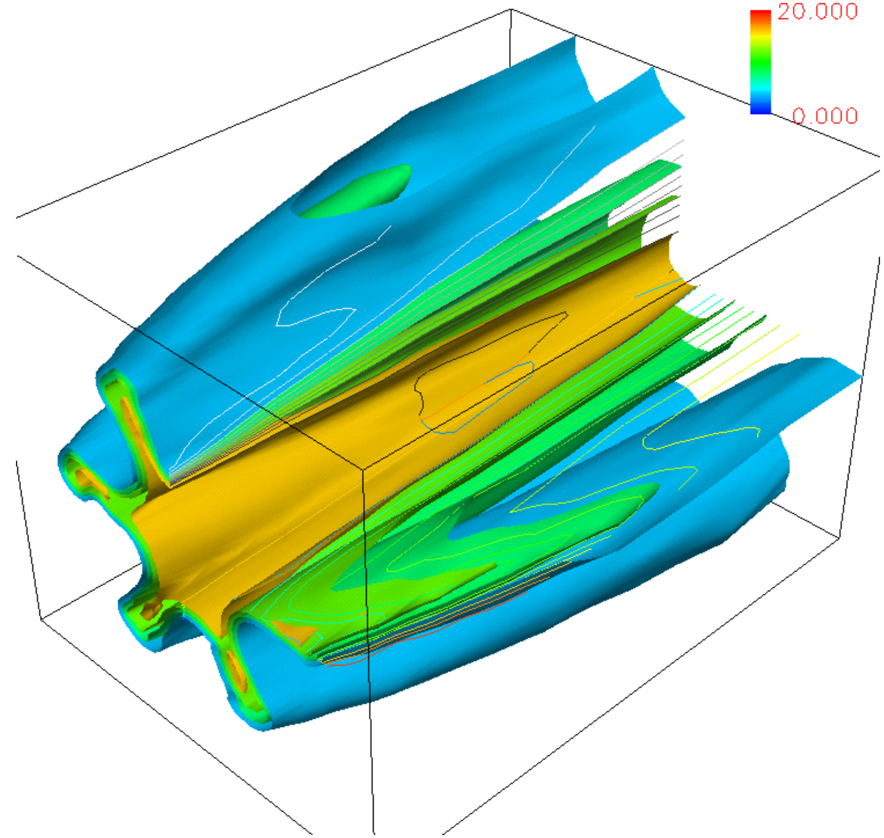
c. ensemble-averaged velocity.

• X= 120 mm downstream

Reconstructed Three-dimensional Flow Field



a. three-dimensional velocity vectors



b.iso-surface of velocity field

- ***Hu H*, Saga T, Kobayashi T, Taniguchi N**, *"A Study on a Lobed Jet Mixing Flow by Using Stereoscopic PIV Technique". Physics of Fluids, Vol.13, No. 11, pp3425-3441, 2001*