Turbulent Flow Induced by Oscillatory Circular Cylinder Arrays

Takaaki SHIGEMATSU, Osaka City University
Hiroshi MATSUMOTO, DENSO Corporation

大阪市立大学
OSAKA CITY UNIVERSITY

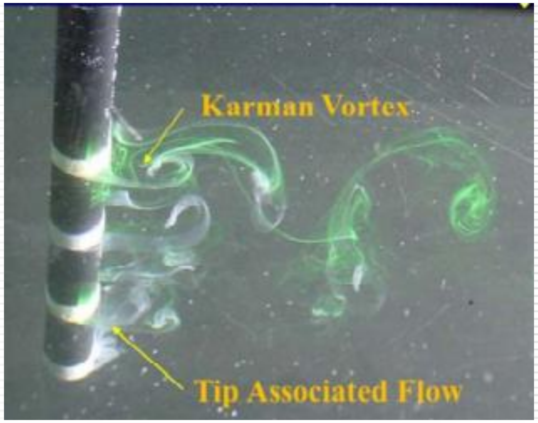
Background

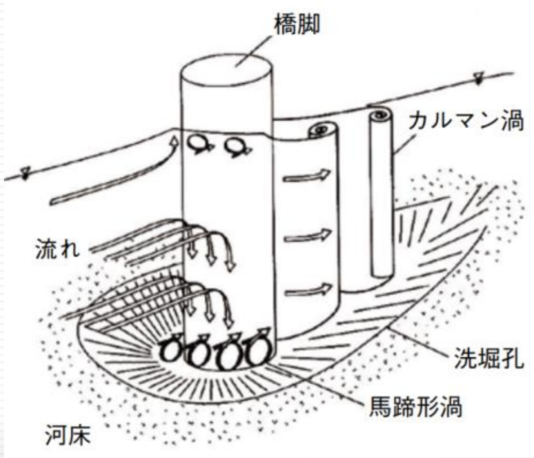
- ✓ Vegetation association
  plays important role
  in the shallower coastal zone
  - for sediment control
  - the nutrient
  - carbon absorption
  - etc.
- ✓ Evaluation of shallow water region including vegetation and wet land

  need to understand the fluid motion including turbulence in the vegetation association

Background

- ✓ The first step for understanding fluid motion in the vegetation association
  - fluid force acting on a circular cylinder
  - fluid motion around a circular cylinder
  - visualization is useful tool to overview the fluid motion





Background

- ✓ Zhida Yuan & Zhenhua Huang(2015)
  - Hydrodynamic coefficients of the transverse force on a circular cylinder oscillating sinusoidally in still water
- ✓ Kuifeng Zhao, Nian-Sheng Cheng, Zhenhua Huang(2014)
  - Experimental study of free-surface fluctuations in open-channel flow in the presence of periodic cylinders array.
- ✓ K. M. Lam, J. C. Hu, and P. Liu(2010) :
  - Vortex formation processes from an oscillating circular cylinder
- ✓ M. Tatsuno, P. W. Bearman(1990) :
  - A visual study of the flow around an oscillating circular cylinder at low Keulegan-Carpenter numbers and low Stokes numbers

Background

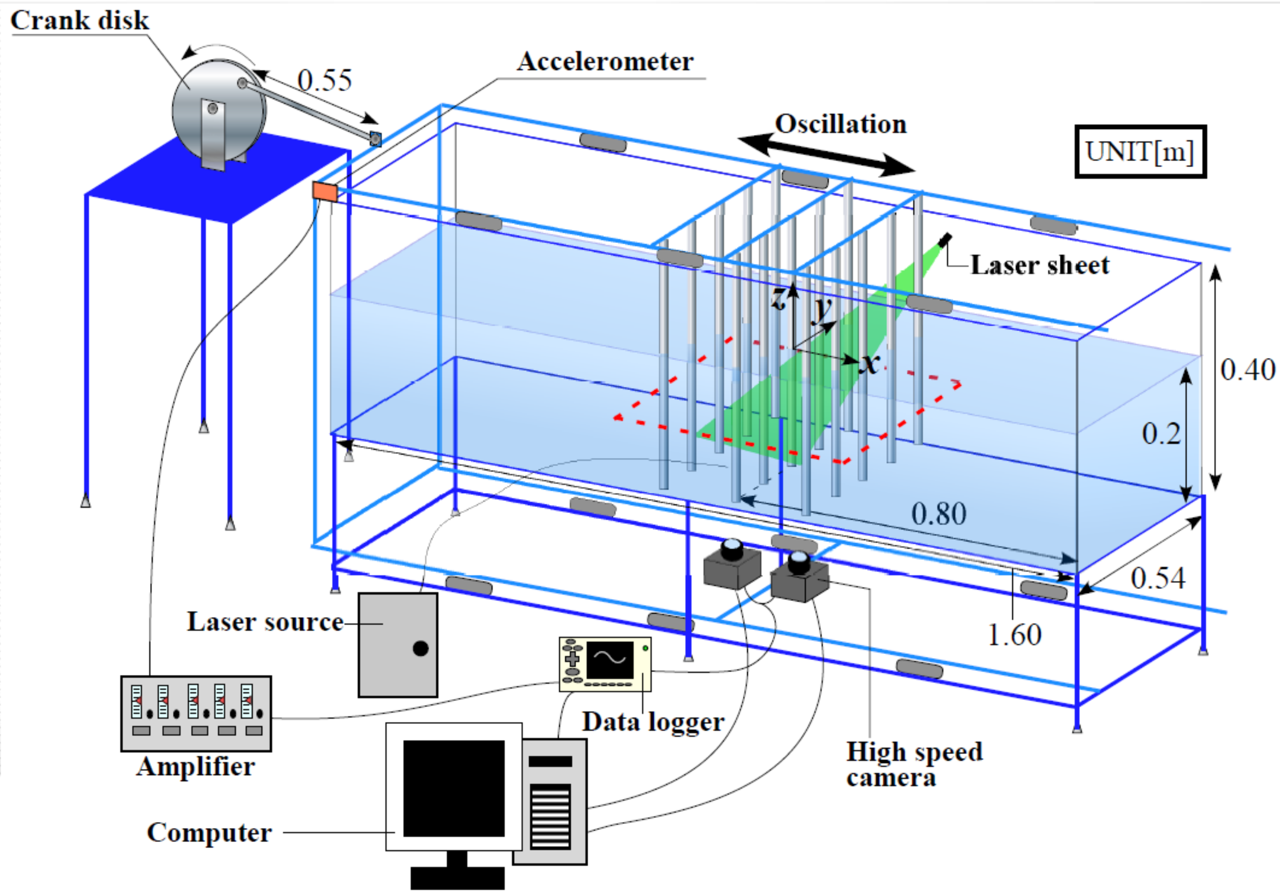
- ✓ The properties of turbulent flow induced around circular cylinders in wave field have not been investigated
  - turbulence transition mechanism
  - spatial-temporal distribution of turbulence

Purpose of this study

- ✓ Understanding the fluid motion including turbulence induced by wave transmitting vegetation association.
  - using the PTV technique measuring fluid motion induced by oscillating circular cylinder arrays.

Experimental setup

- ✓ Tank : 1.6 m x 0.54 m x 0.4 m
- ✓ Water depth : 0.2 m
- ✓ Cylinder arrays : rotation of a crank disk



Experimental setup

✓ Cylinder arrays :

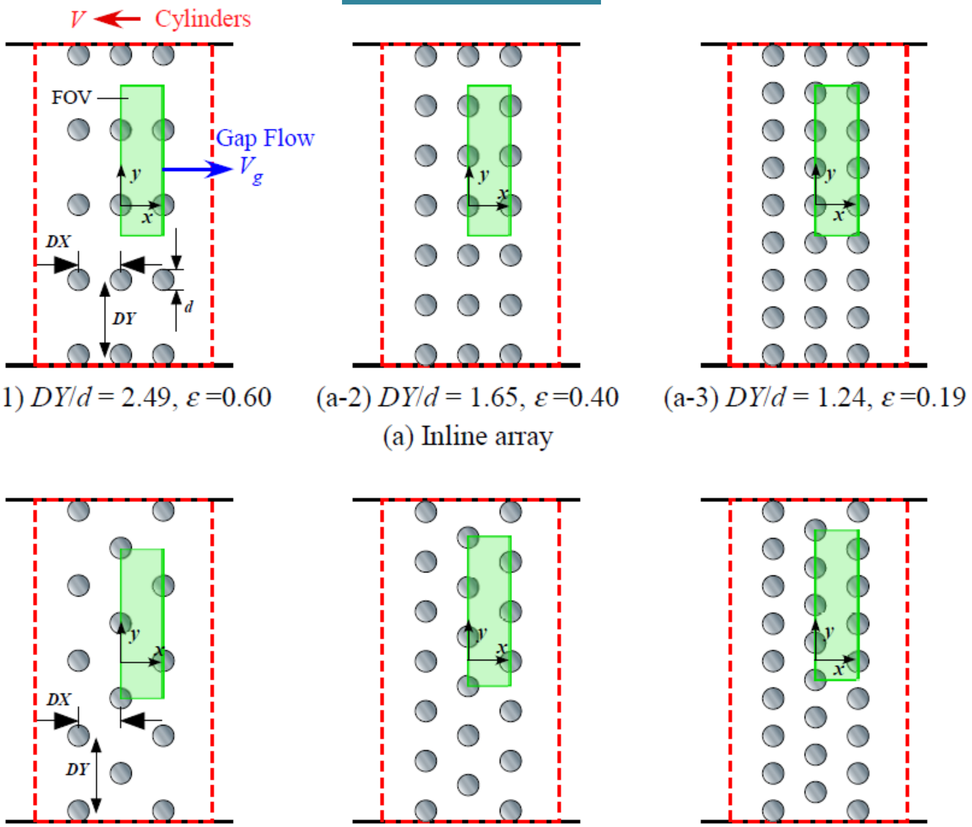
d : cylinder diameter
d = 0.49 m

DX : distance between arrays in oscillatory direction
DX / d = 2.00, 2.50, 2.78, 3.00

DY : distance between cylinders in an array
DY/ d = 1.24, 1.65, 2.49

arrangement: in-line & staggered

in-line



(a-1) DY/d = 2.49, ε =0.60 (a-2) DY/d = 1.65, ε =0.40 (a-3) DY/d = 1.24, ε =0.19
(a) Inline array

