WIV – Wake-Induced Vibration

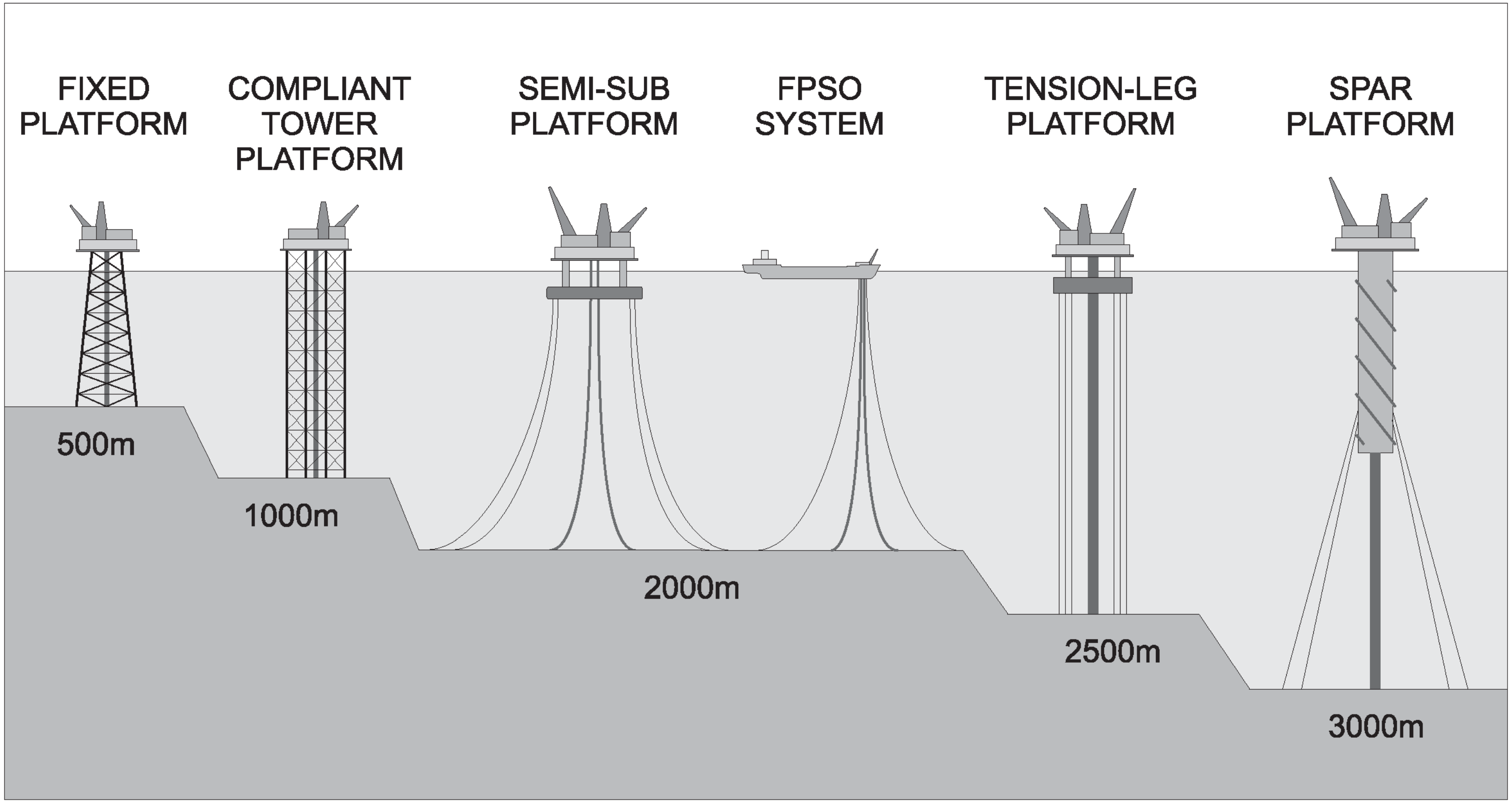
Prof Gustavo R. S. Assi
Dept. Naval Arch. & Ocean Eng., EPUSP
University of São Paulo

PNV 5203
Fluid-Structure Interaction

References

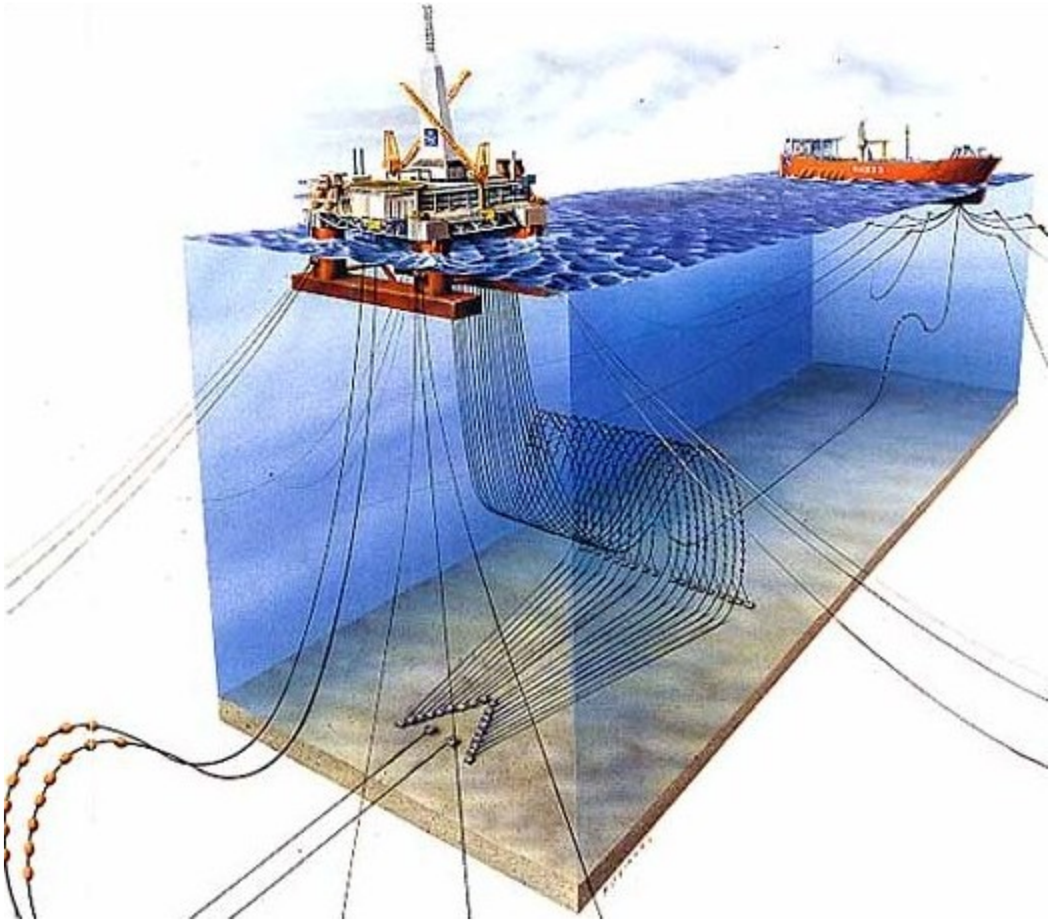
- GRS Assi (2009) **Mechanisms for flow-induced vibration of interfering bluff bodies**, PhD Thesis, Imperial College London
- GRS Assi, PW Bearman, JR Meneghini (2010) **On the Wake-Induced Vibration of Tandem Circular Cylinders: the Vortex Interaction Excitation Mechanism**, Journal of Fluid Mechanics, v. 661, p. 365-401.
- GRS Assi, PW Bearman, BS Carmo, JR Meneghini, SJ Sherwin, RHJ Willden (2013) **The role of wake stiffness on the wake-induced vibration of the downstream cylinder of a tandem pair**, Journal of Fluid Mechanics, v. 718, p. 210-245.

Motivation



FIXED PLATFORM
COMPLIANT TOWER PLATFORM
SEMI-SUB PLATFORM
FPSO SYSTEM
TENSION-LEG PLATFORM
SPAR PLATFORM
500m
1000m
2000m
2500m
3000m

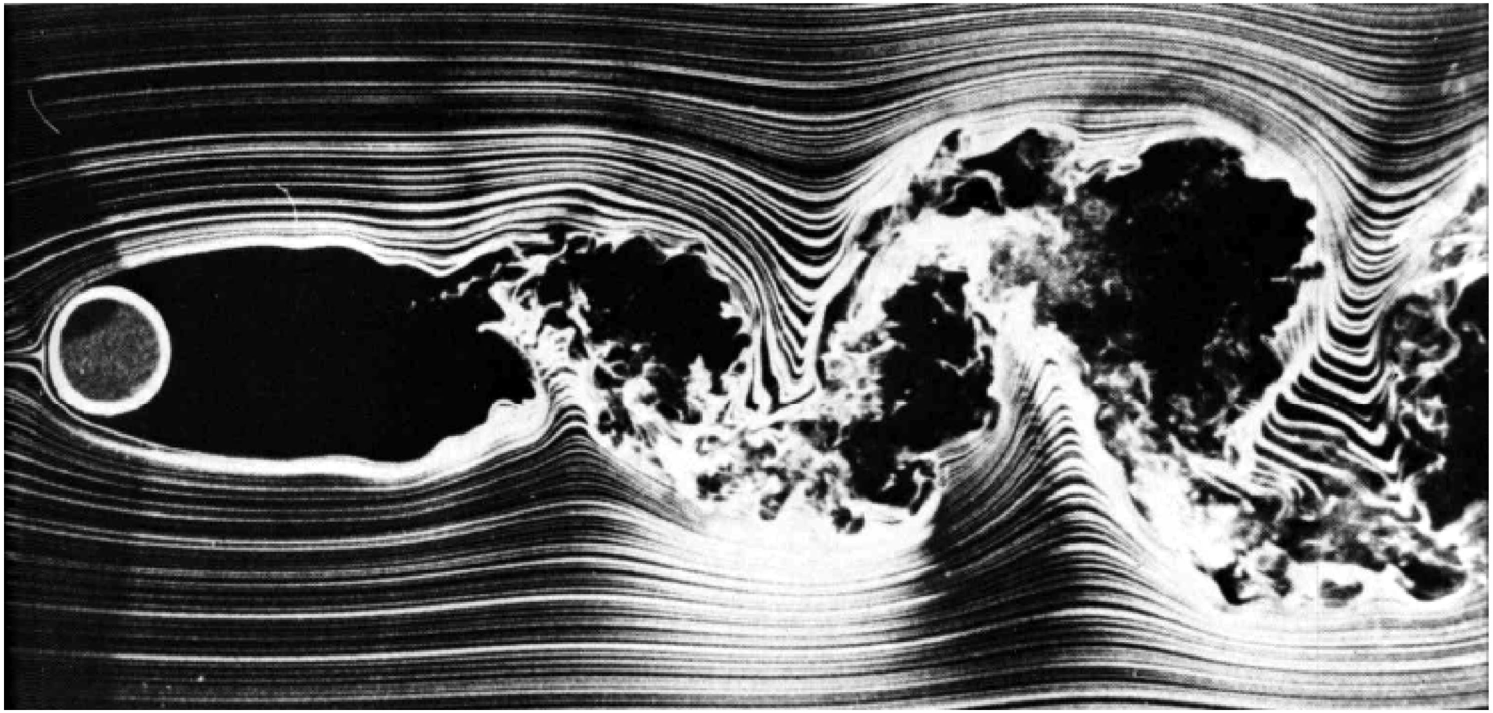
Motivation



VIV – VORTEX-INDUCED VIBRATION

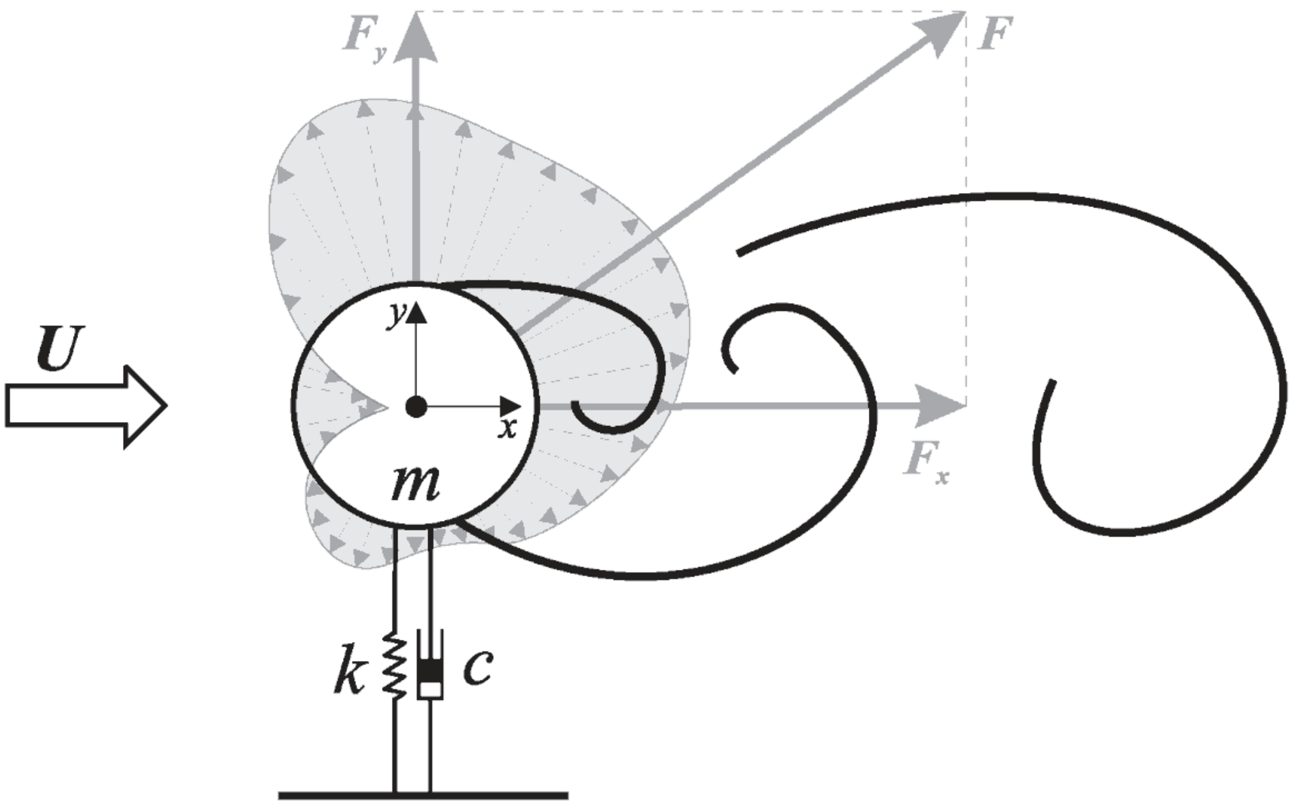
VIV – Vortex-Induced Vibration

$$f_s = St\,\frac{U}{D}$$

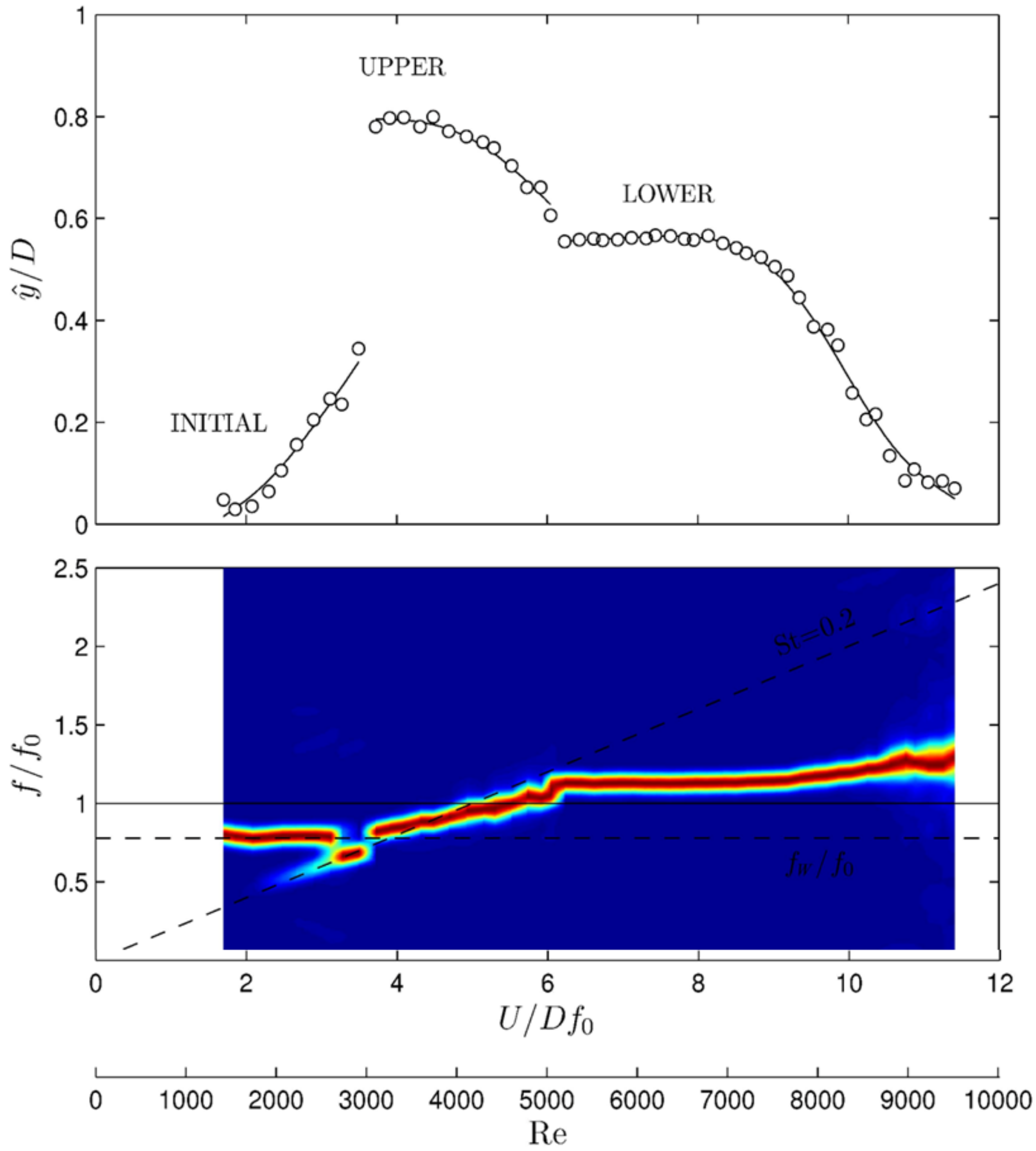


Re=10^4 (van Dyke, 1982)