(b-1) DY/d = 2.49, ε =0.60 (b-2) DY/d = 1.65, ε =0.40 (b-3) DY/d = 1.24, ε =0.19
(b) Staggered array

staggered

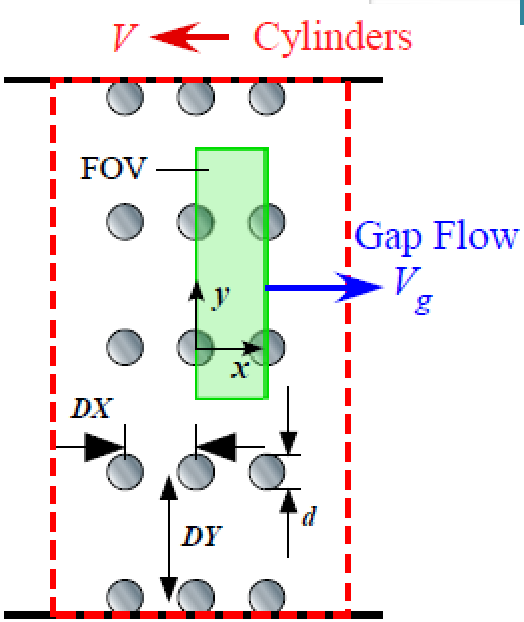
Experimental setup

$$V_g = \frac{V_0}{\epsilon}$$

$$\epsilon = \frac{DY - d}{DY}$$

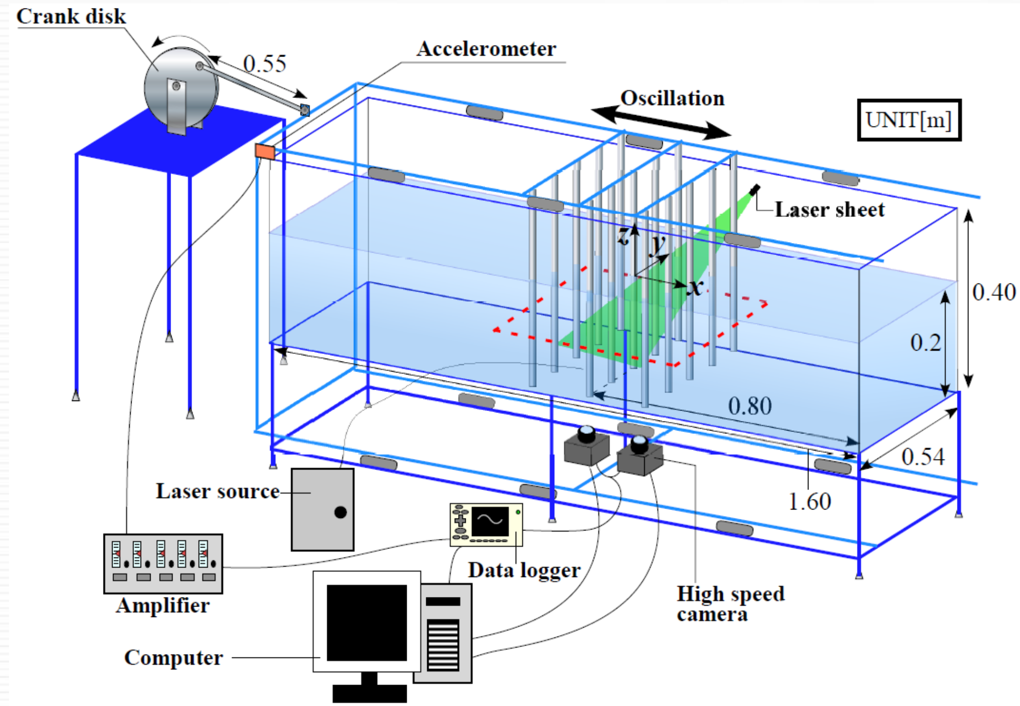
$$KC = \frac{V_0 T}{d}$$

$$Re_g = \frac{V_g d}{\nu}$$



Arrangement	DX/d	DY/d	ϵ	T[s]	V_0[m/s]	V_g[m/s]	KC	Re_g
in-line	2.00	1.65	0.40	7.4	0.060	0.150	9.0	8,952
		2.49	0.60	3.7	0.120	0.200		10,687
		1.65	0.40	4.9	0.090	0.225		13,429
		1.65	0.40	3.7	0.120	0.300		17,905
		1.65	0.40	3.0	0.148	0.370		22,083
		1.24	0.19	3.7	0.120	0.632		38,741
		2.49	0.60	5.3	0.120	0.200	13.0	10,687
		1.65	0.40	5.3	0.120	0.300		17,905
		1.24	0.19	5.3	0.120	0.632		38,741
		2.49	0.60	7.0	0.120	0.200	17.1	10,687
		1.65	0.40	7.0	0.120	0.300		17,905
		1.24	0.19	7.0	0.120	0.632		38,741
	2.50	2.49	0.60	3.7	0.120	0.200	9.0	10,687
		1.65	0.40	3.7	0.120	0.300		17,905
		1.24	0.19	3.7	0.120	0.632		38,741
	3.00	2.49	0.60	3.7	0.120	0.200	9.0	10,687
		1.65	0.40	3.7	0.120	0.300		17,905
		1.24	0.19	3.7	0.120	0.632		38,741
staggered	2.00	1.65	0.40	7.4	0.060	0.150	9.0	7,836
				4.9	0.090	0.225		11,754
				3.7	0.120	0.300		15,672
				3.0	0.148	0.370		19,328
				5.3	0.120	0.300	13.0	15,672
				7.0	0.120	0.300	17.1	15,672

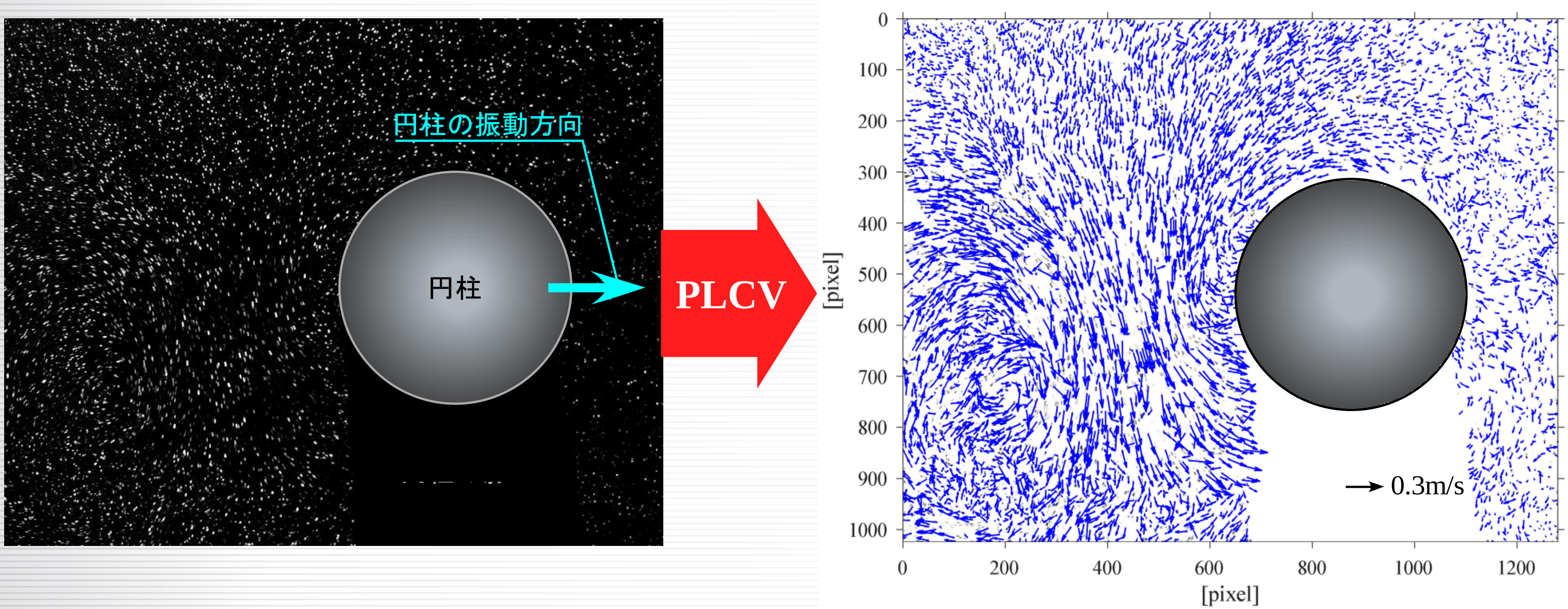
Experimental setup



- ✓ PTV measurement
  - continuum laser light sheet
  - capture interval
    - 1/200 s
  - exposure time
    - 1/200 s
  - spatial resolution
    - 1.2×10^{-2} cm/pixel
  - tracer number density
    - 30 # / cm^2
  - algorithm
    - PLCV(path line connecting velocimetry, Umase et.al.; 2011)

Experimental setup

- ✓ path line connecting method (Umase et. al., 2011)

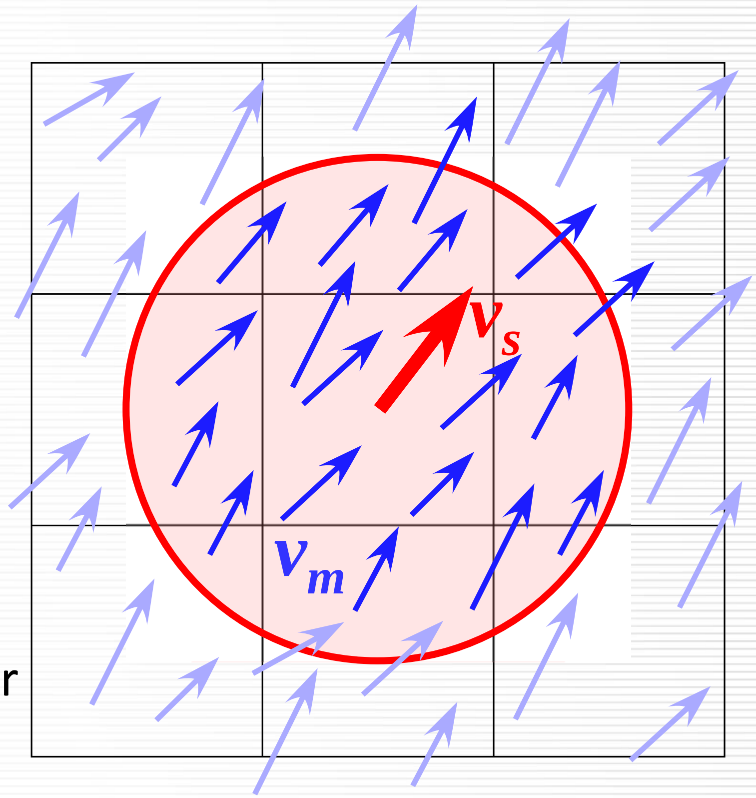


Experiment setup

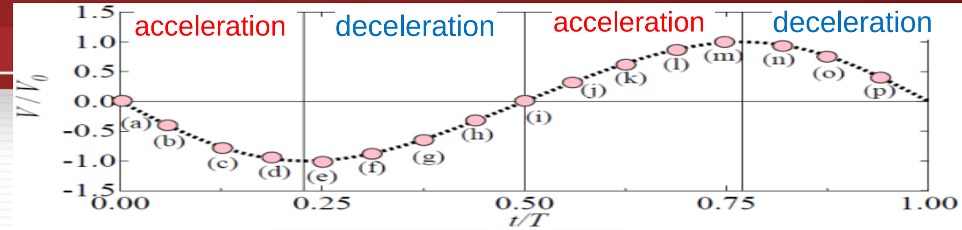
- ✓ Velocities on the regular grid points were obtained by spatial-averaging measured velocities in a control volume with an certain diameter