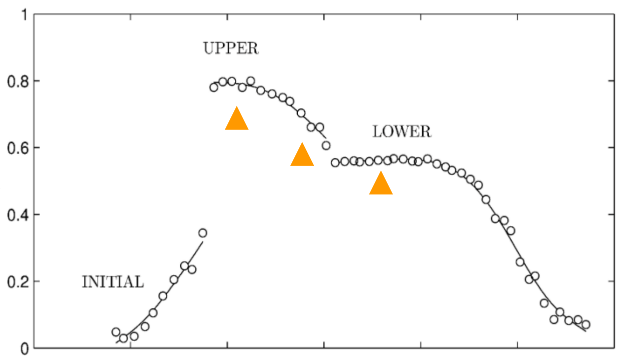
VIV – Vortex-Induced Vibration

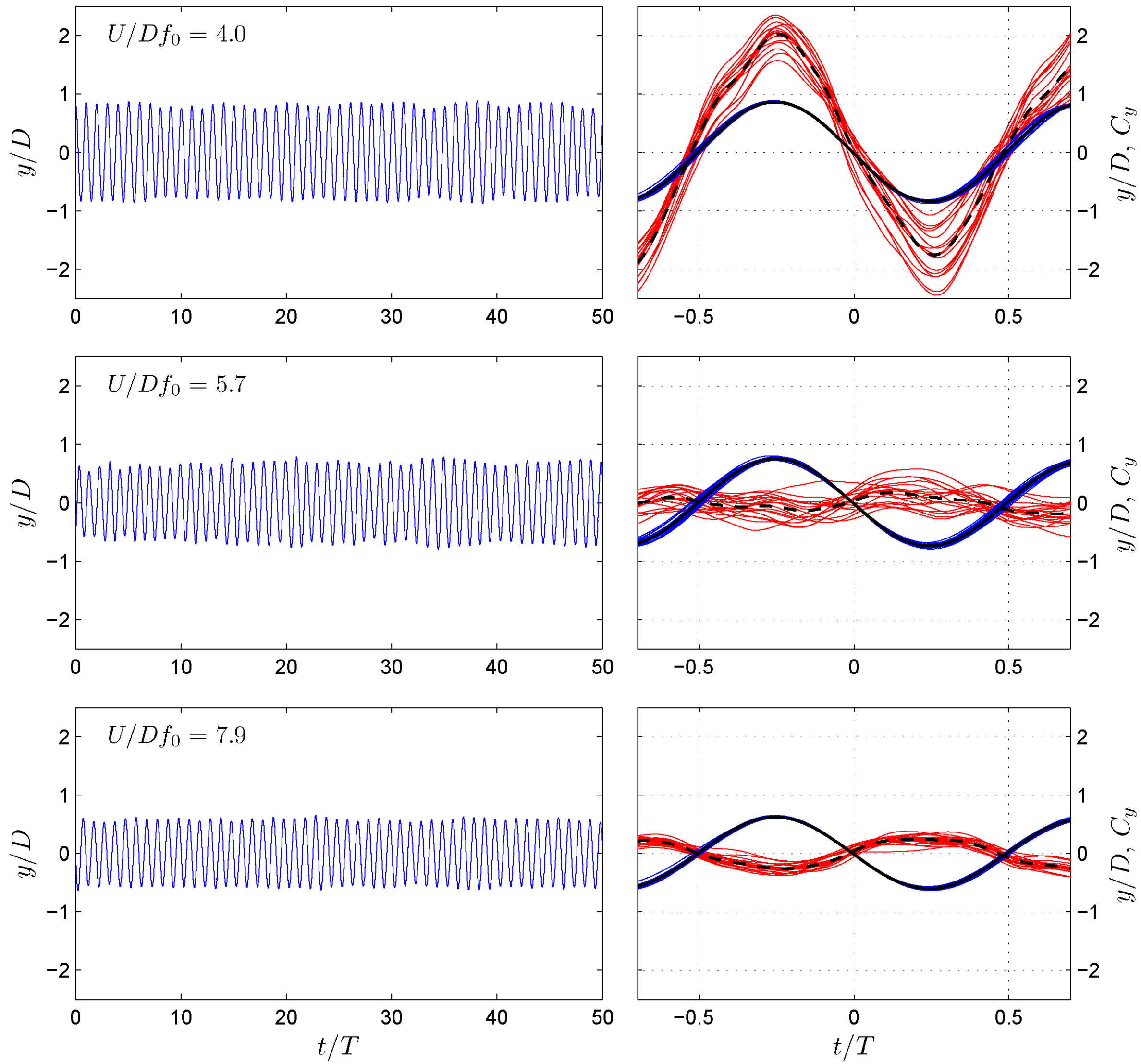


VIV – Vortex-Induced Vibration



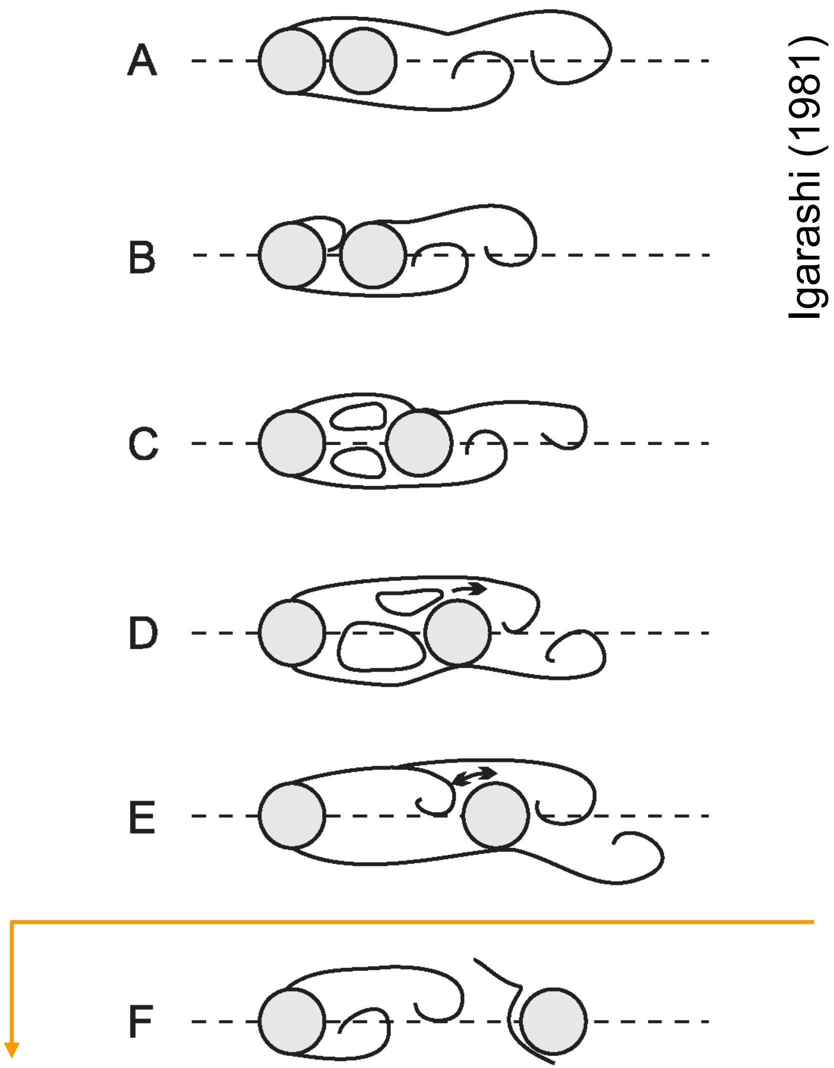
VIV – Vortex-Induced Vibration



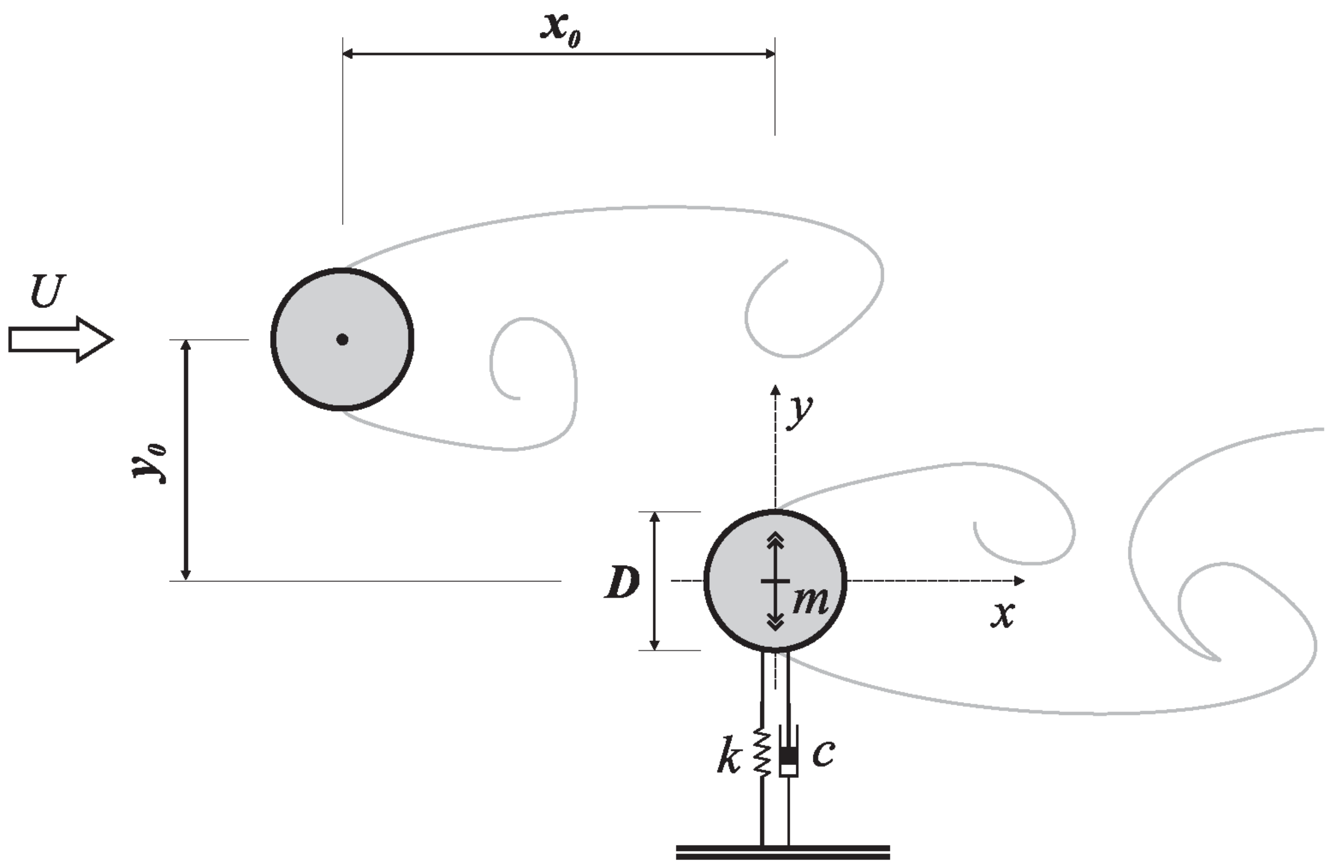


WIV – WAKE-INDUCED VIBRATION

Wake interference

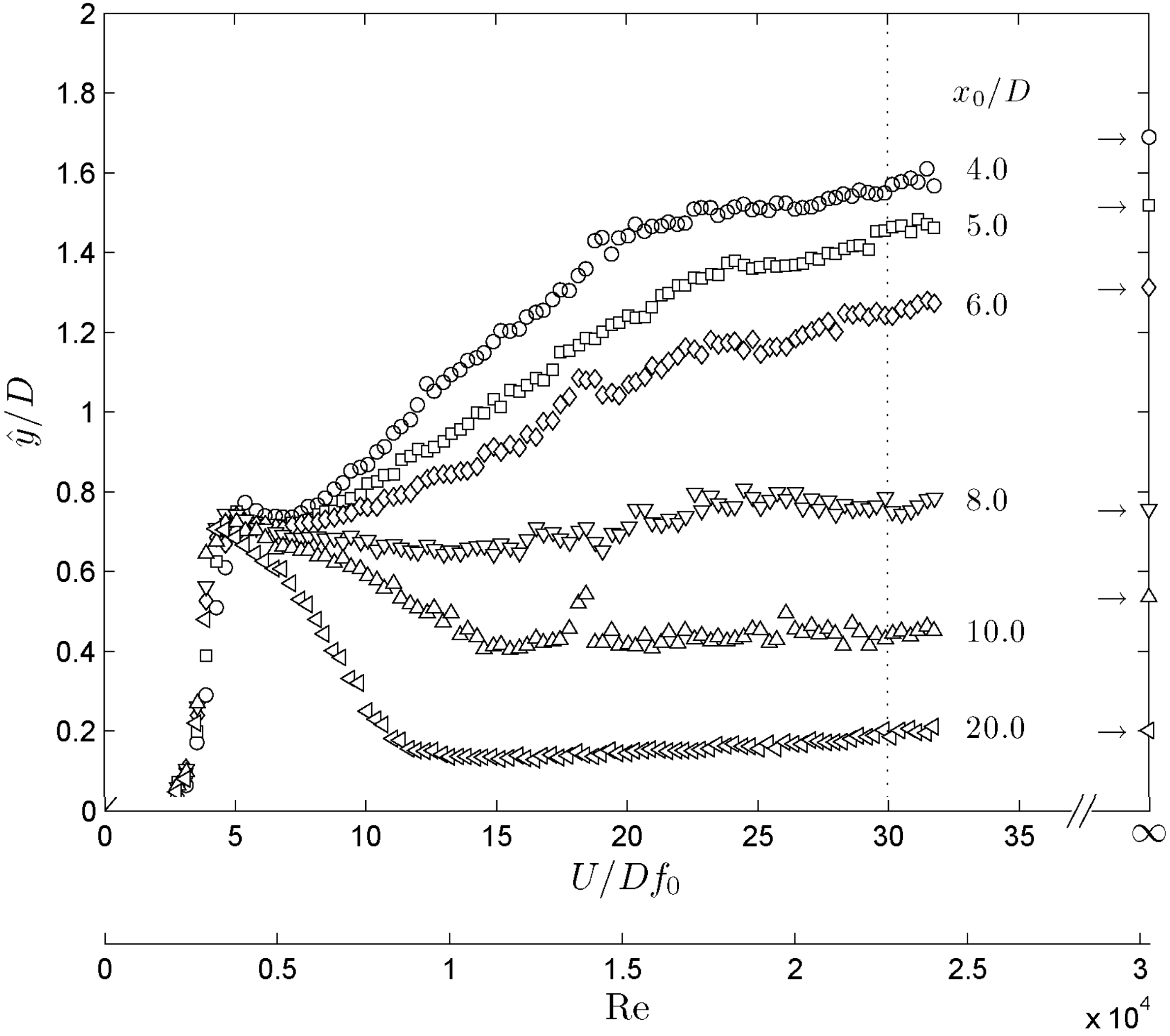


WIV response

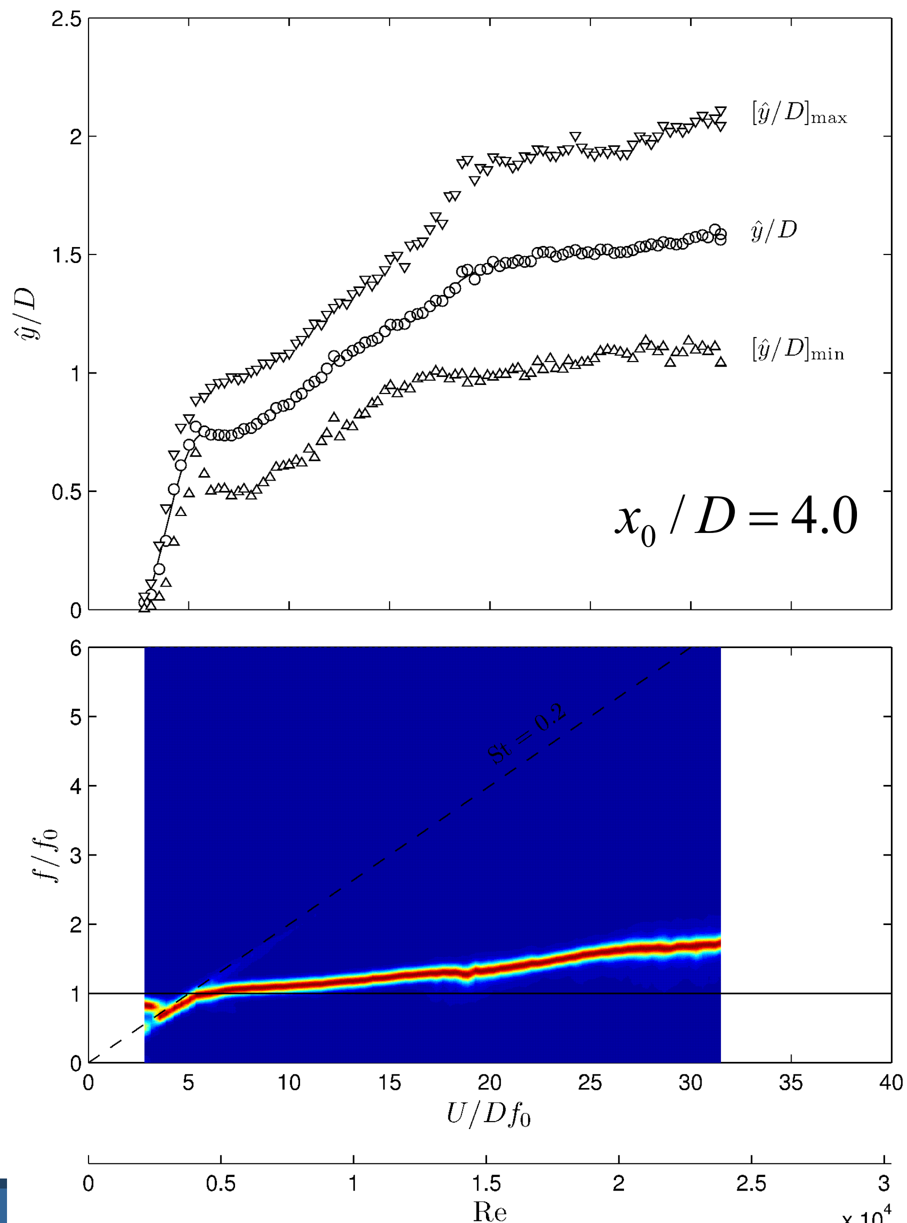


$$\frac{\hat{y}}{D} = \mathrm{f}\left(\frac{\rho U D}{\mu}, \frac{U}{D f_0}, \frac{x_0}{D}, m^*, \zeta\right)$$

WIV response

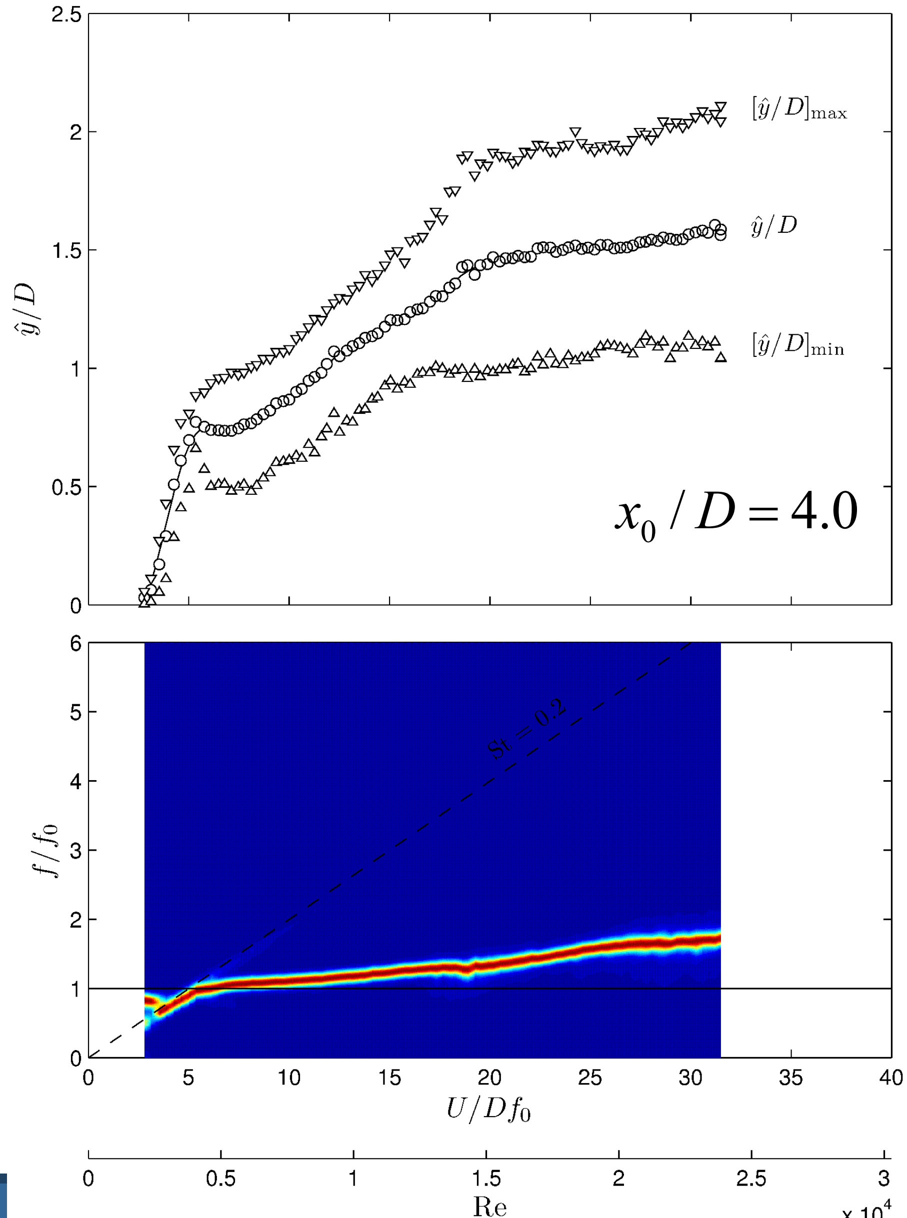


WIV response

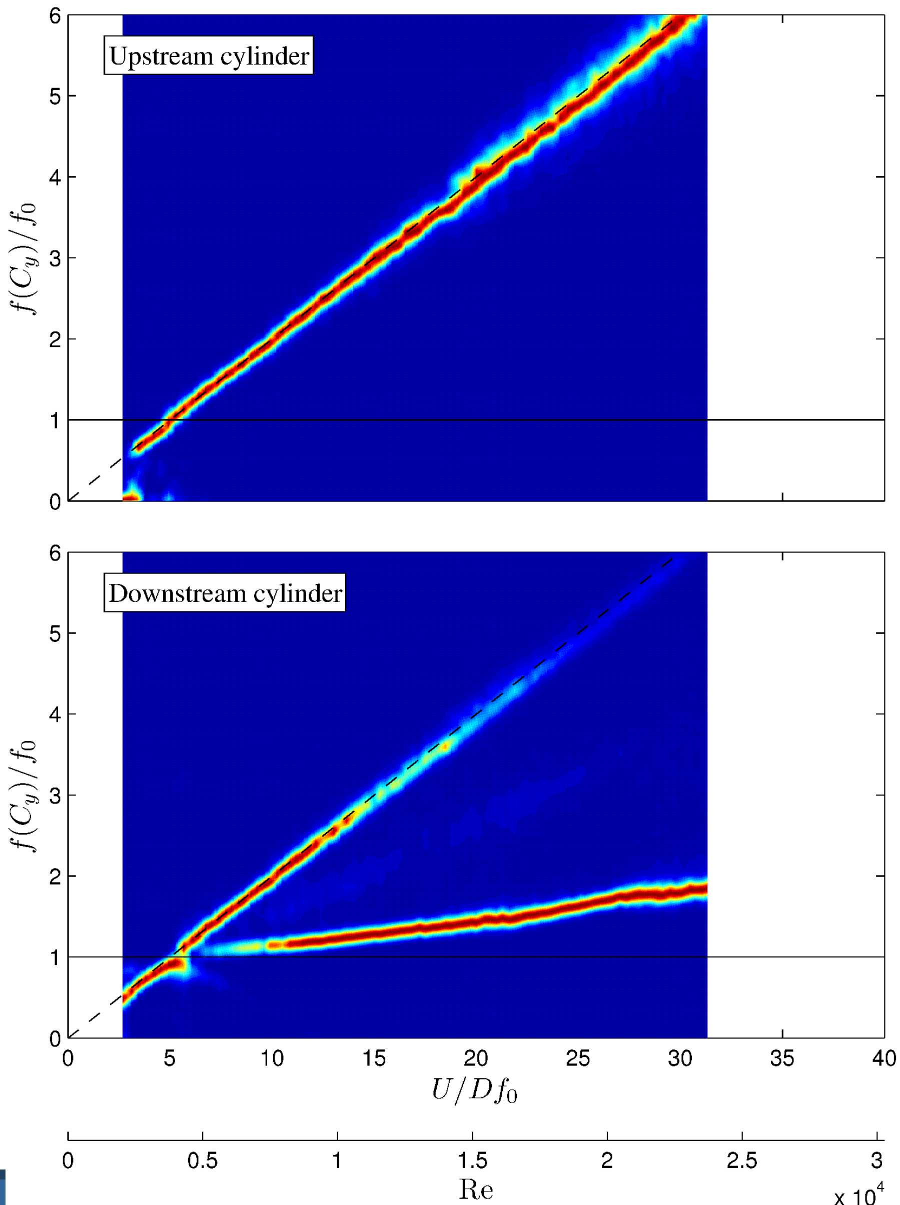


$$\frac{\hat{y}}{D} = \mathrm{f}\left(\frac{\rho U D}{\mu}, \frac{U}{D f_0}, \cancel{\frac{x_0}{D}}, \cancel{m^*}, \cancel{\zeta}\right)$$

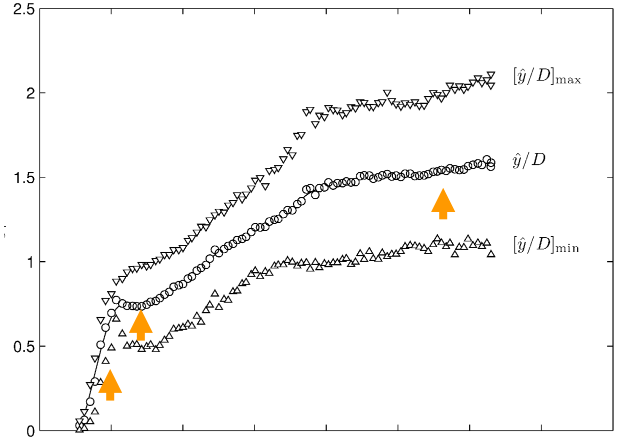
WIV response

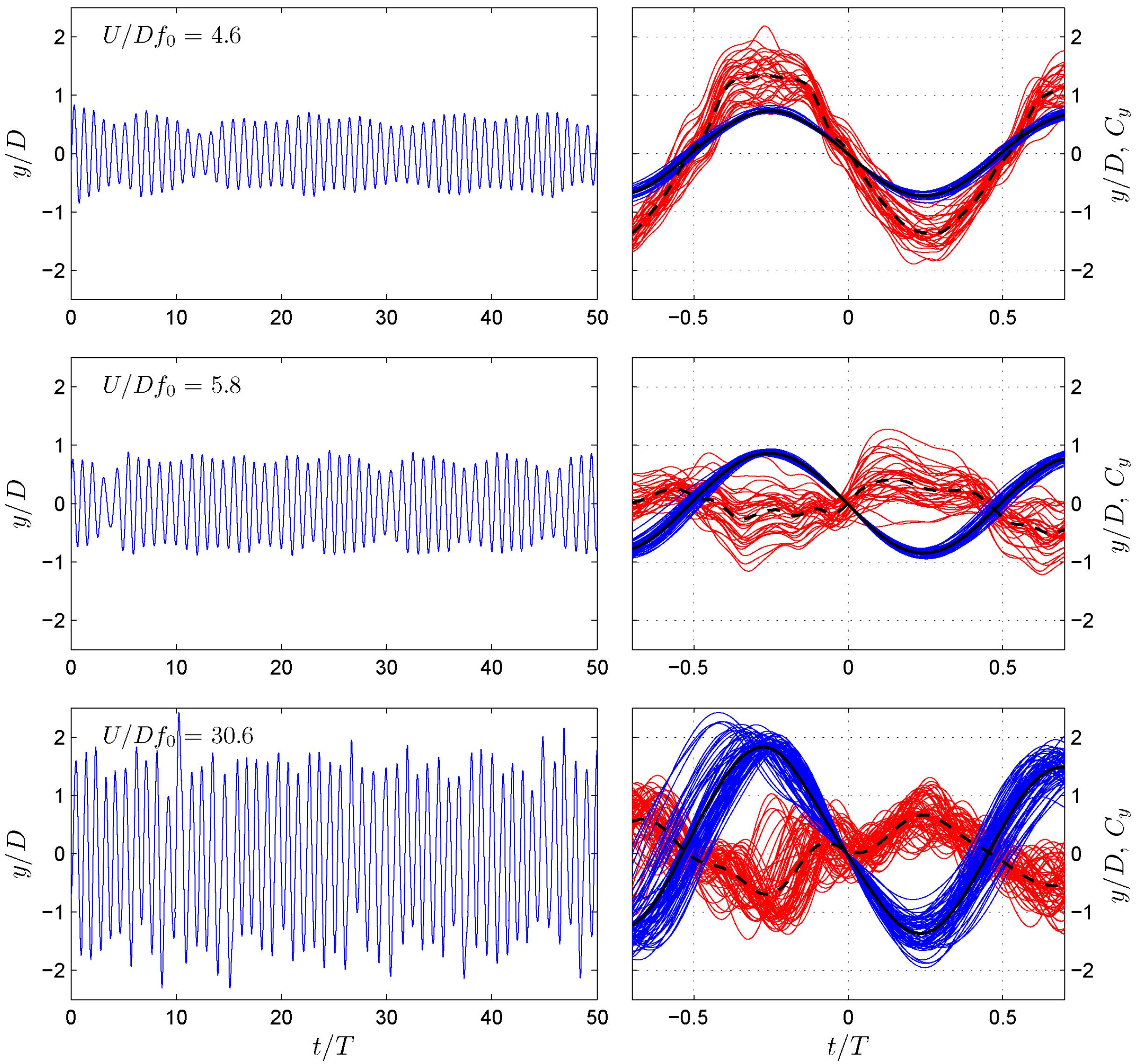


Lift



WIV response





What sustains high-amplitude vibrations so far from the resonance range?

Excitation mechanism

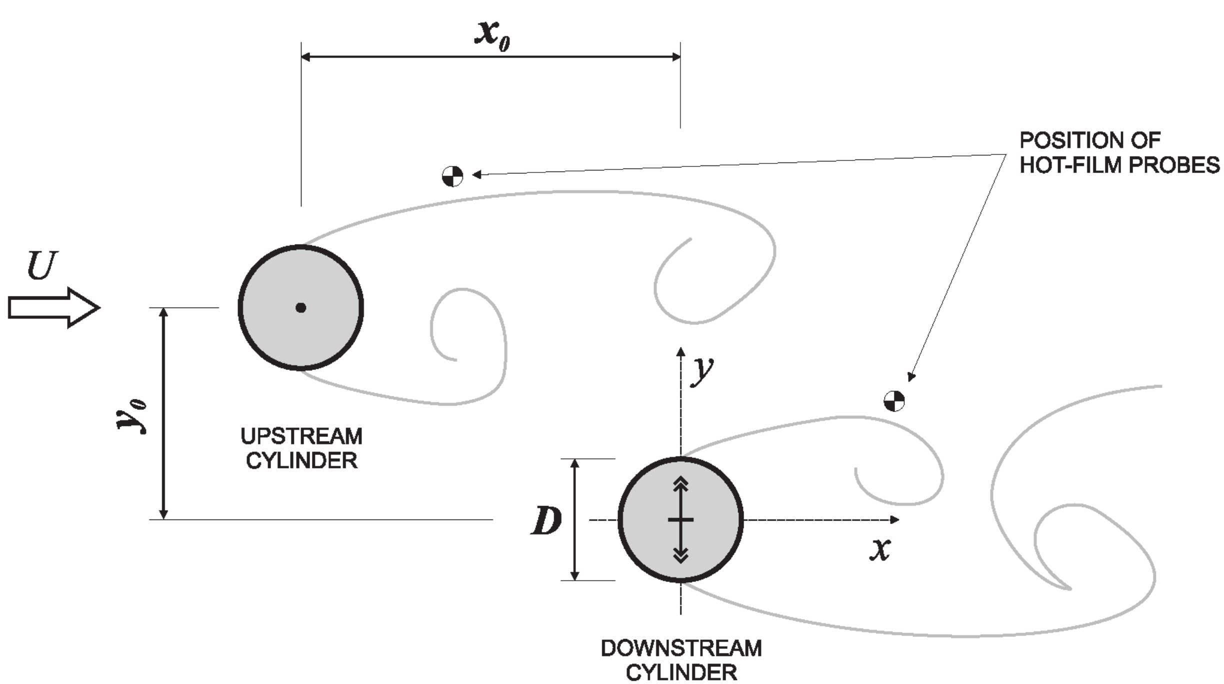
Lift on the downstream cylinder

Investigate lift on the downstream cylinder…

- Key to understand hydroelastic mechanism
  - Phase lag $\phi \rightarrow$ Energy transfer $\rightarrow$ WIV excitation

Steady lift field

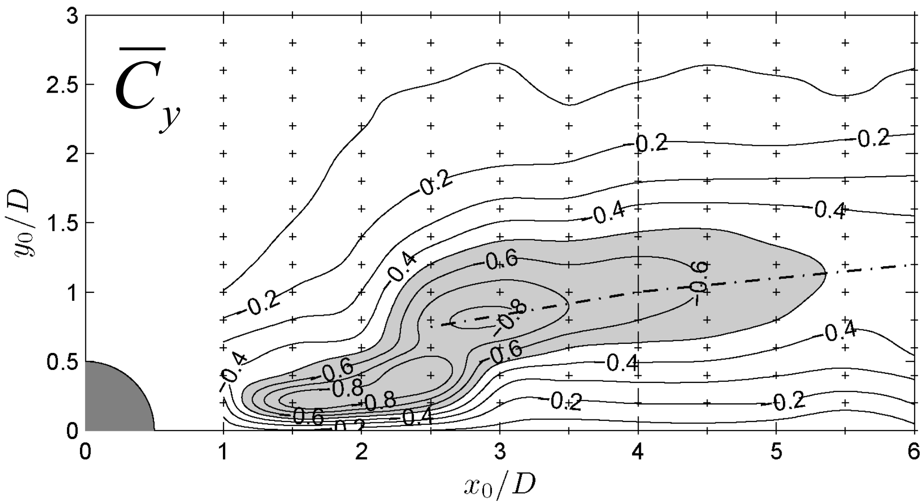
- Quasi-steady approach? Staggered arrangement...



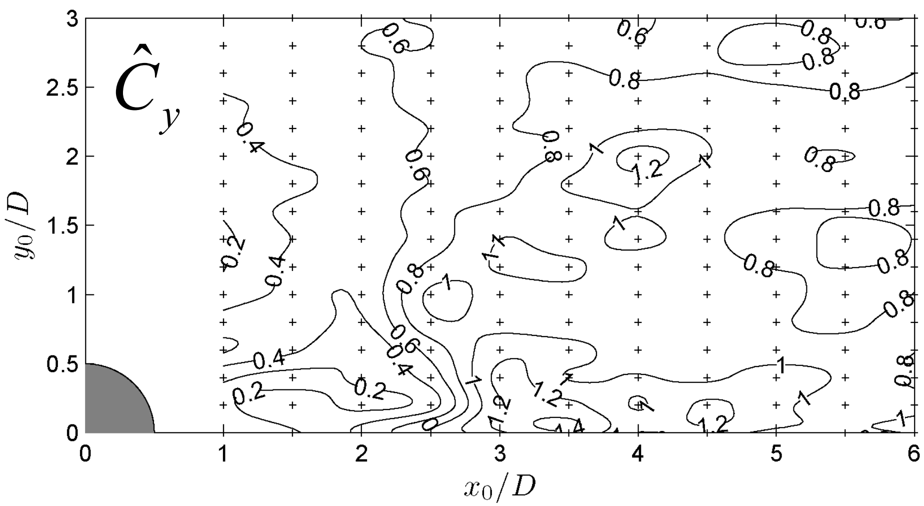
Lift

$$m\ddot{y} + c\dot{y} + ky = \frac{1}{2}\rho U^2 DL \left[\overline{C}_y + \hat{C}_y \sin(2\pi f t + \phi)\right]$$