$$\boldsymbol{v}_S(x_c, y_c) = \sum_{m=1}^{M} \boldsymbol{v}_m(x_m, y_m)/M$$

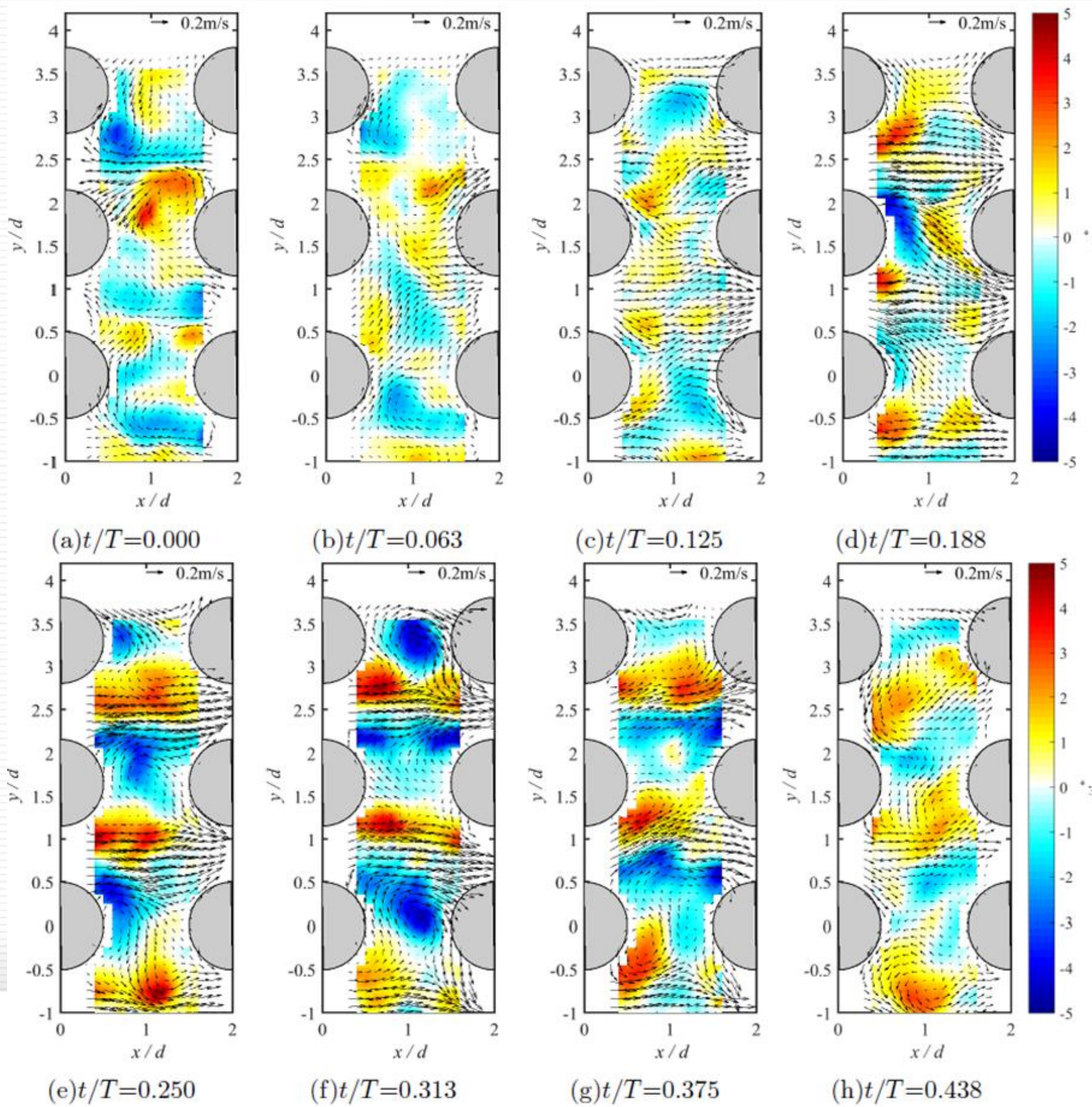
M : number of measured velocities in control volume with an certain diameter

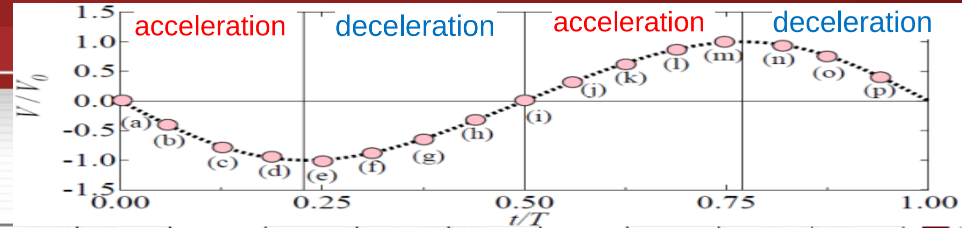


Results



- ✓ Distribution of Velocity : v_s
  - in-line
  - DX/d=2.0
  - DY/d=1.65
  - KC=9.0
  - Re_g=10,687

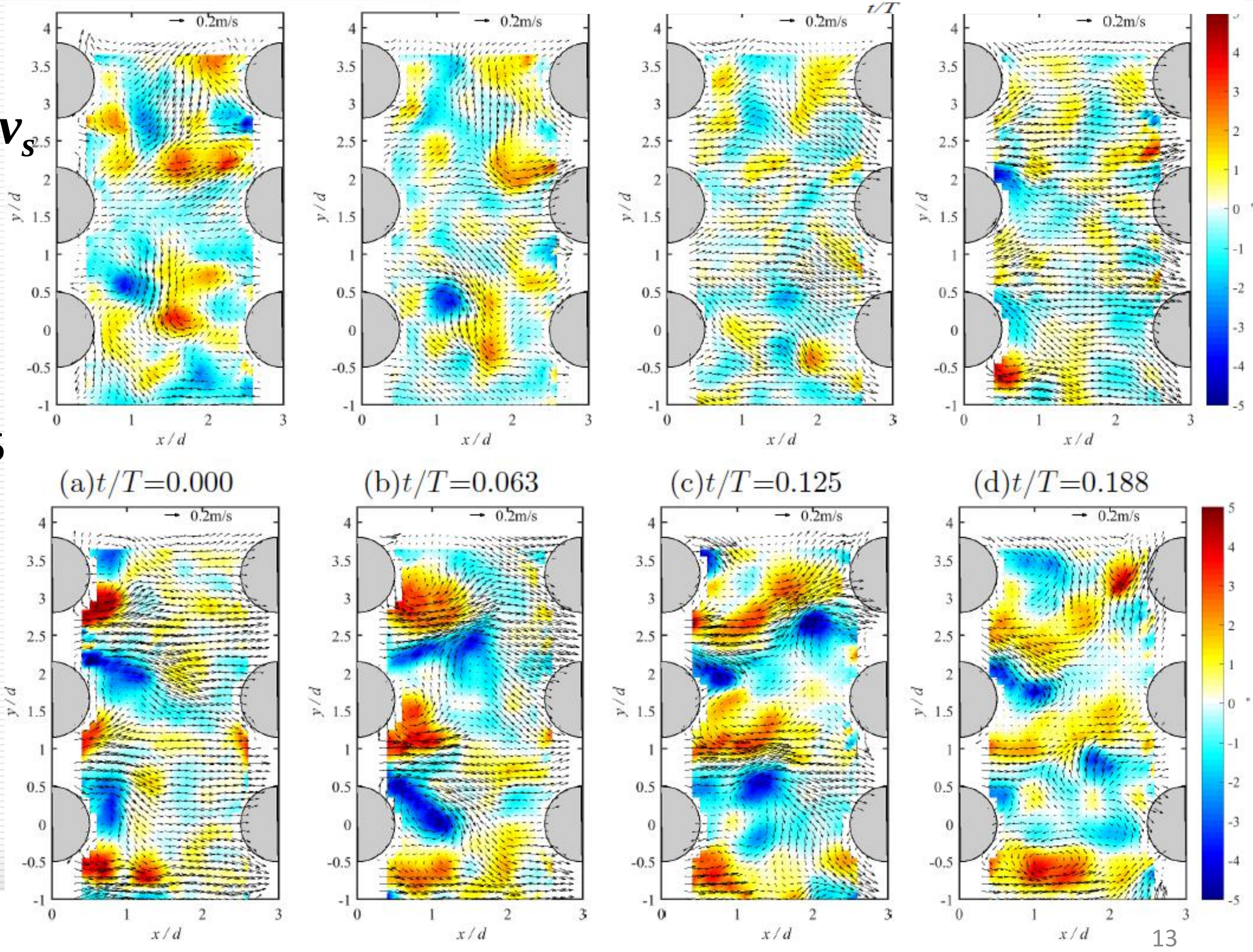




Results

✓Distribution of Velocity : $\boldsymbol{v_s}$

- in-line
- $\boldsymbol{DX/d}$ =3.0
- $\boldsymbol{DY/d}$=1.65
- $\boldsymbol{KC}$=9.0
- $\boldsymbol{Re}_\mathrm{g}$=17,905



(a)t/T=0.000 (b)t/T=0.063 (c)t/T=0.125 (d)t/T=0.188

(e)t/T=0.250 (f)t/T=0.313 (g)t/T=0.375 (h)t/T=0.438

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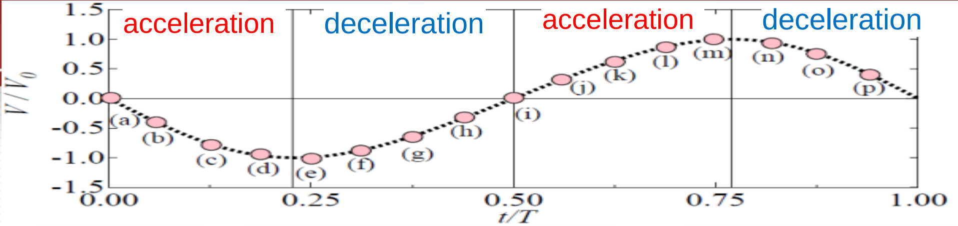
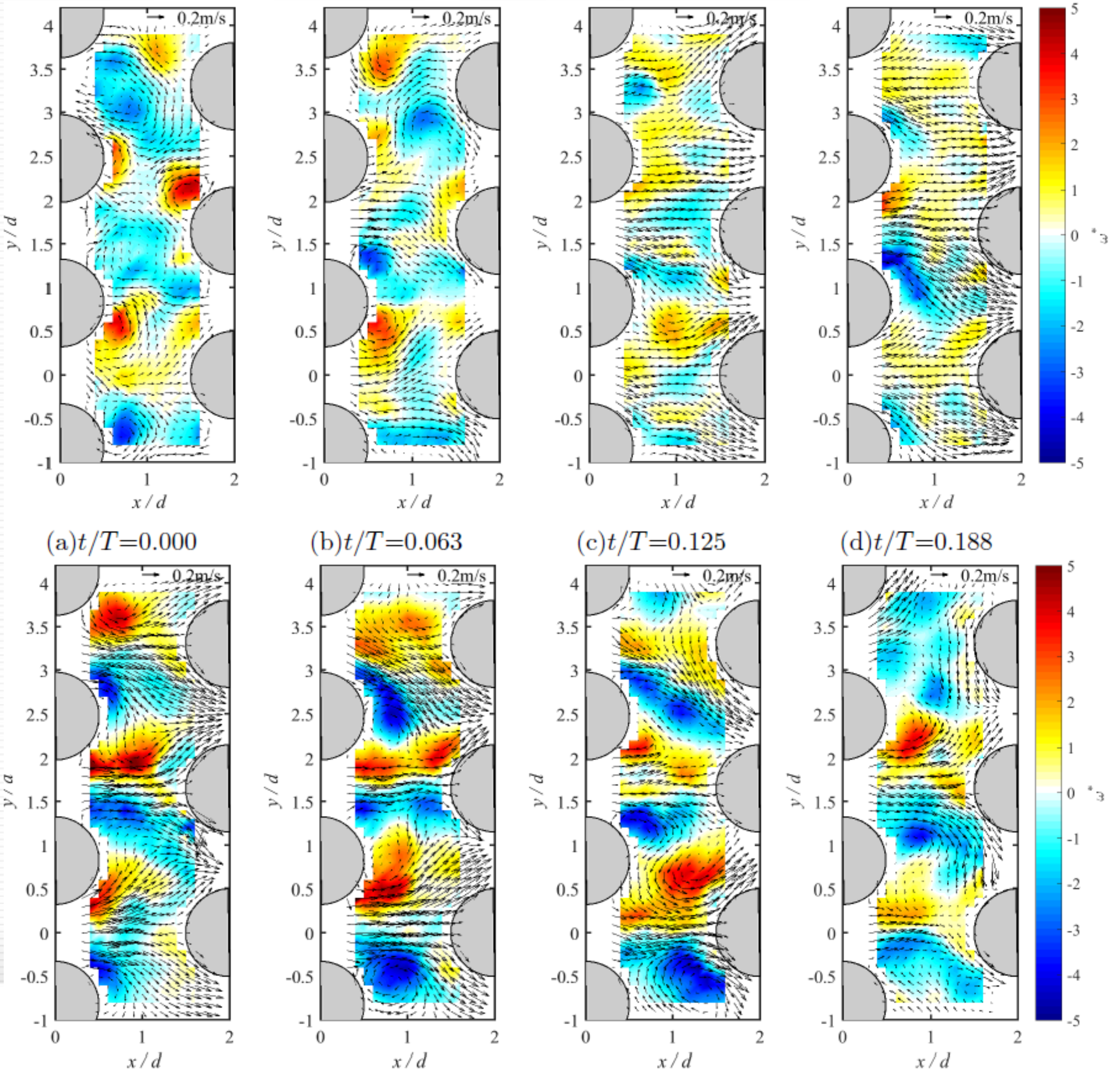
Results