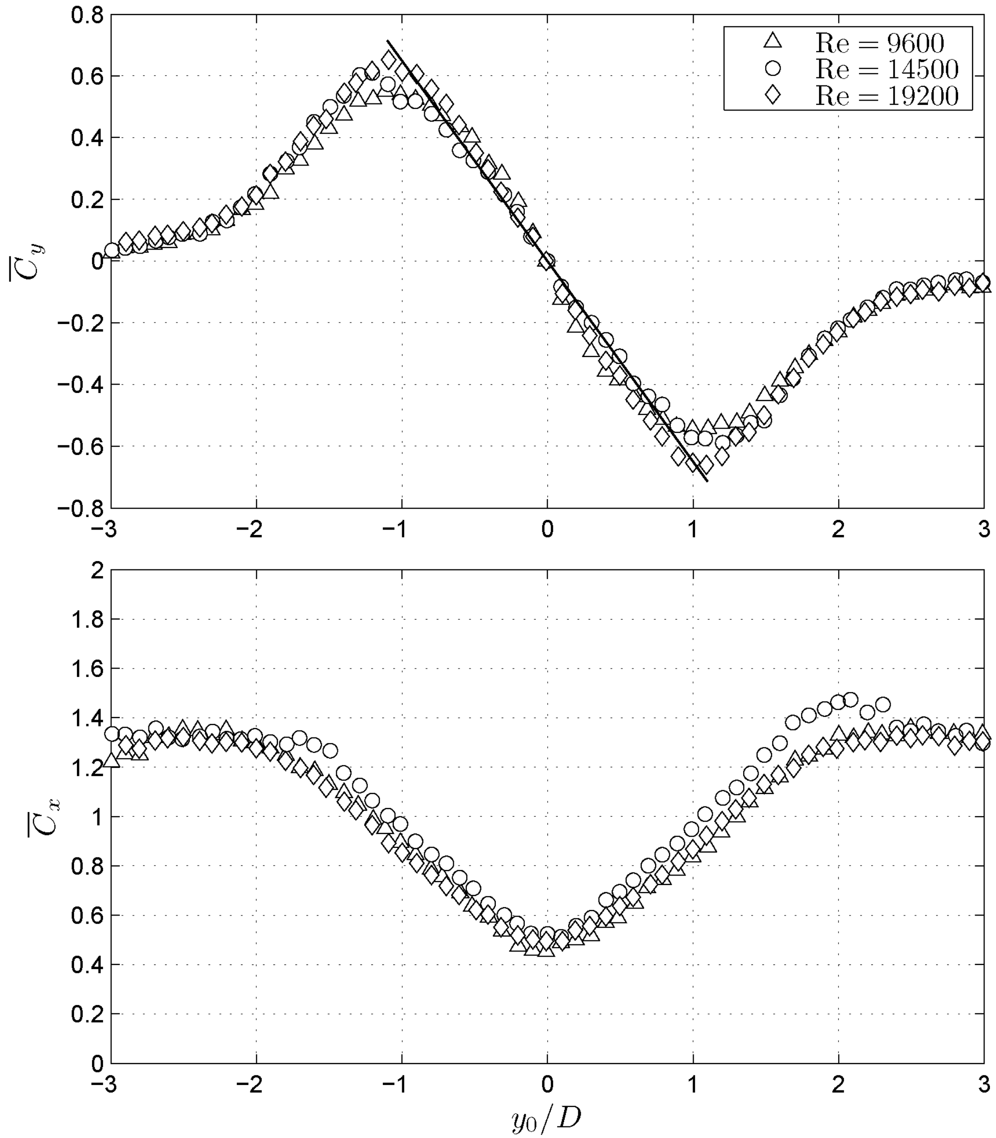
Mean



Fluctuating



Mean lift and drag



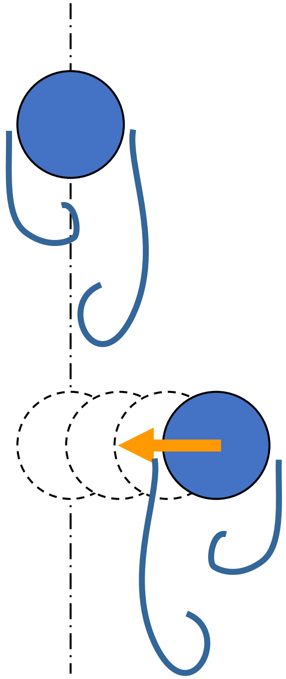
Quasi-steady approach

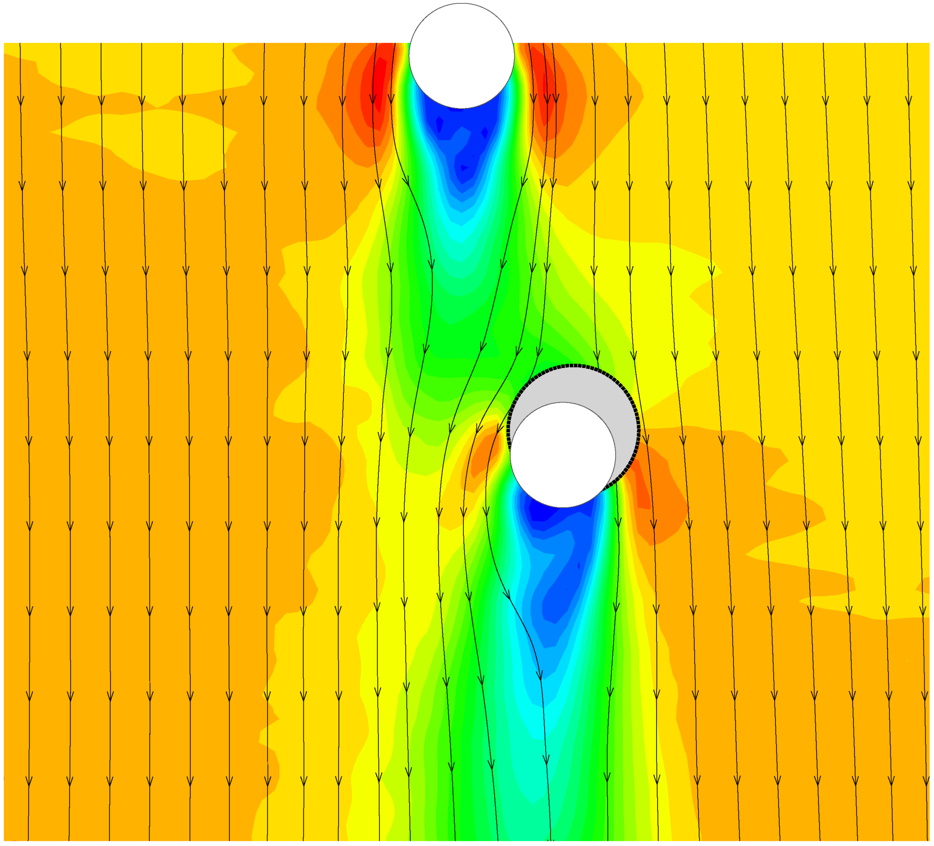
Attempts to model WIV

Classical galloping

Stabilising force

Quasi-steady model does not provide phase lag to excite WIV

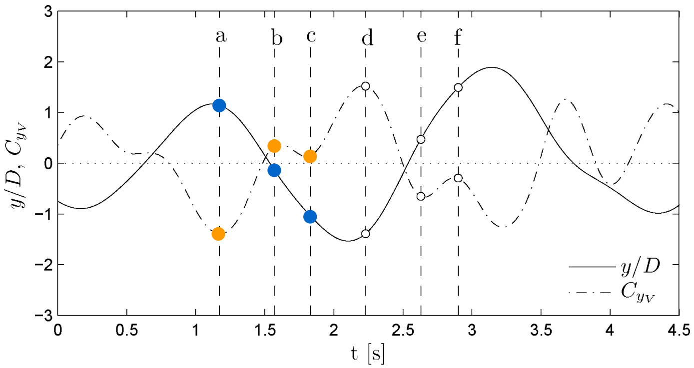


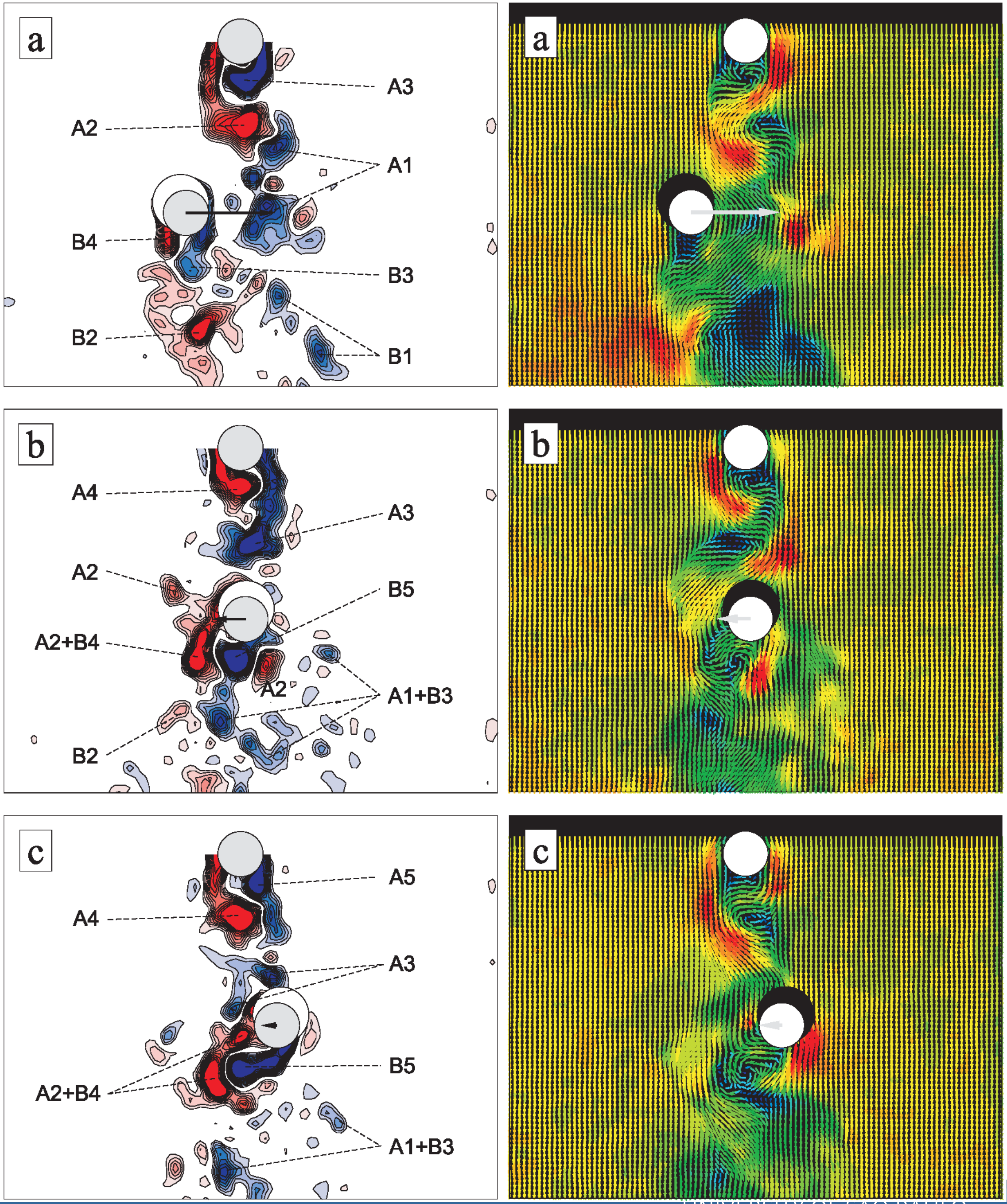


$$x_0 / D = 4.0$$

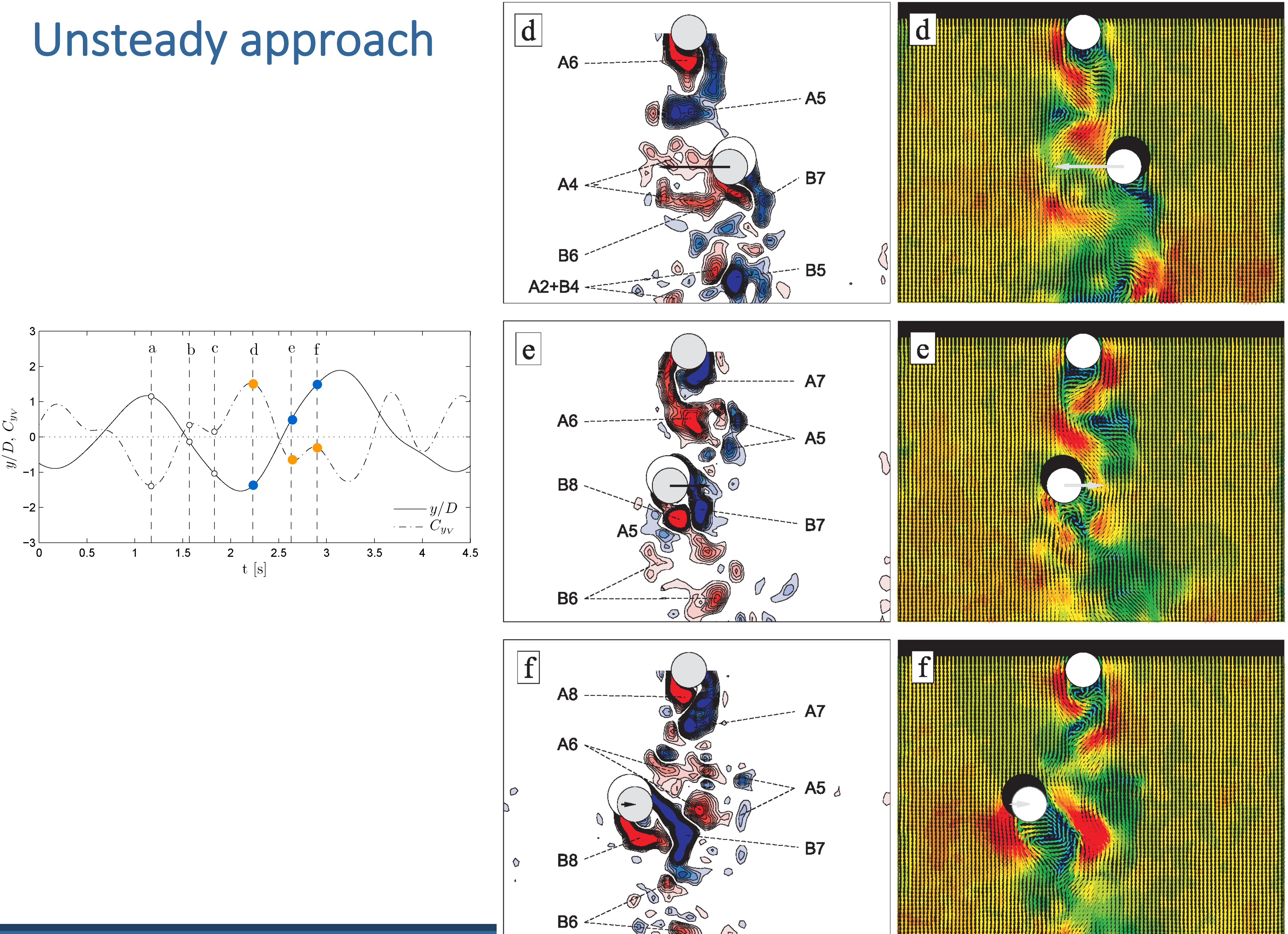
$$y_0 / D = 1.0$$

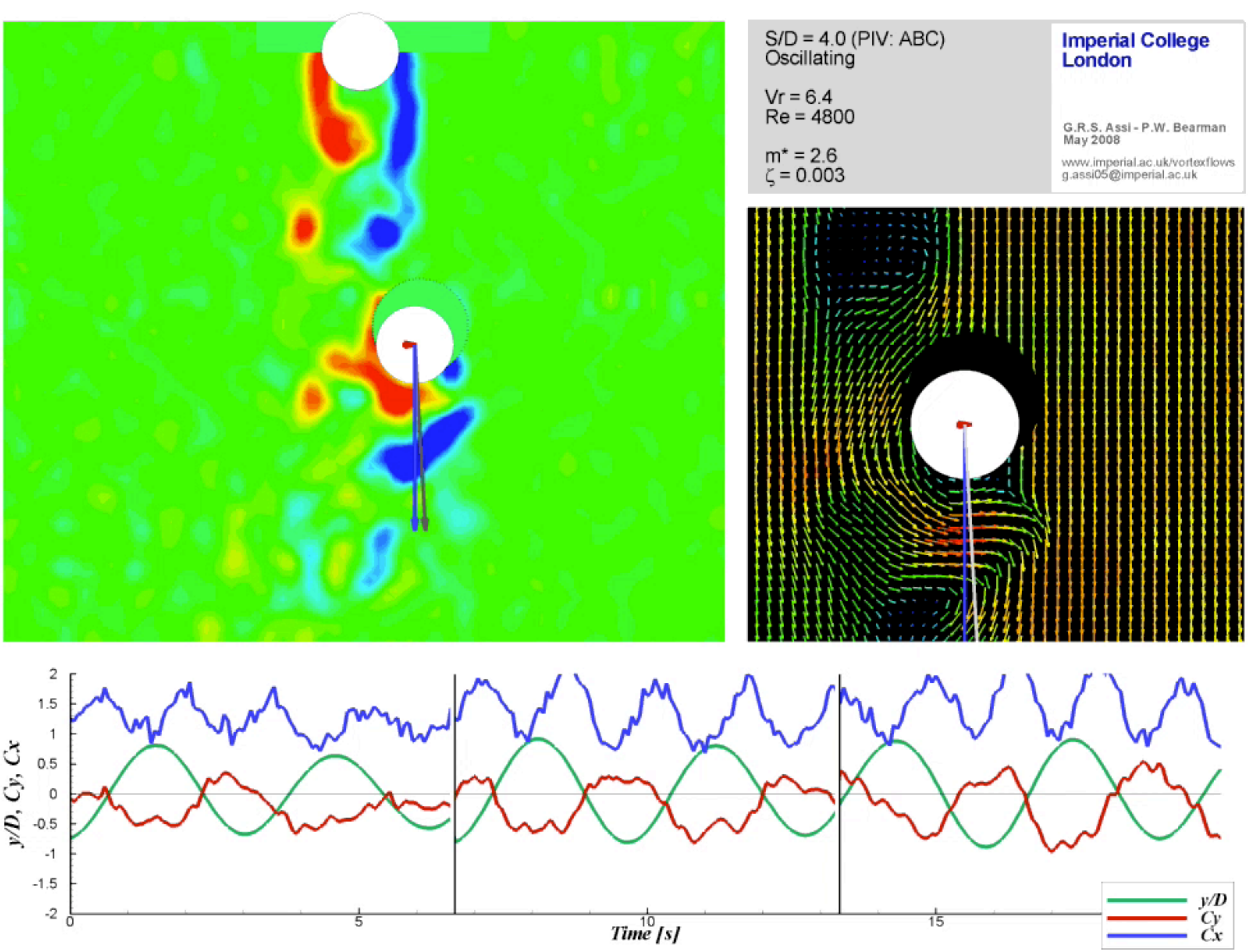
Unsteady approach

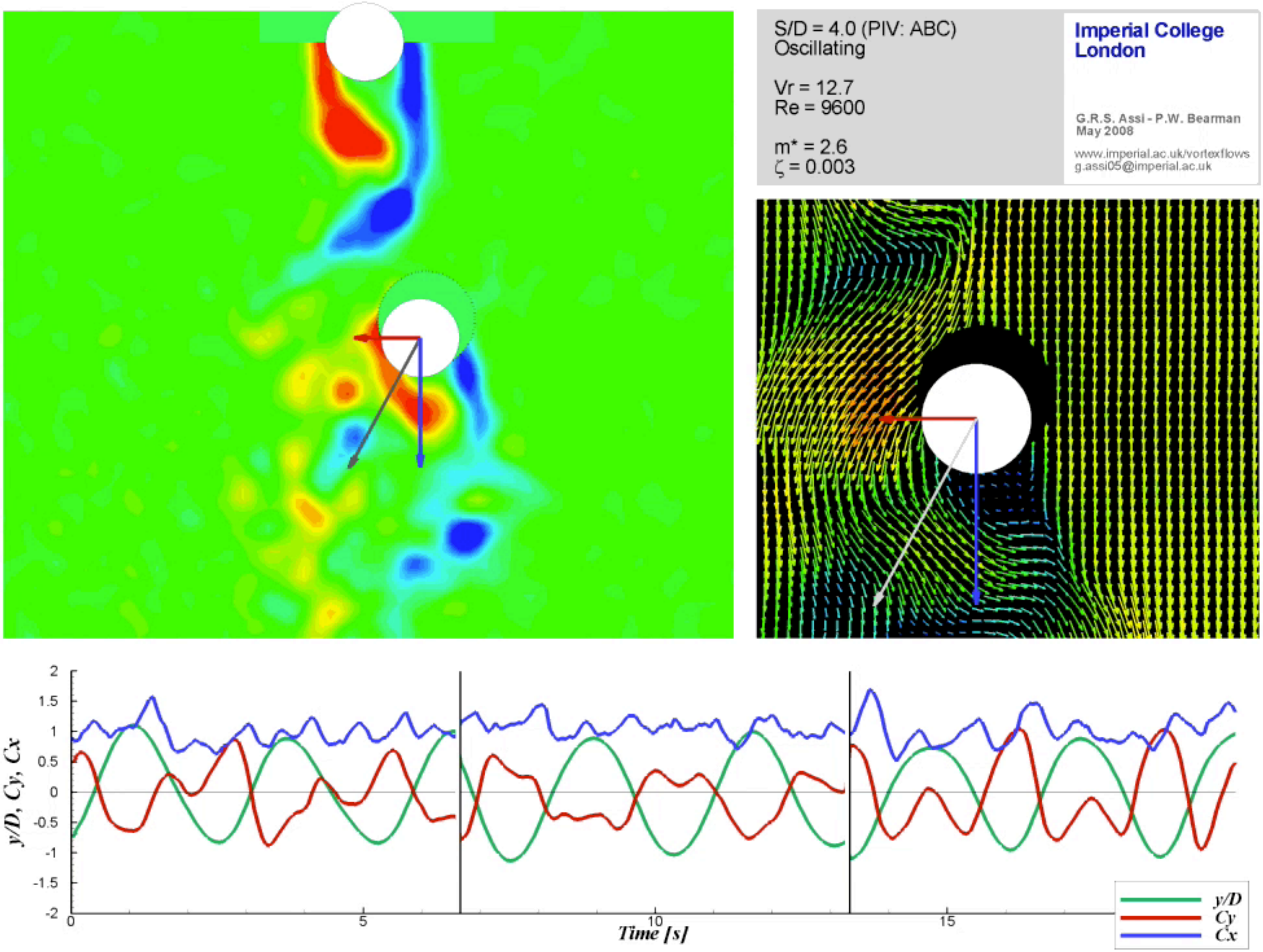




Unsteady approach




S/D = 4.0 (PIV: ABC)
Oscillating
Vr = 6.4
Re = 4800
m* = 2.6
ζ = 0.003
Imperial College London
G.R.S. Assi - P.W. Bearman
May 2008
www.imperial.ac.uk/vortexflows
g.assi05@imperial.ac.uk
y/D, Cy, Cx
Time [s]
y/D
Cy
Cx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Oscillating
Vr = 12.7
Re = 9600
m* = 2.6
ζ = 0.003
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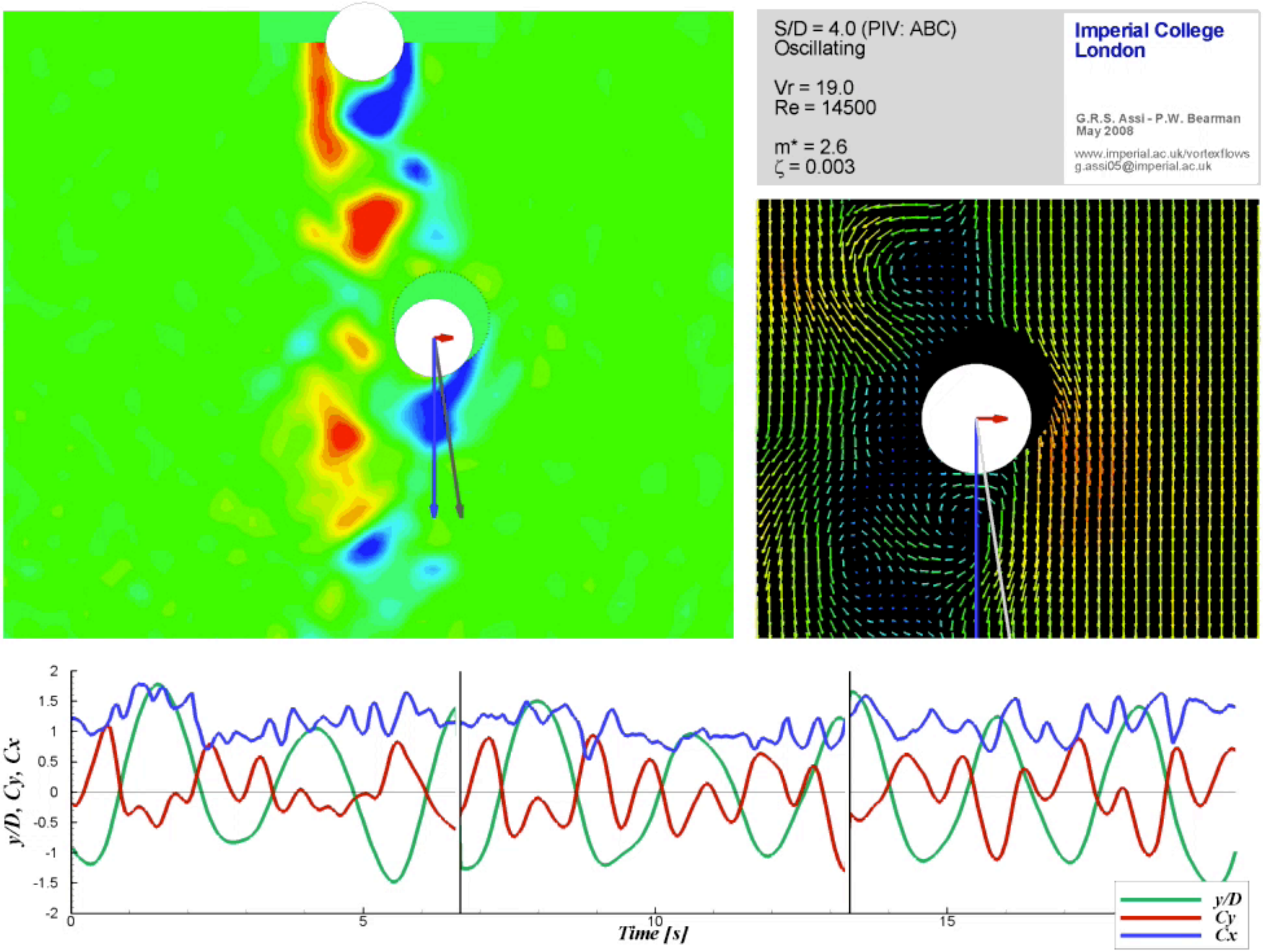