- ✓ Distribution of Velocity : v_s
  - staggered
  - DX/d =2.0
  - DY/d =1.65
  - KC=9.0
  - Re_g=15,672





(a)t/T=0.000 (b)t/T=0.063 (c)t/T=0.125 (d)t/T=0.188

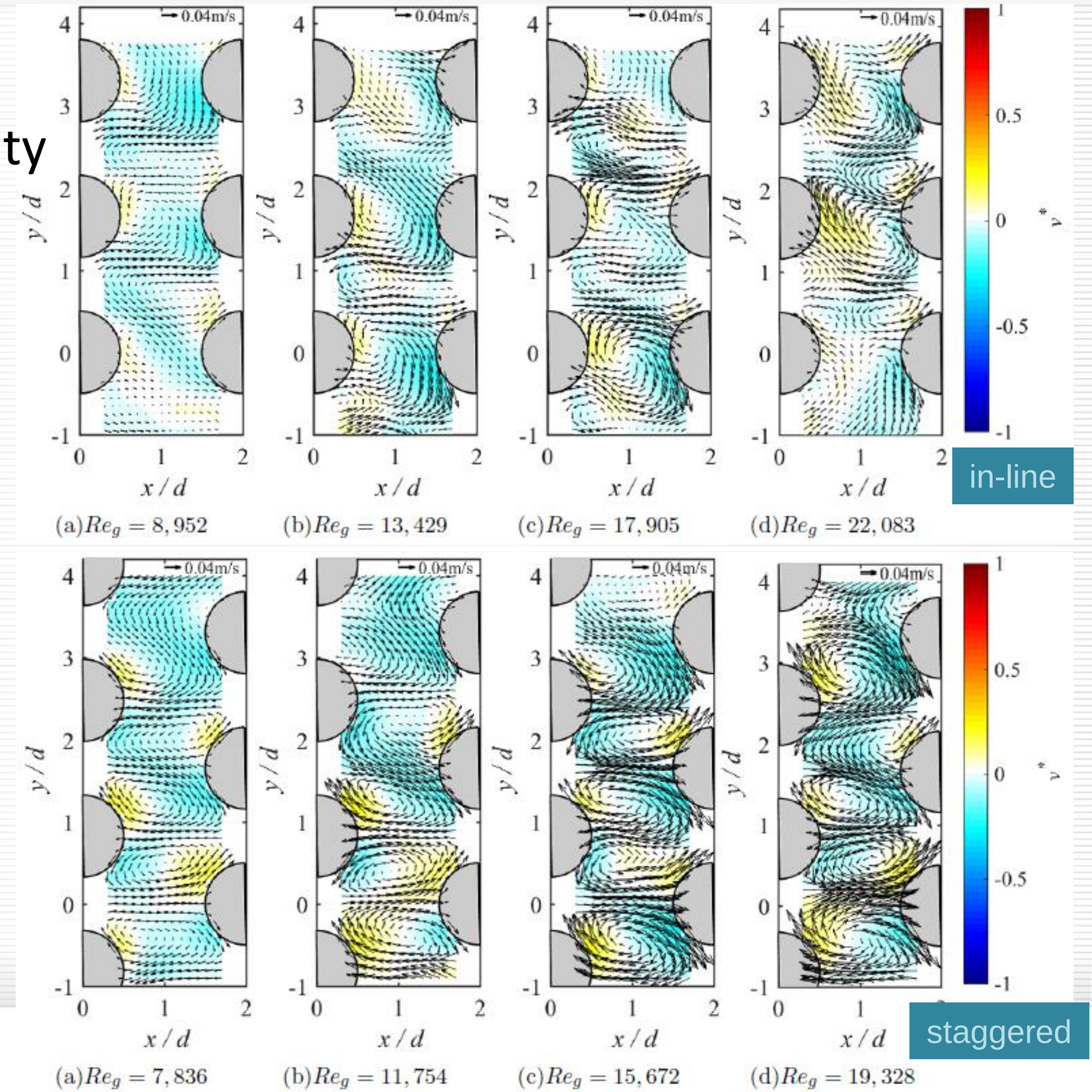
(e)t/T=0.250 (f)t/T=0.313 (g)t/T=0.375 (h)t/T=0.438

Results

- ✓ Time-averaged velocity over a period : $\overline{v_s}$

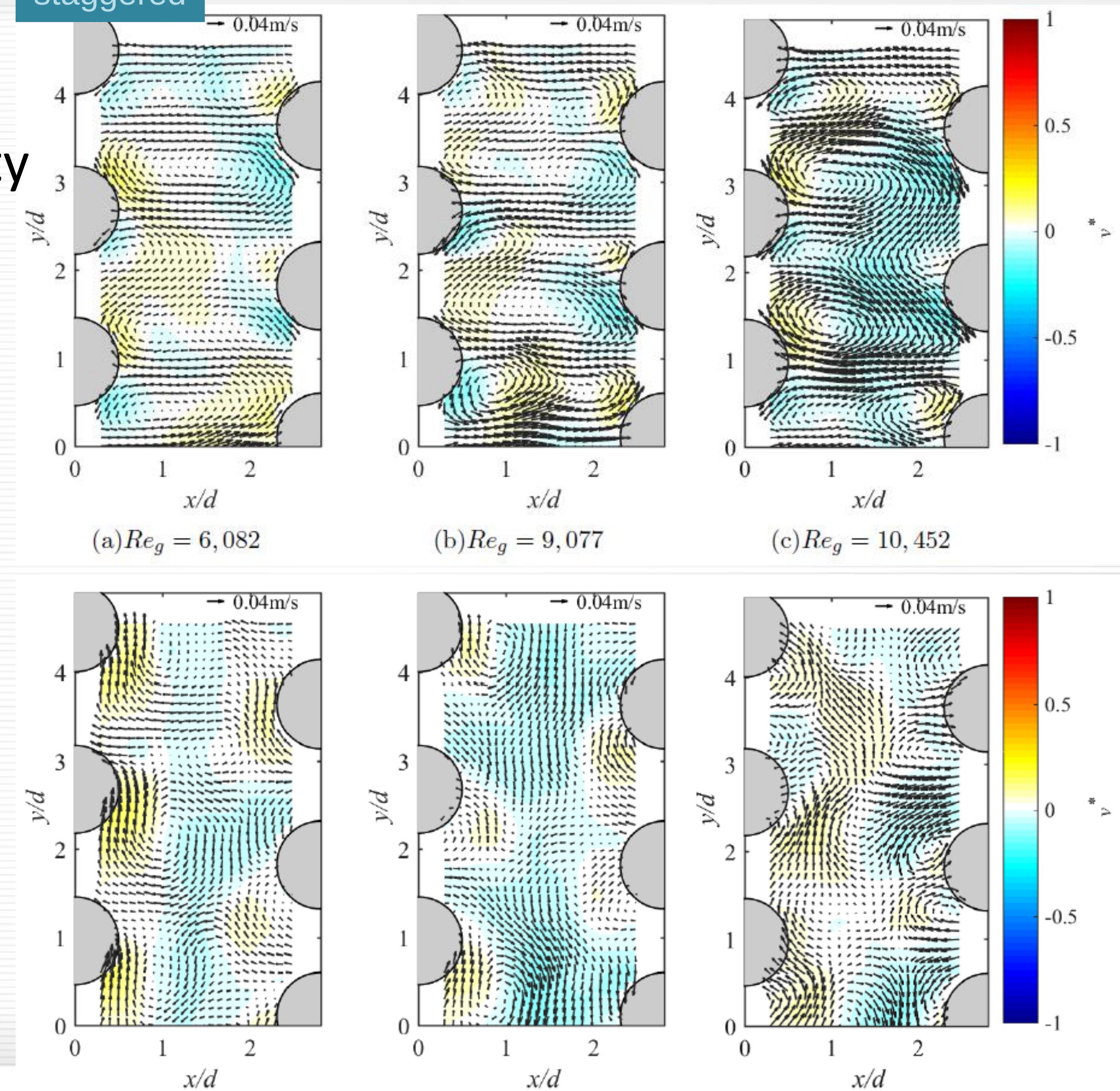
$$\overline{\boldsymbol{v}_S} = \frac{1}{T}\int_0^T \boldsymbol{v}_S dt$$

  - DX/d=2.0
  - DY/d=1.65
  - KC=9.0



Results

staggered



(a) $Re_g = 6,082$ (b) $Re_g = 9,077$ (c) $Re_g = 10,452$
(d) $Re_g = 12,319$ (e) $Re_g = 13,797$ (f) $Re_g = 15,678$

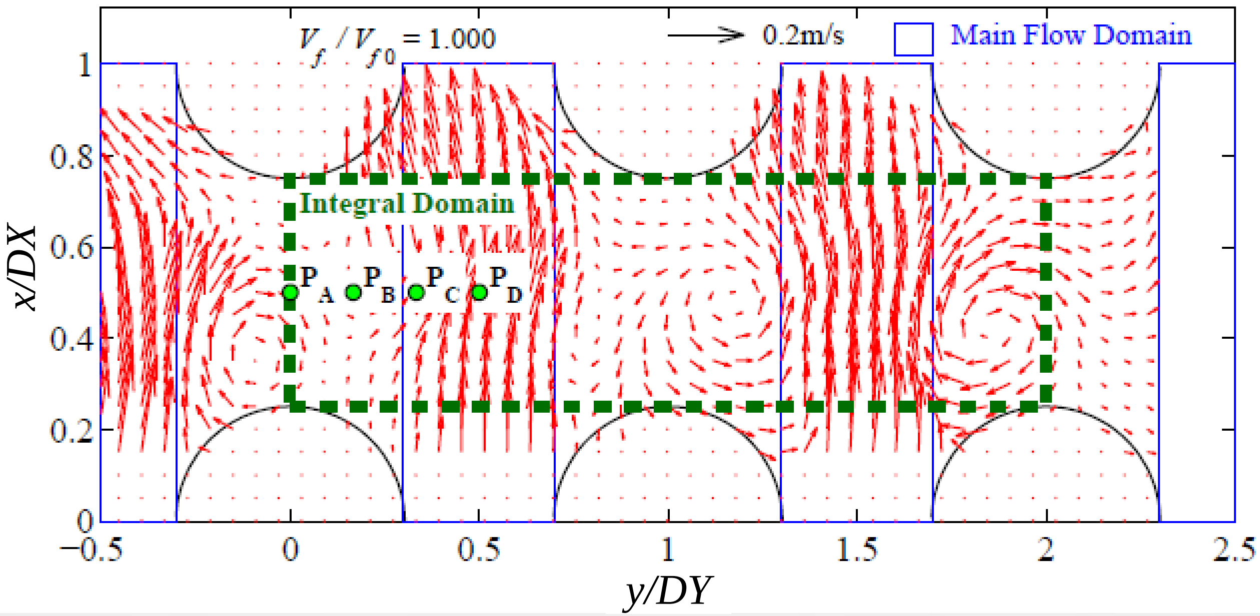
- ✓ Time-averaged velocity over a period : $\overline{v_s}$

$$\overline{v_S} = \frac{1}{T}\int_0^T v_S dt$$

– ***DX/d***=2.78
– ***DY/d***=1.84
– ***KC***=17.1

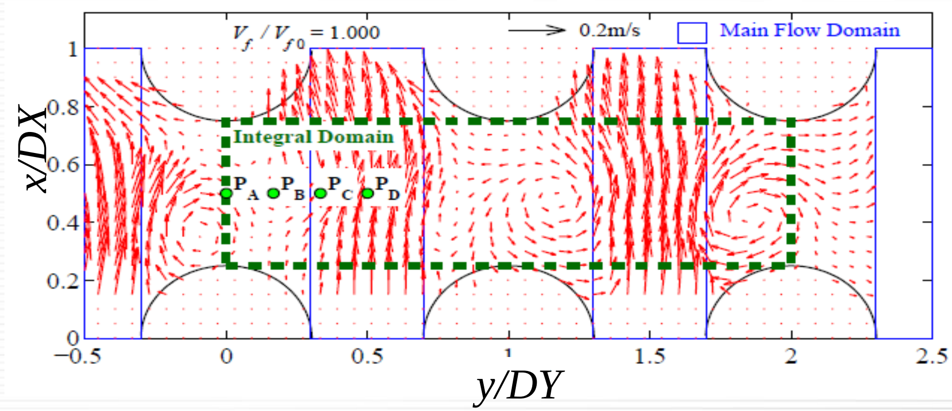
Results

- ✓ Characteristic of time history of velocity : $\boldsymbol{v_s}$
  - separations and vortexes are observed
  - focus the time variation of spatial averaged velocity $\boldsymbol{v_s}$ on P_A, P_B, P_C ,P_D