g.assi05@imperial.ac.uk
y/D, Cy, Cx
Time [s]
y/D
Cy
Cx


S/D = 4.0 (PIV: ABC)
Oscillating
Vr = 19.0
Re = 14500
m* = 2.6
ζ = 0.003
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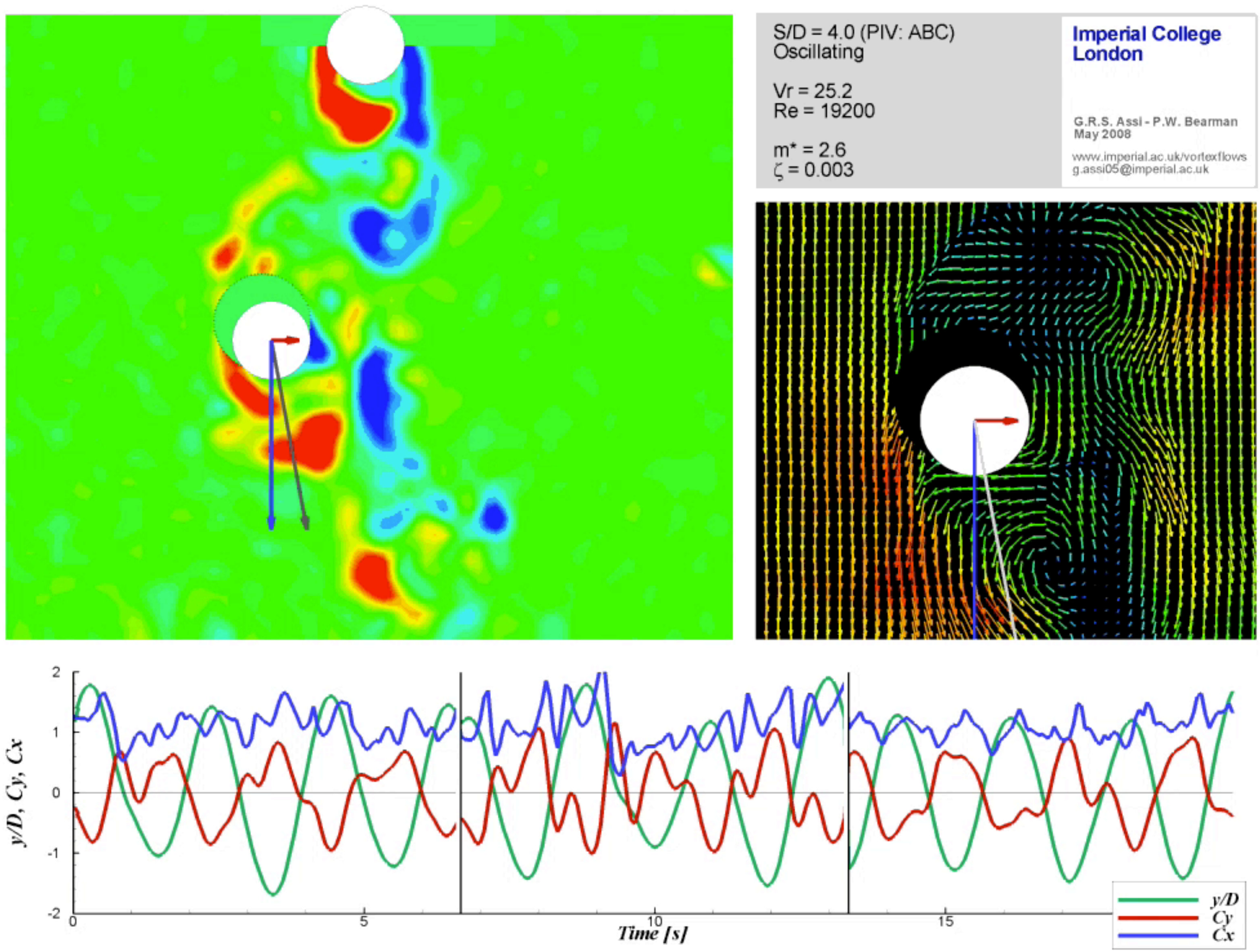
g.assi05@imperial.ac.uk
y/D, Cy, Cx
Time [s]
y/D
Cy
Cx



S/D = 4.0 (PIV: ABC)
Oscillating
Vr = 25.2
Re = 19200
m* = 2.6
ζ = 0.003
Imperial College London
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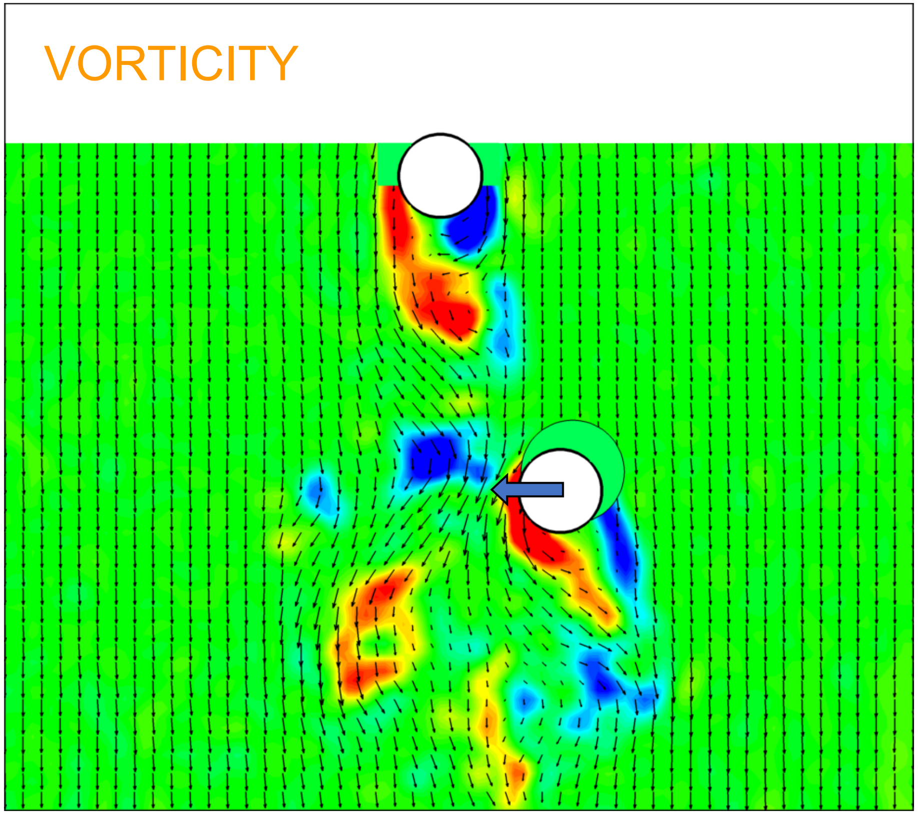
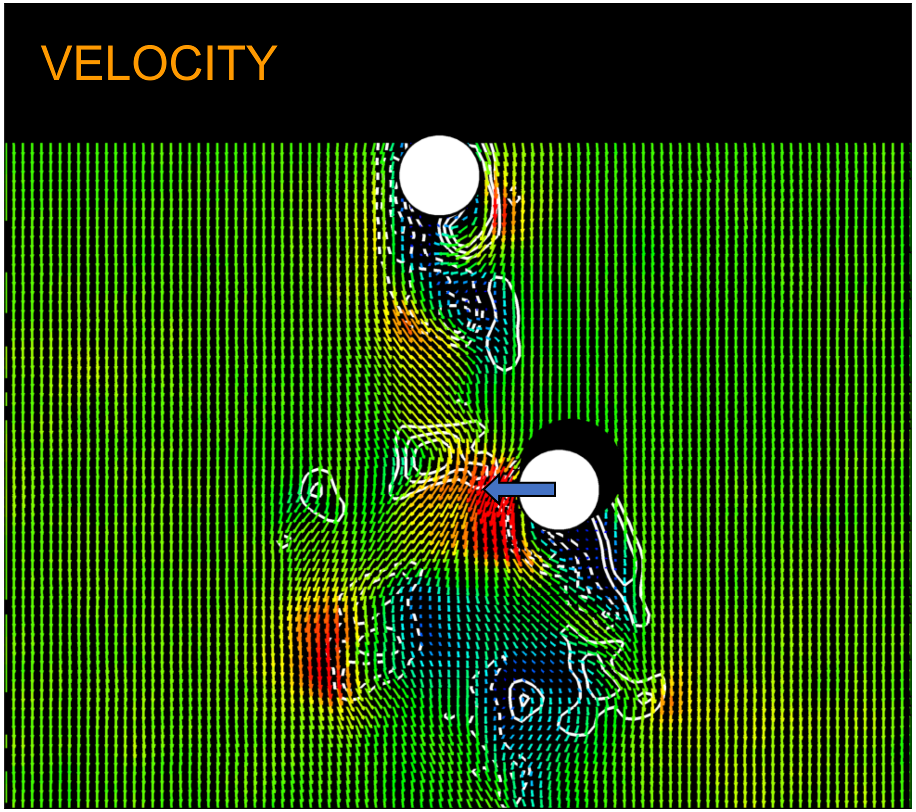
g.assi05@imperial.ac.uk
y/D, Cy, Cx
Time [s]
y/D
Cy
Cx

Vortex-interaction mehanism

Can result in reinforcement or attenuation of the vibration.

Depending on the wake at each time (unsteadiness).





Unsteady mechanism

WIV excitation mechanism

Requires interaction with unsteady vortices

”Vortex-interaction excitation mechanism”

There is no excitation without unsteady vortices…

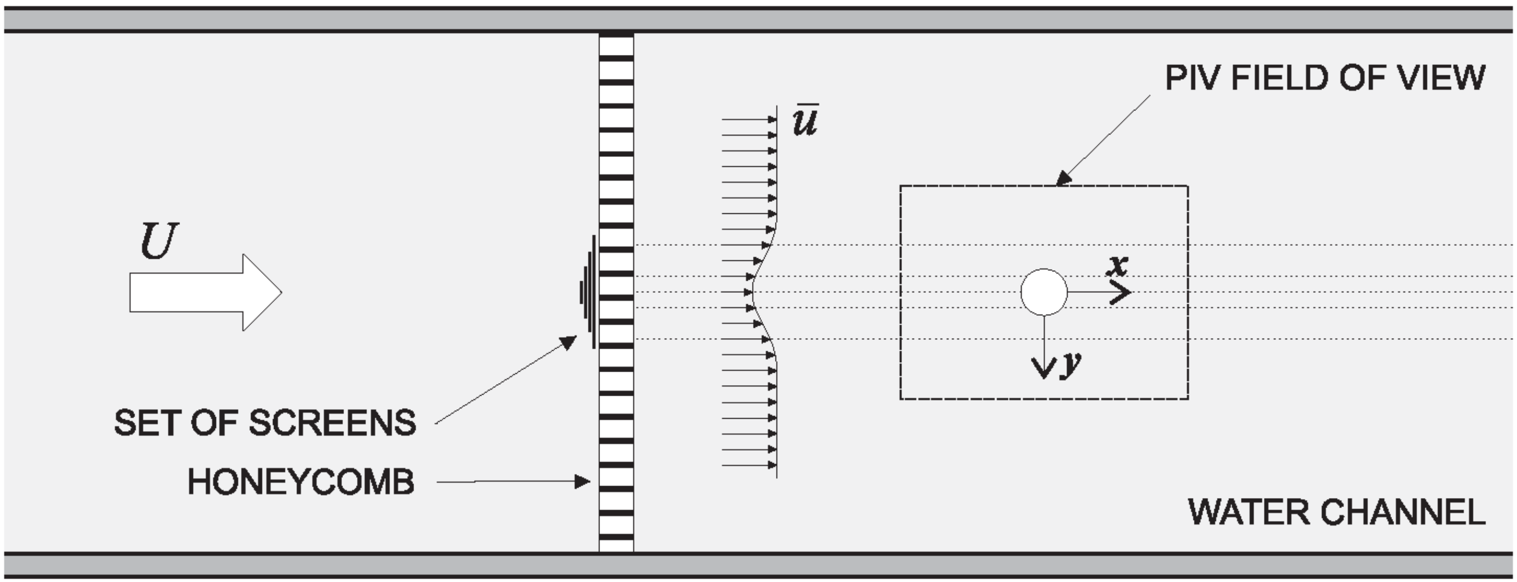
Idea: What if we remove a fundamental frequency?