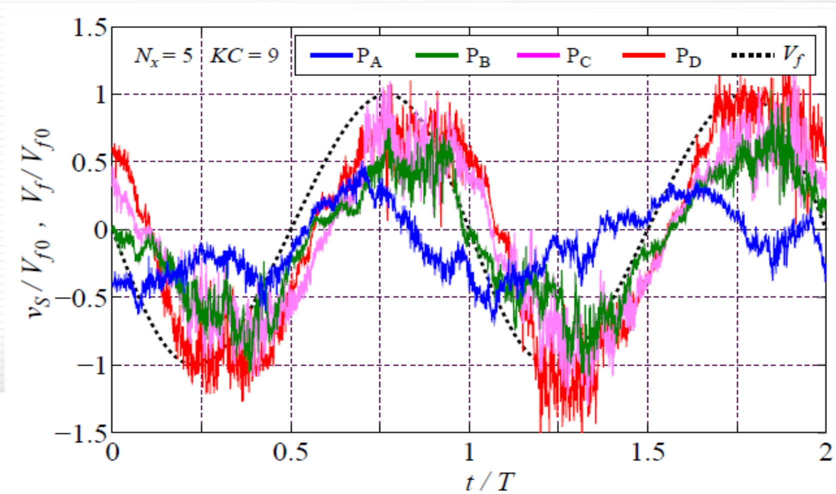


Results

- ✓ Characteristic of time history of velocity : $\boldsymbol{v_s}$
  - separations and vortexes are observed
  - focus the time variation of spatial averaged velocity v_s on P_A, P_B, P_C, P_D



- ✓ Different characteristics at the different points around a circular cylinder
  - include strong fluctuation
  - have different phases at different points

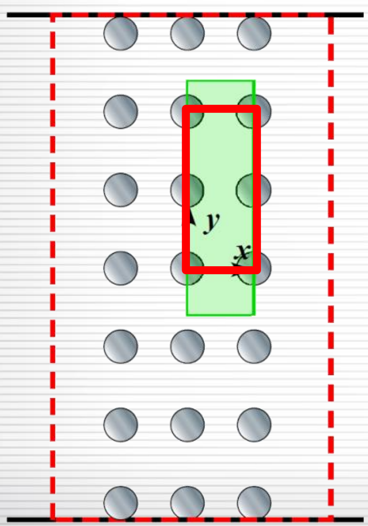


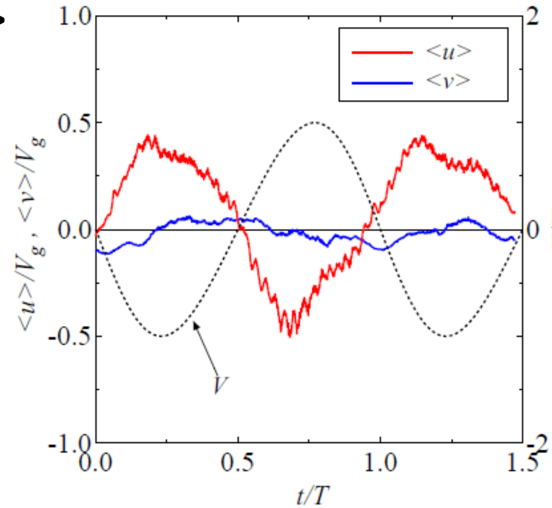
Results

- ✓ Spatial averaged v_s : $\langle v_s \rangle$

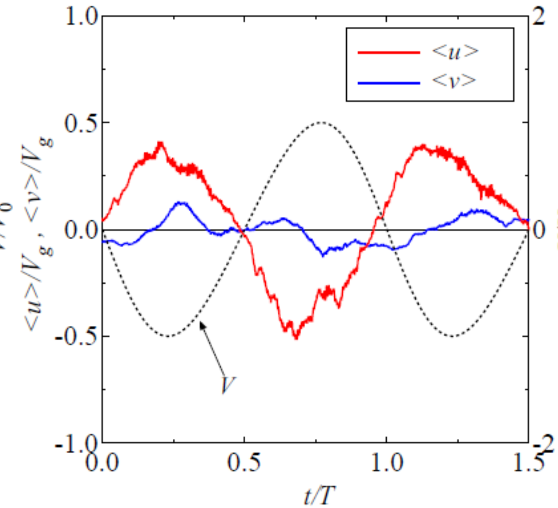
$$\langle \boldsymbol{v}_S \rangle = \int \boldsymbol{v}_S dxdy/(N_x N_y)$$

  - DX/d = 2.0
  - DY/d = 1.65
  - KC = 9.0

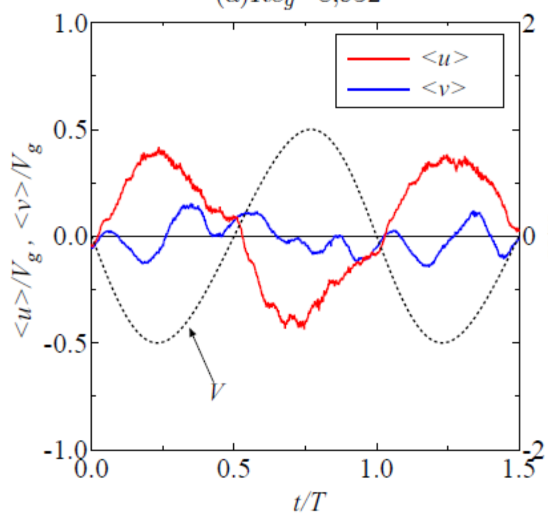




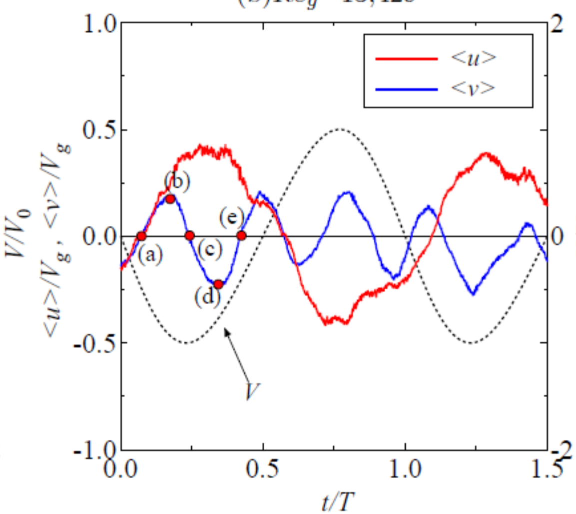
(a) Re_g=8,952



(b) Re_g=13,429



(c) Re_g=17,905



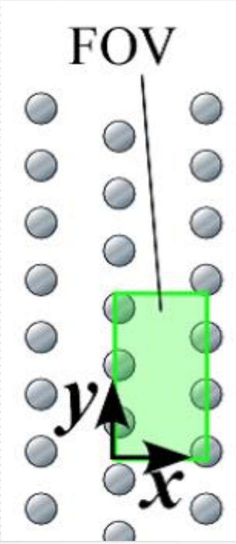
(d) Re_g=22,083

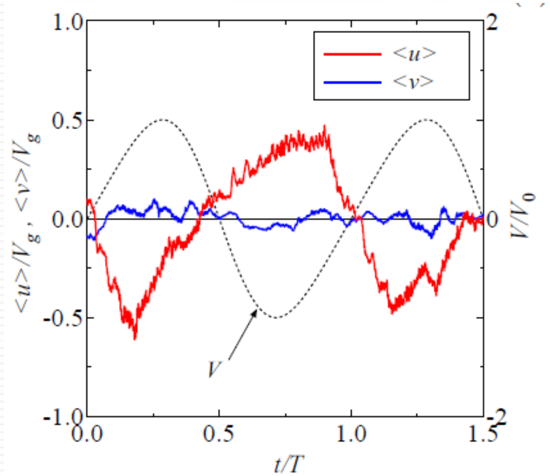
Results

- Spatial averaged $\boldsymbol{v_s}$: <$\boldsymbol{v_s}$>

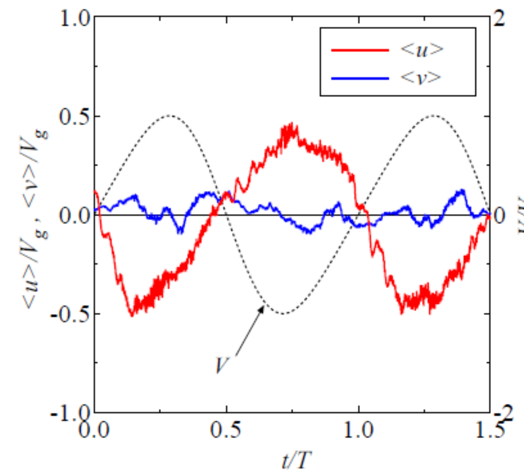
$$\langle \boldsymbol{v}_S \rangle = \int \boldsymbol{v}_S dx dy / (N_x N_y)$$