Make $f_s = 0$, i.e. no vortex-shedding frequency

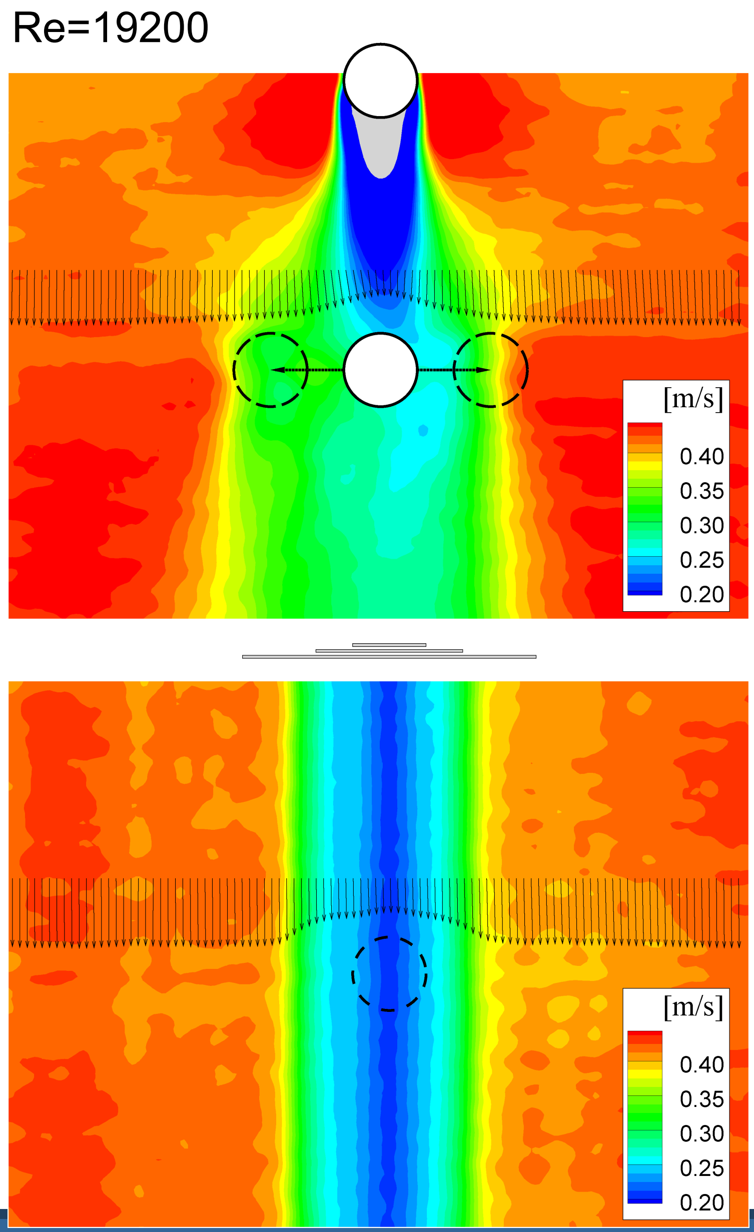
Verification…

Experiment

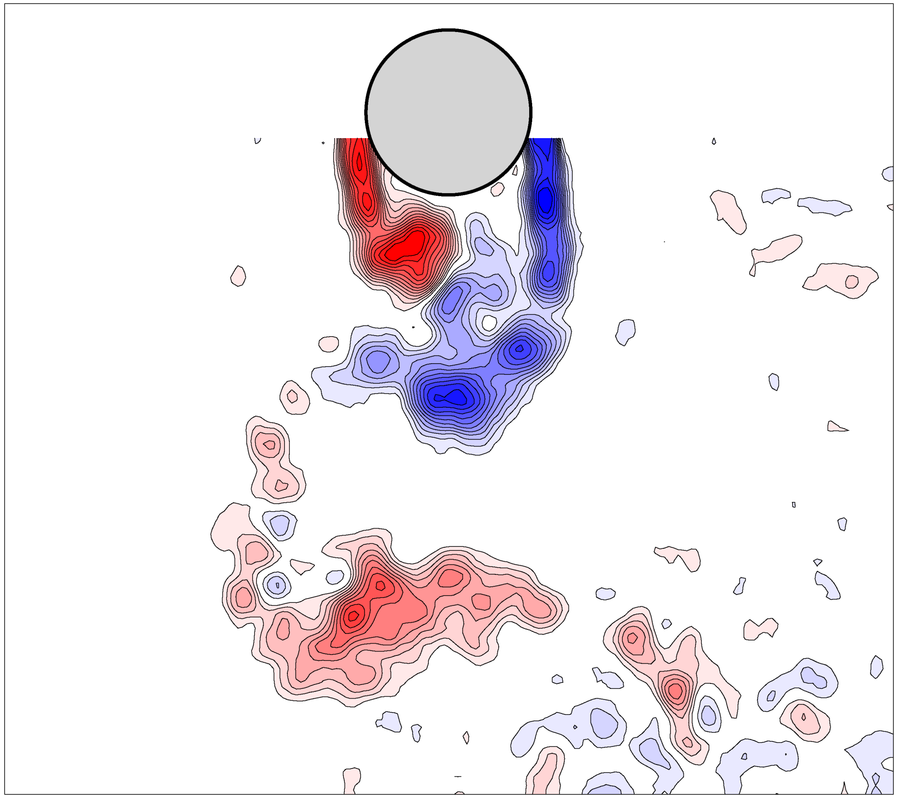
“Steady wake”: no vortices, but with an equivalent mean velocity profile.