  - DX/d = 2.0
  - DY/d = 1.65
  - KC = 9.0

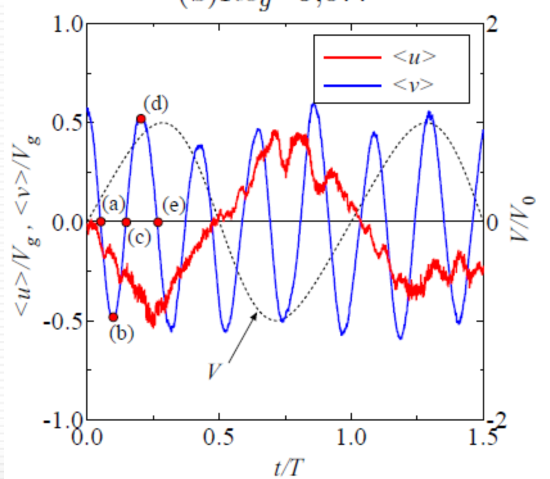




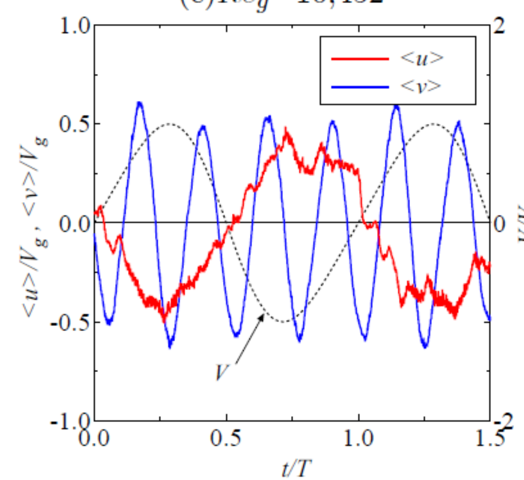
(b) Re_g=9,077



(c) Re_g=10,452



(d) Re_g=12,319

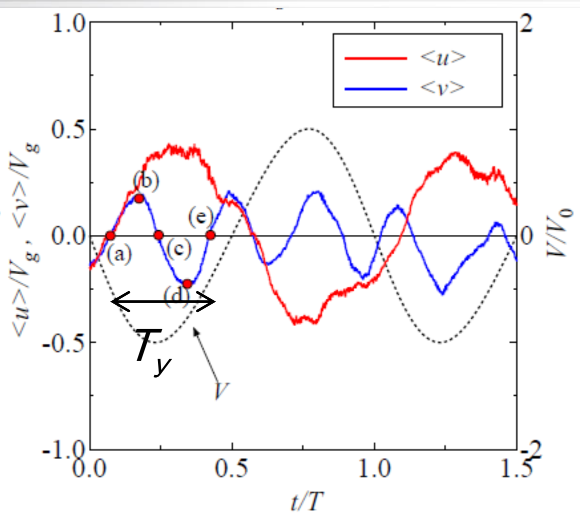


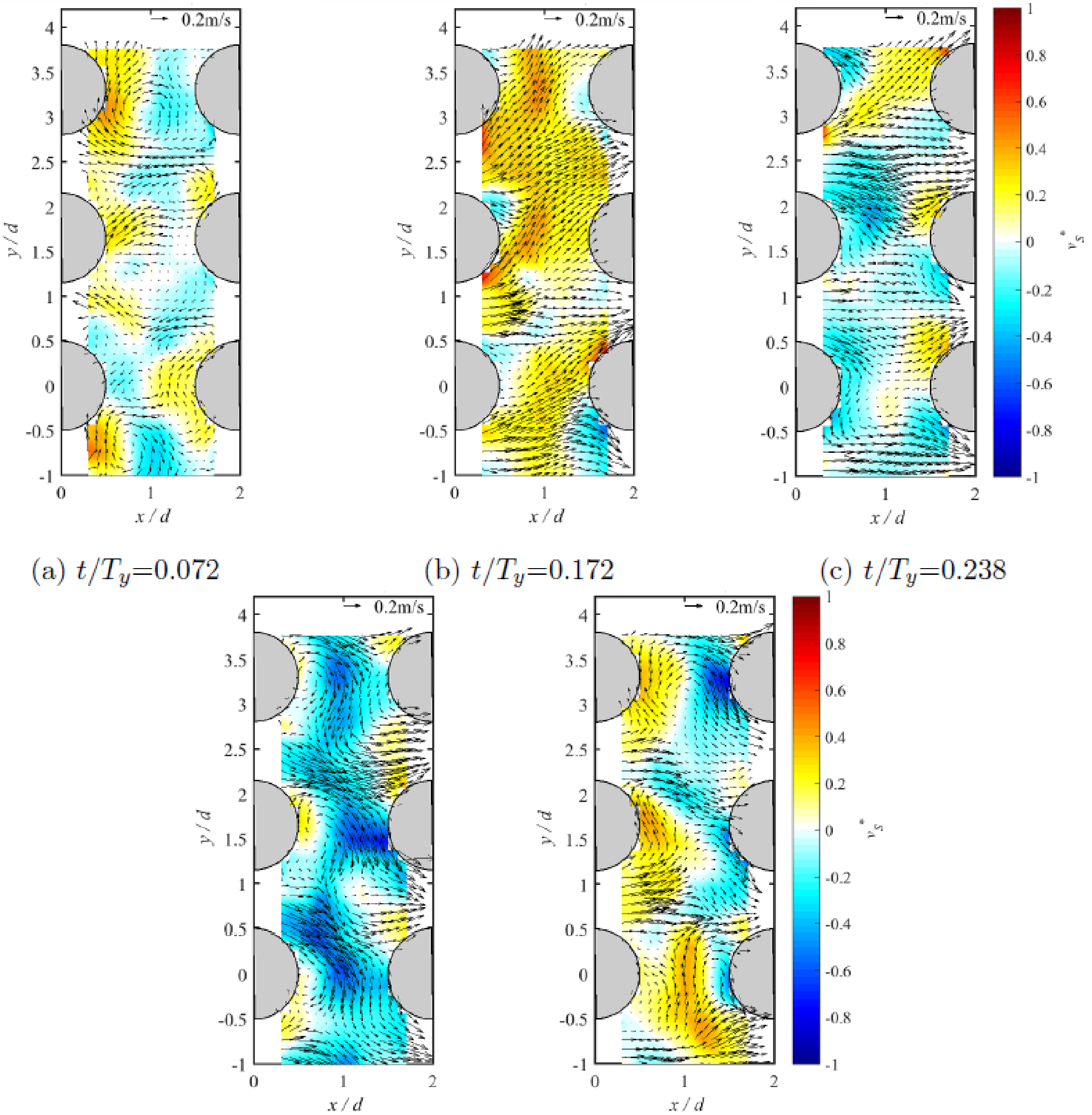
(e) Re_g=13,797

Results

✓ Distribution of v_s

- DX/d =2.0
- DY/d =1.65
- KC=9.0
- Re_g=22,083

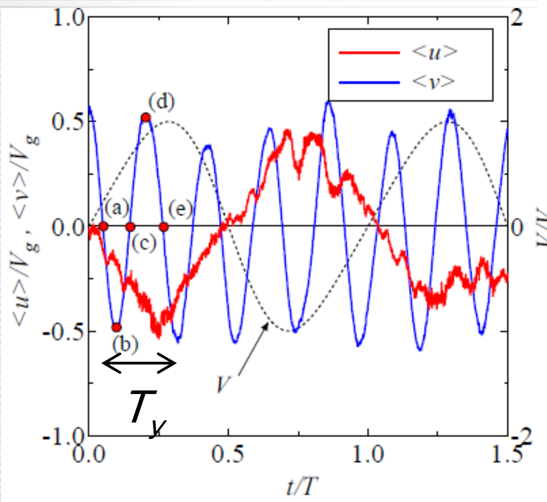


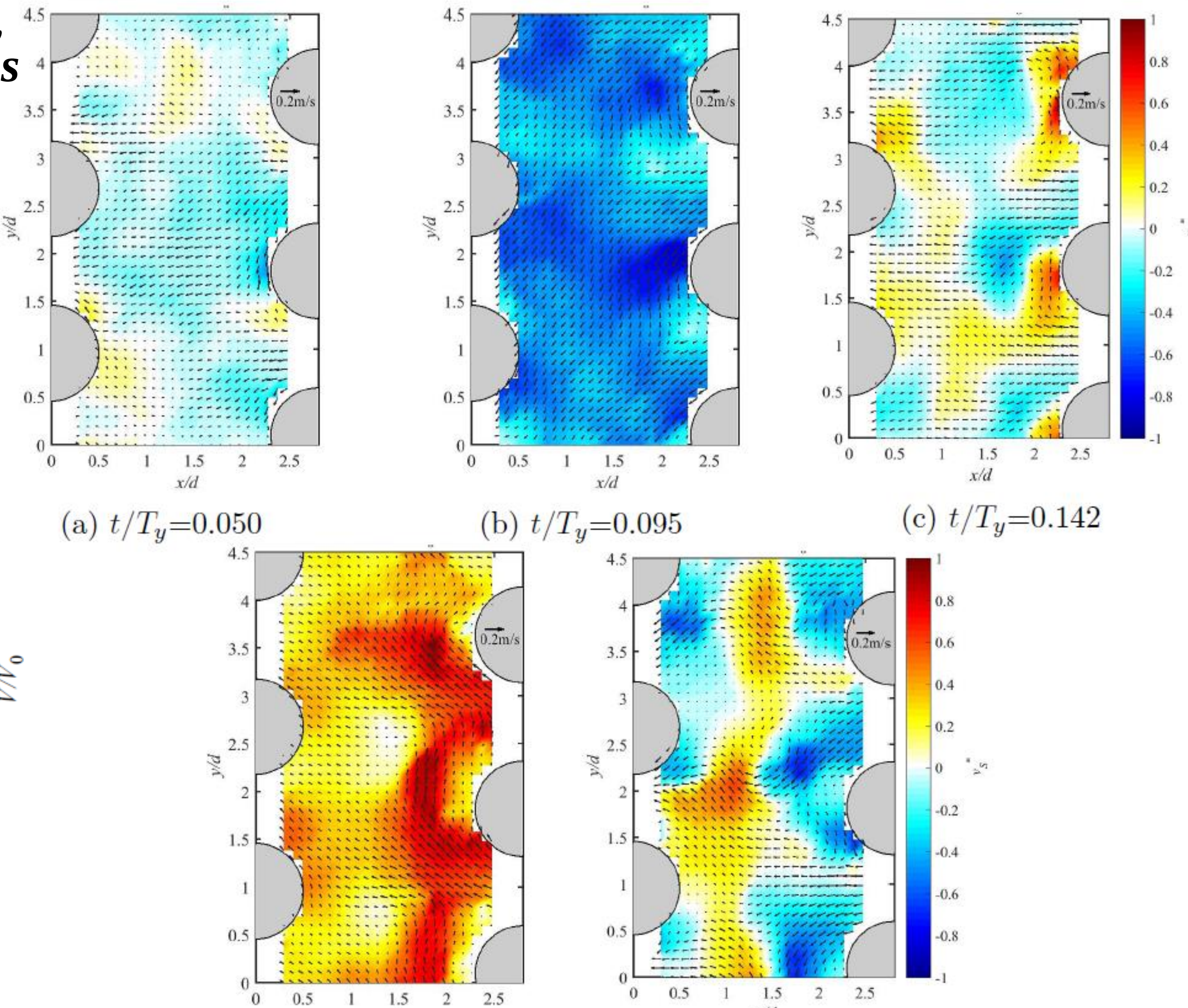


(a) t/T_y=0.072 (b) t/T_y=0.172 (c) t/T_y=0.238 (d) t/T_y=0.340 (e) t/T_y=0.425

Results

- ✓ Distribution of v_s
  - – DX/d=2.78
  - – DY/d=1.84
  - – KC=17.1
  - – Re_g=12,319



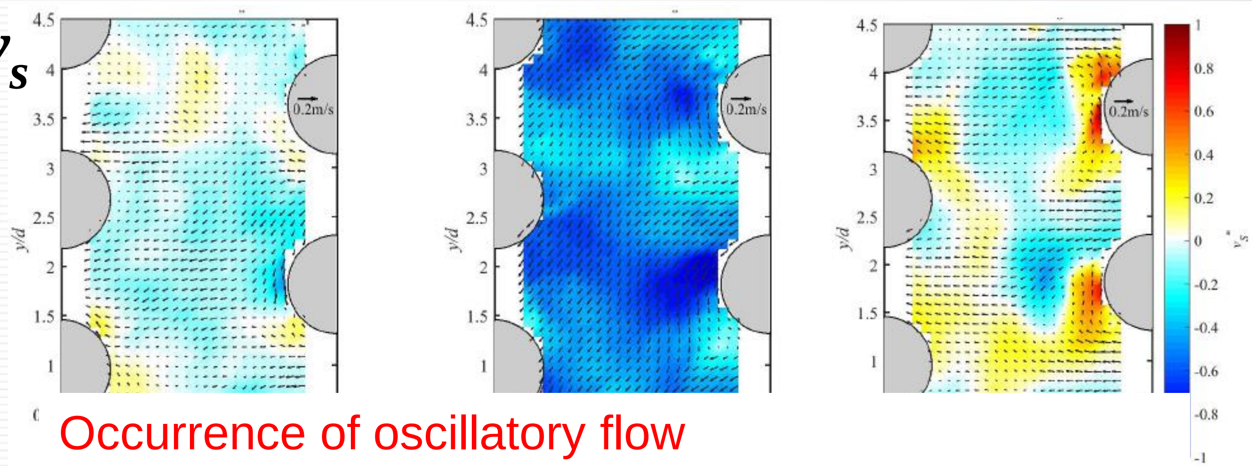


(a) t/T_y=0.050 (b) t/T_y=0.095 (c) t/T_y=0.142

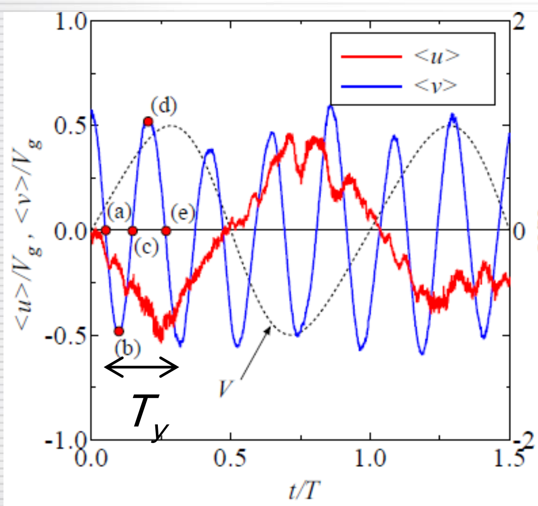
(d) t/T_y=0.199 (e) t/T_y=0.265

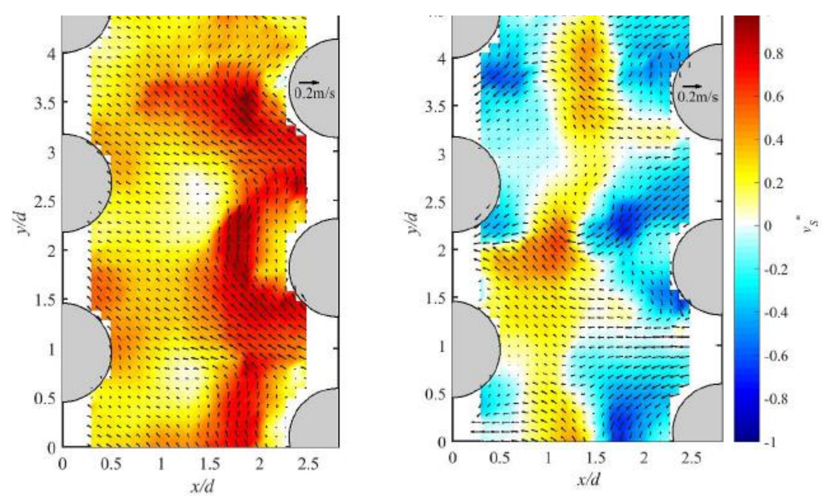
Results

- ✓ Distribution of v_s
  - – DX/d=2.78
  - – DY/d=1.84
  - – KC=17.1
  - – Re_g=12,319



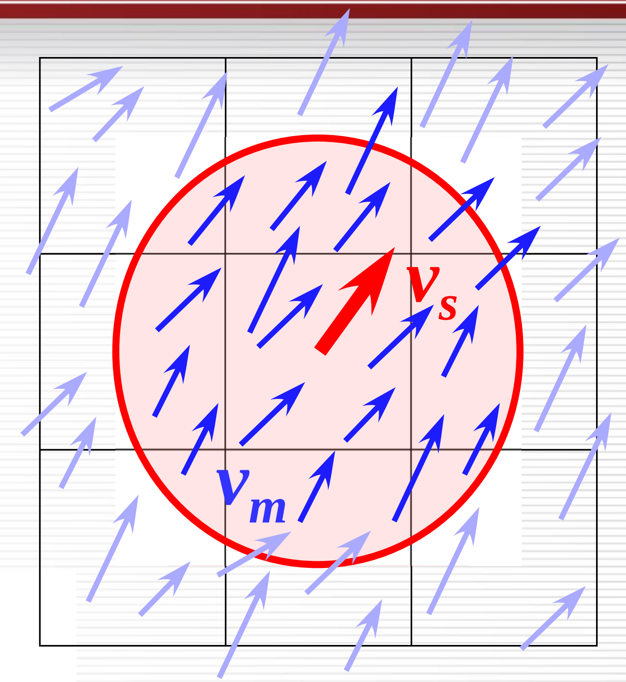
Occurrence of oscillatory flow
in the transverse direction of cylinder oscillation
under certain conditions



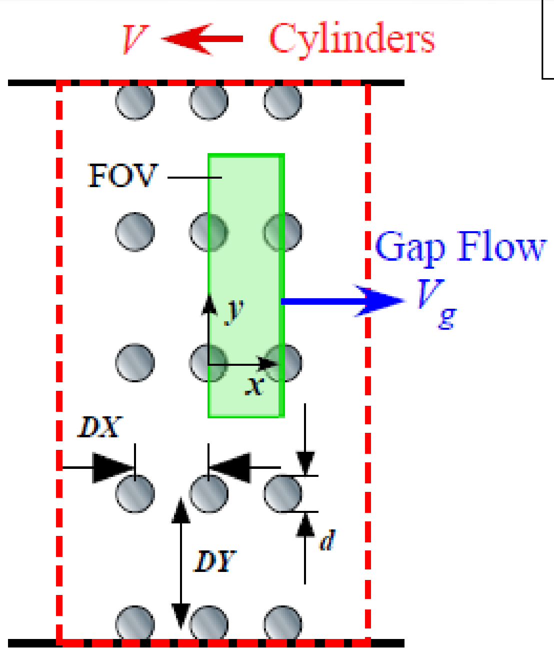


(d) t/T_y=0.199 (e) t/T_y=0.265

Results

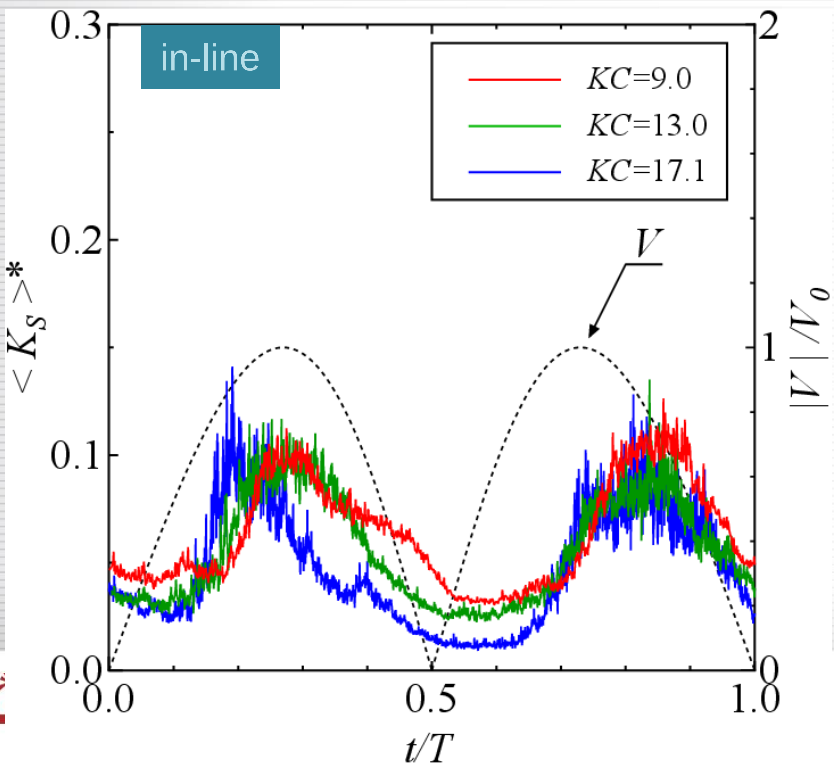


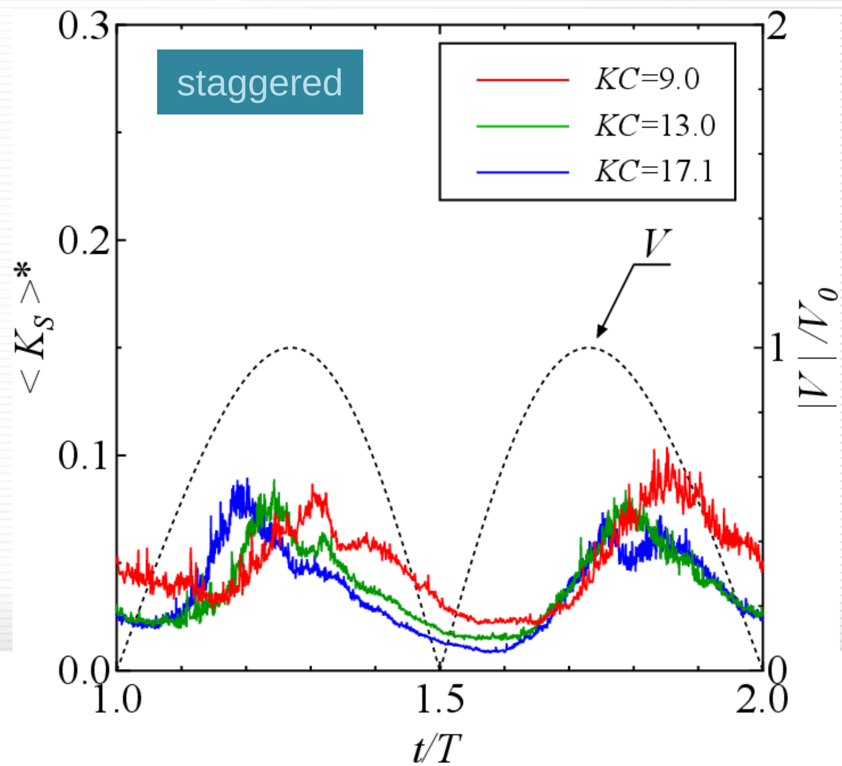
- ✓ Definition of turbulence
  - $v_s' = v_m - v_s$
- ✓ Definition of turbulence energy
  - $K_s = 0.5 v_s'^2$
  - $\langle K_s \rangle^* = K_s / V_g^2$



Results

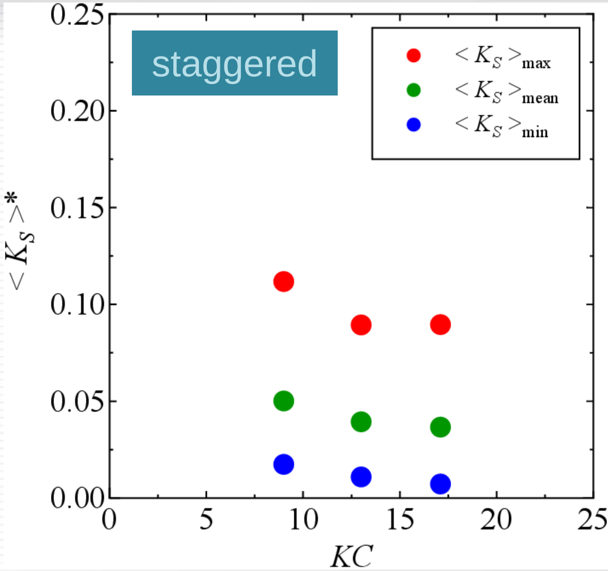
- ✓ Phase variation of $<K_s>^*$
  - The larger KC, the smaller the minimum $<K_s>^*$
  - The larger KC, the phase of $<K_s>^*$ tends to shift
  - Deviation of $<K_s>^*$ for in- line larger than for staggered

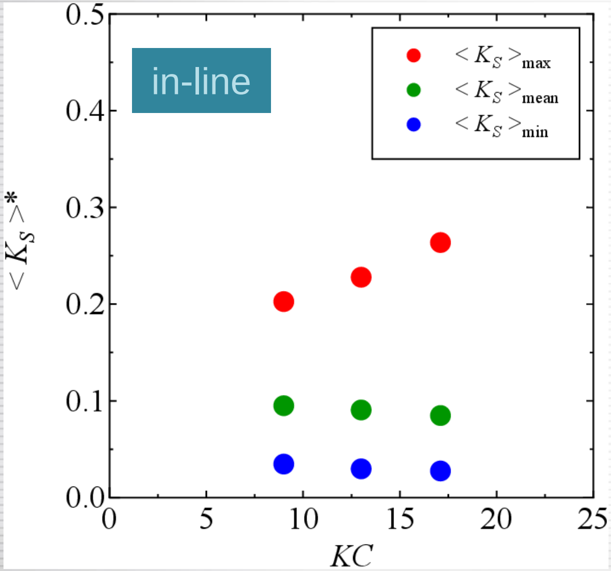


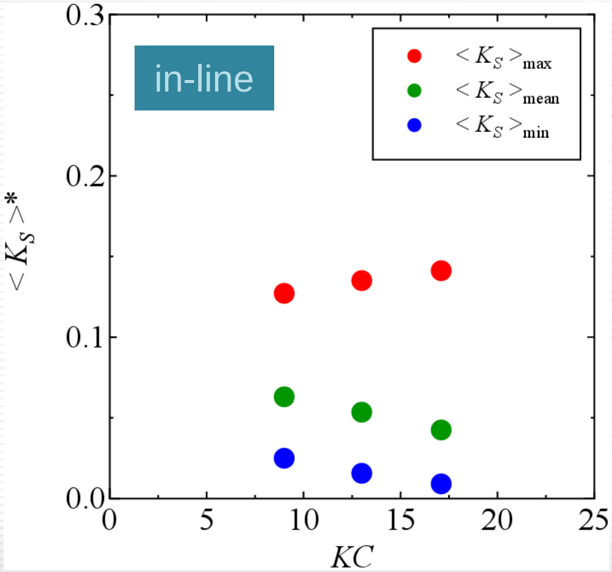


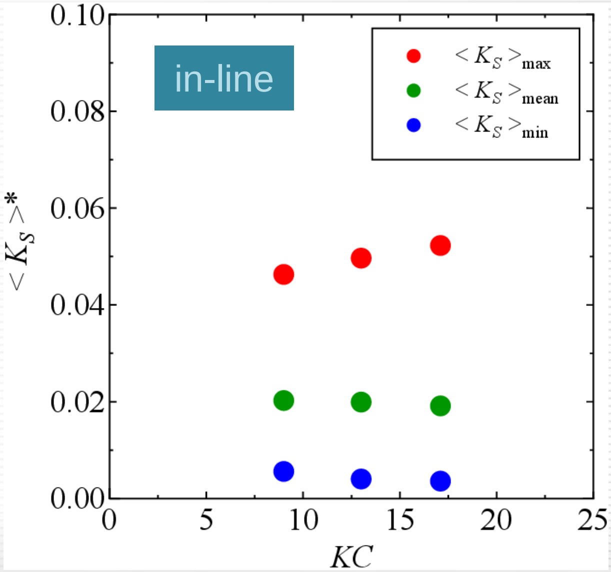
Results

- ✓ Relation between $<K_s>$ * and KC
  - min. and average of $<K_s>^*$ become smaller as ***KC*** increase





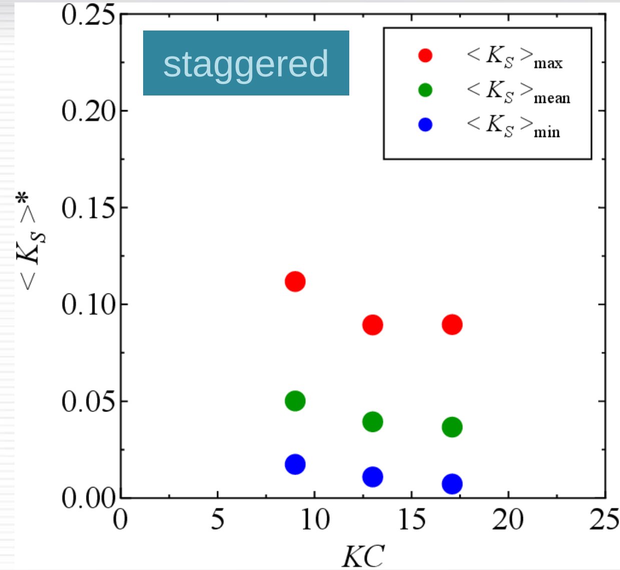


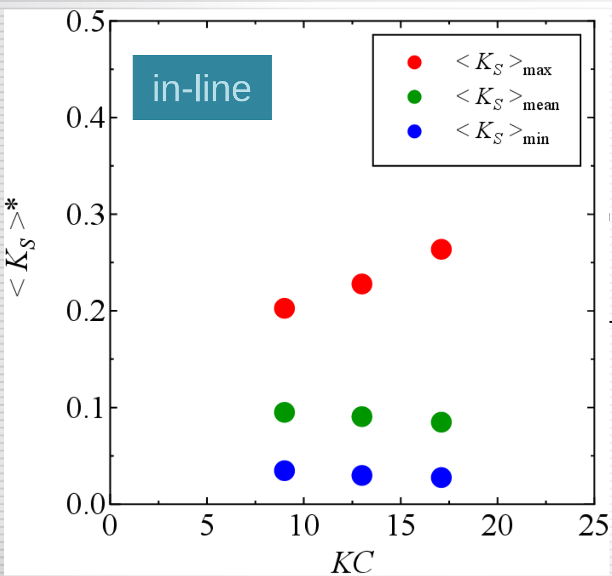


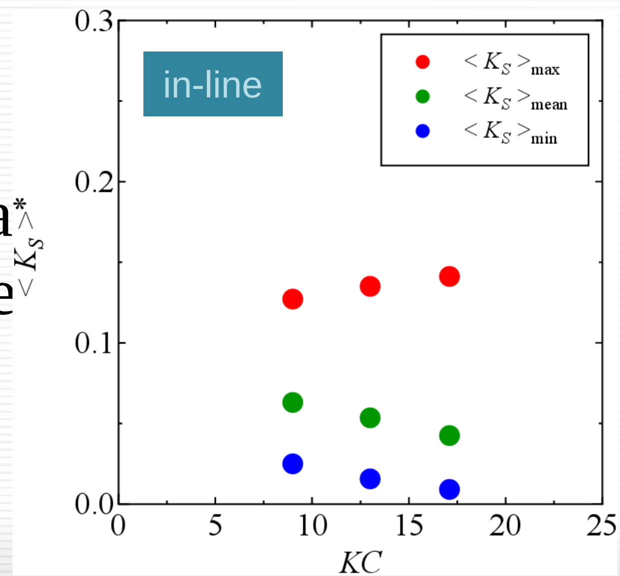
Results

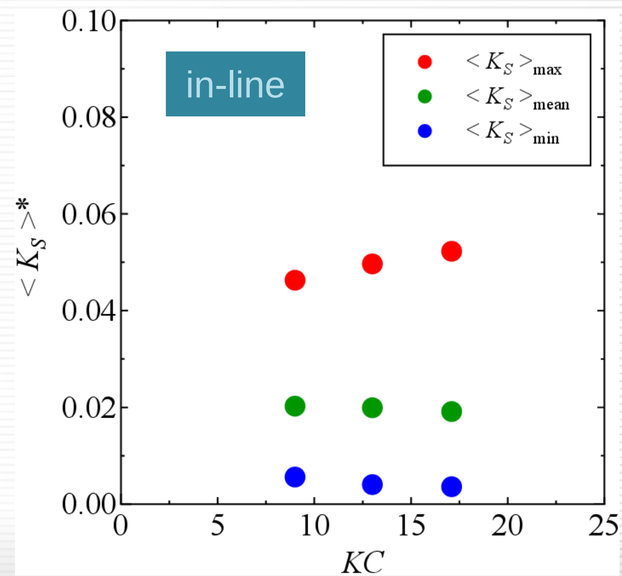
✓ Relation between $<K_s>^*$ and ***KC***

- Increase of ***KC*** for in-line
  max. become greater
- Increase of ***KC*** for staggered
  max. become smaller



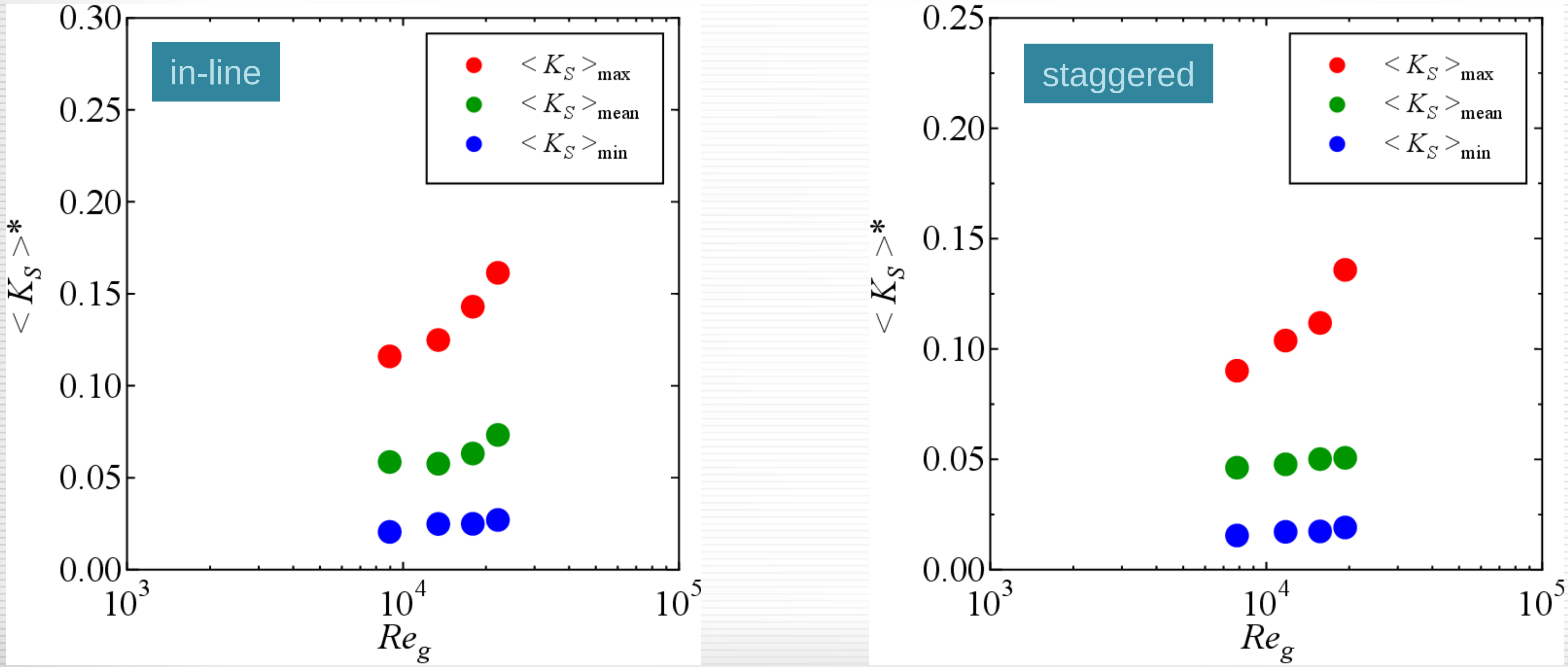






Results

- ✓ Relation between $<K_s>^*$ and Re
  - As Re become greater, min. of average of $<K_s>$ become greater and max. becomes much greater



Conclusions

Flow field in the gap of the oscillating circular cylinders was measured in detail by the PTV under different conditions, distance between cylinders, oscillatory period, ***KC***, ***Re***.

Velocity field:

✓ Complex fluid motion

- Separations, vortexes, oblique flow, and so on.
- Different fluid motions were observed under different conditions ***KC***, $\boldsymbol{Re}_g$, arrangement of circular cylinders
- Oscillating flow in the transverse direction of cylinder oscillation was confirmed to be generated under some conditions.

Conclusions

Turbulence field:

- ✓ Relation between $<K_s>^*$ and KC
  - For in-line arrangement, maximum value of $<K_s>^*$ become greater as KC increases.
  - For staggered arrangement, maximum value of $<K_s>^*$ become smaller as KC increases.
  - For both cases, minimum and average value of become smaller as KC increases.
- ✓ Relation between $<K_s>^*$ and Re
  - As Re become greater, minimum of average value of $<K_s>^*$ become greater and maximum value becomes much greater.

Thank you for your kind attentions !