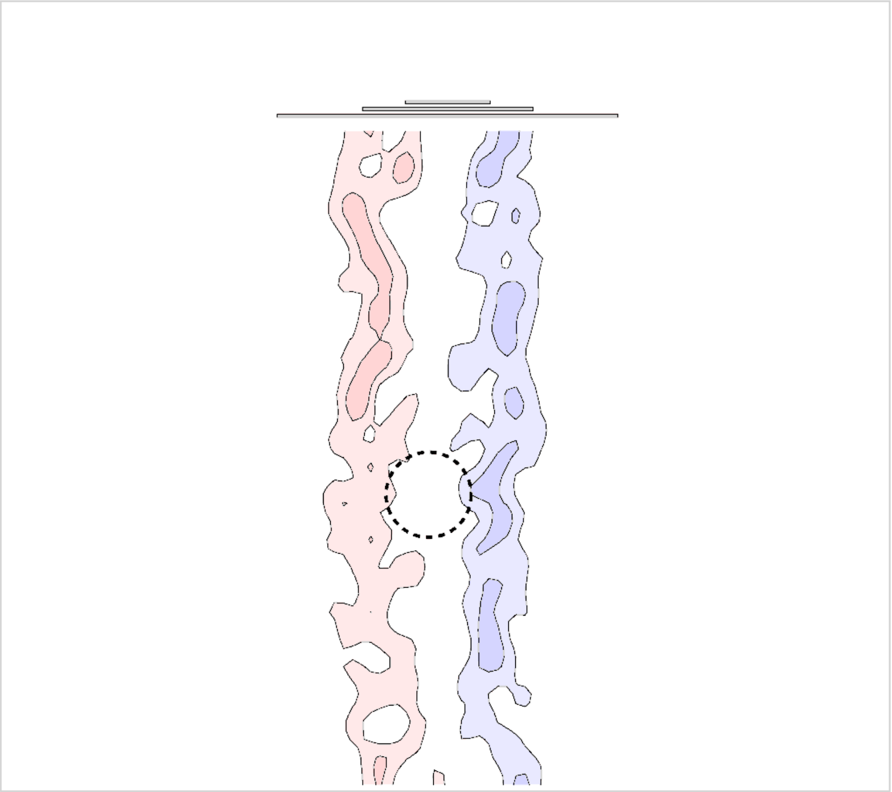


”Steady-wake” experiment

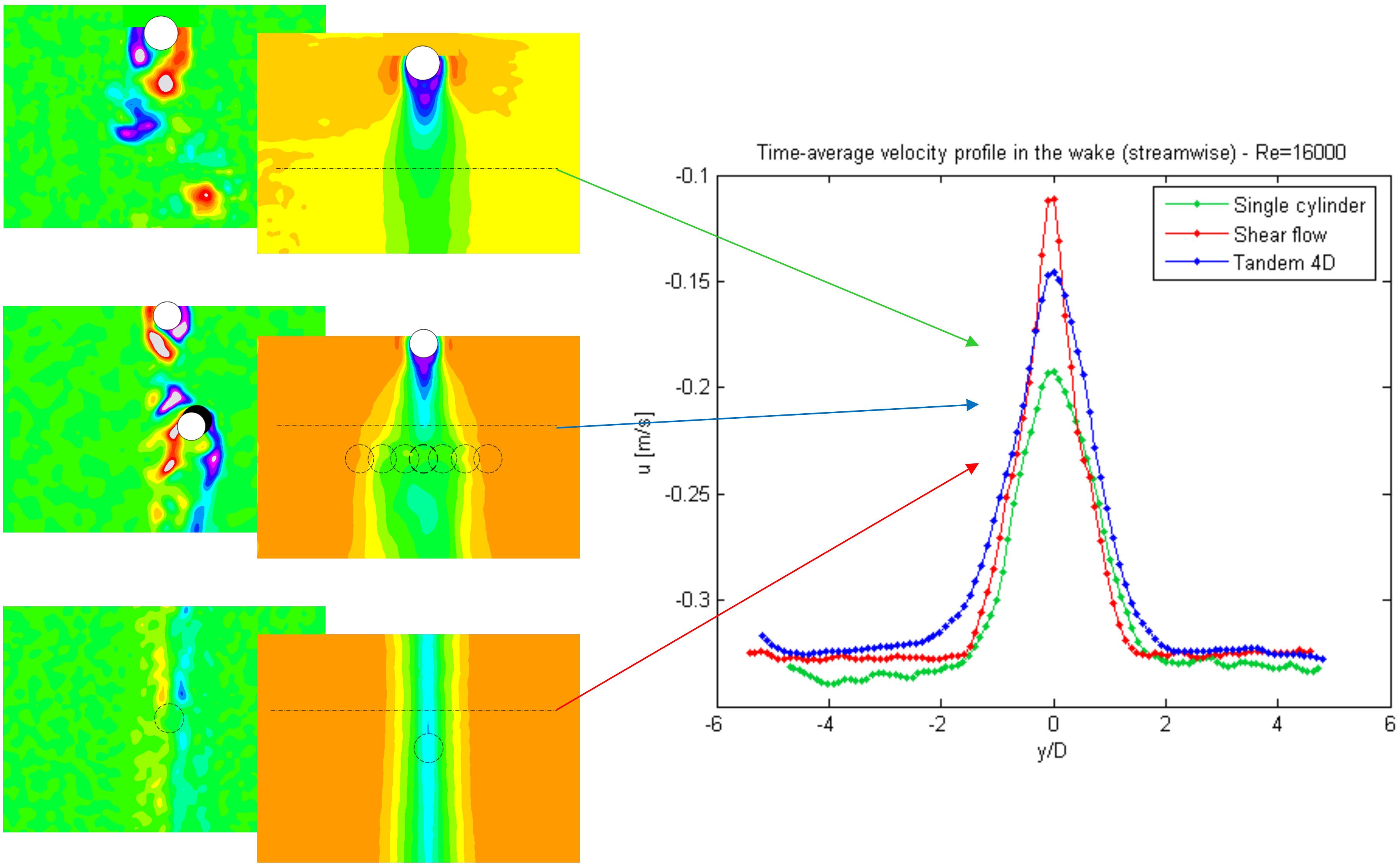


”Steady-wake” experiment

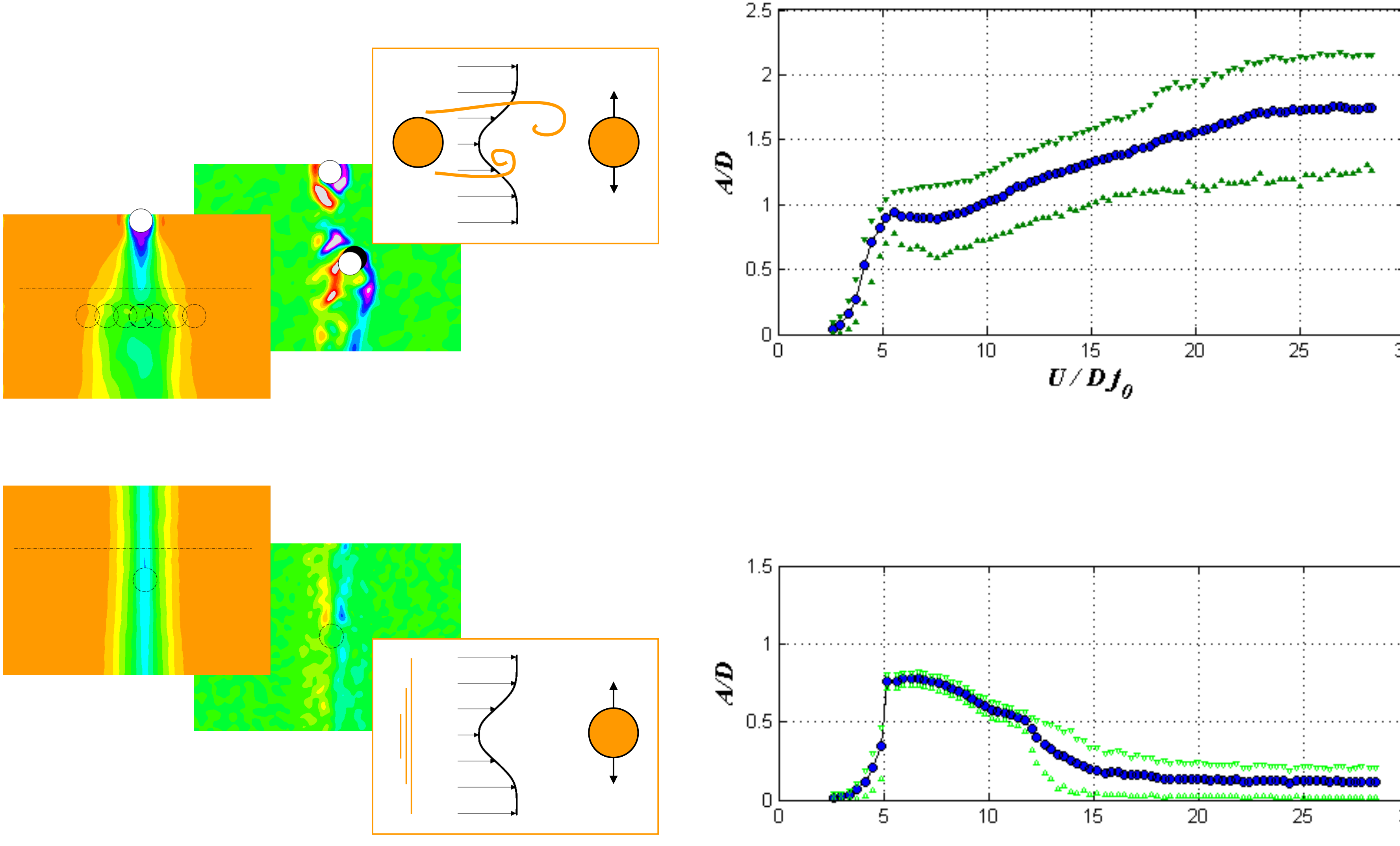




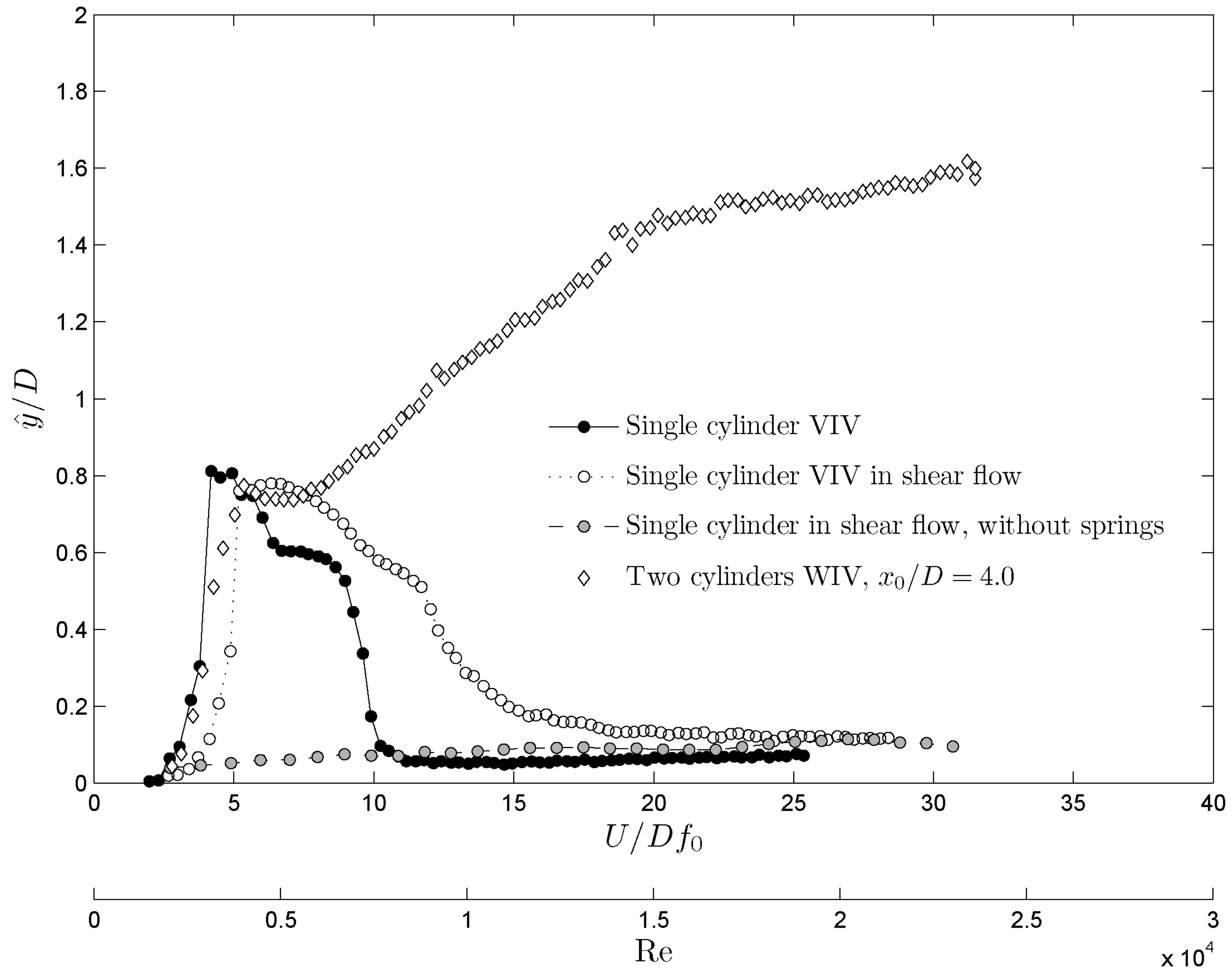
”Steady-wake” experiment



”Steady-wake” experiment



”Steady-wake” experiment



Conclusion

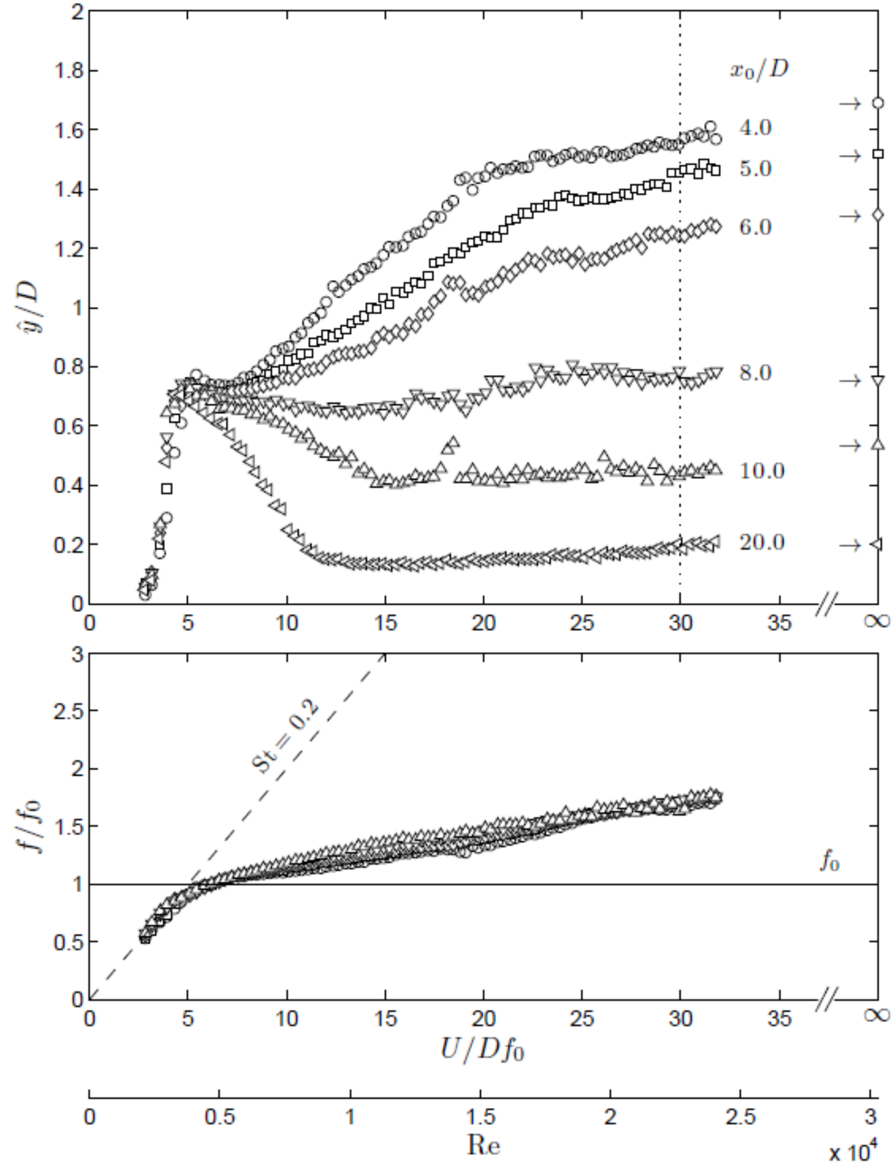
WIV excitation mechanism

- Comes form the unsteady interaction with upstream vortices
- The unsteadiness is necessary
- Remove the unsteady vortices and there will be no WIV

WAKE STIFFNESS

Frequency signature

Frequency



WIV response

Amplitude of vibration

Variation of peaks

Deviation increasing beyond VIV resonance.

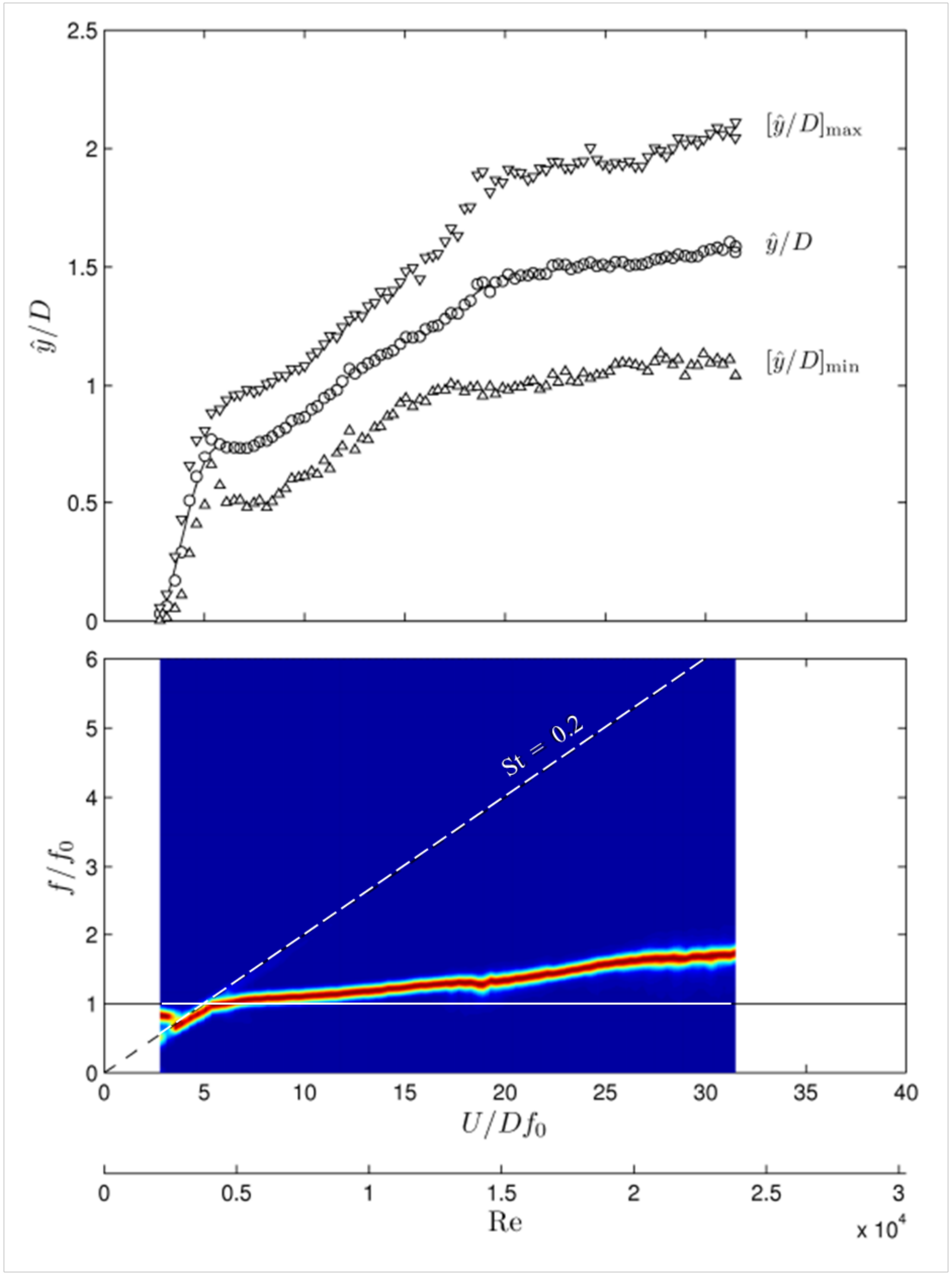
Frequency of vibration

Well behaved...

$f \neq f_s$

$f \neq f_0$

Why?



WIV response

Investigating frequency...

Excitation does not depend on resonance...

Idea: remove a fundamental frequency

make $f_0 = 0$ by removing the springs

Expected response without springs...

No local peak of VIV... (no resonance $f_s = f_0$)

Oscillatory motion?

WIV response

With springs

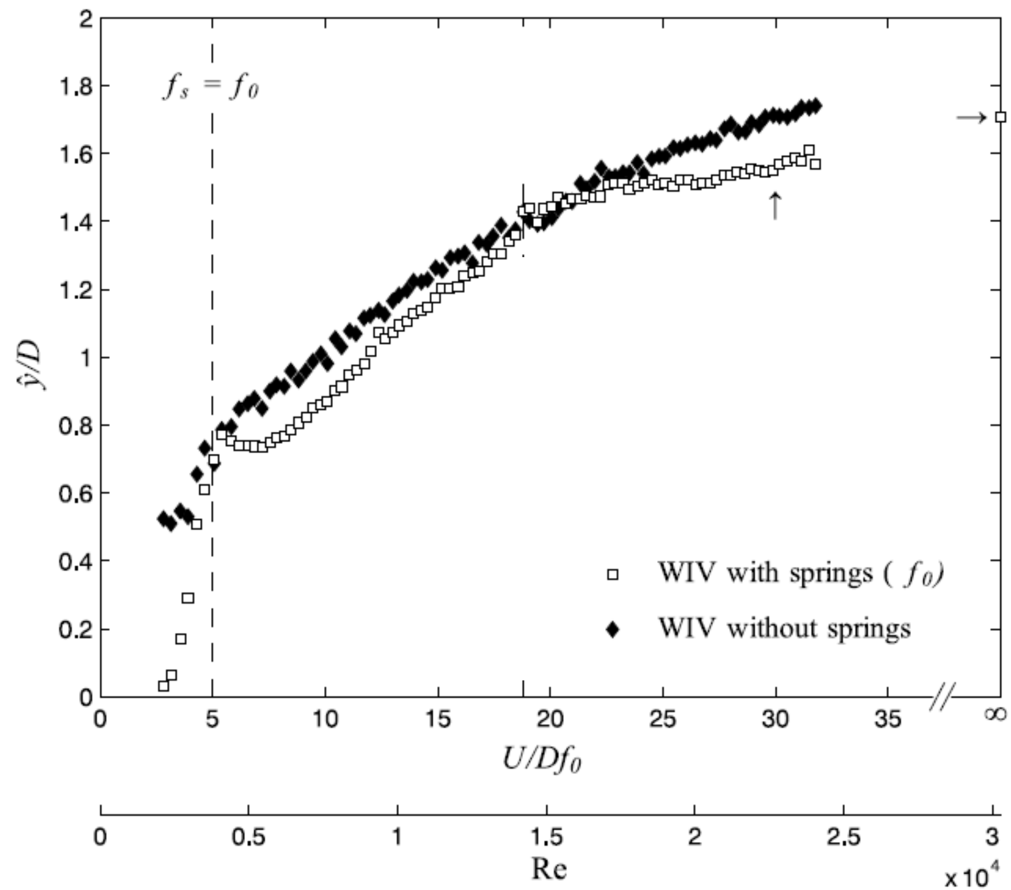
- Local VIV resonance
- Amplitude build-up

Without springs

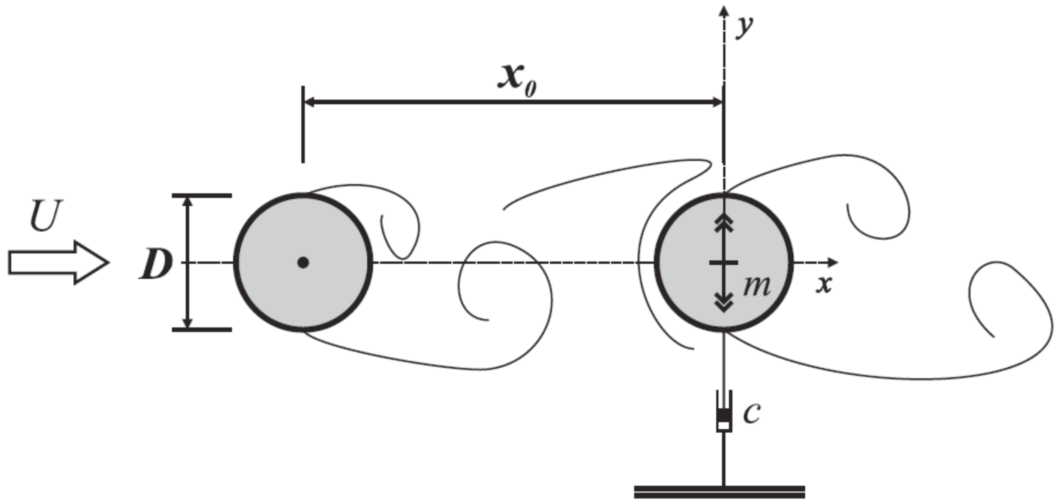
- Oscillatory motion!
- No VIV resonance
- Amplitude increasing
  - $U/Df_0 = \infty$
  - Dependency on Re

Similar response...

- Small variations

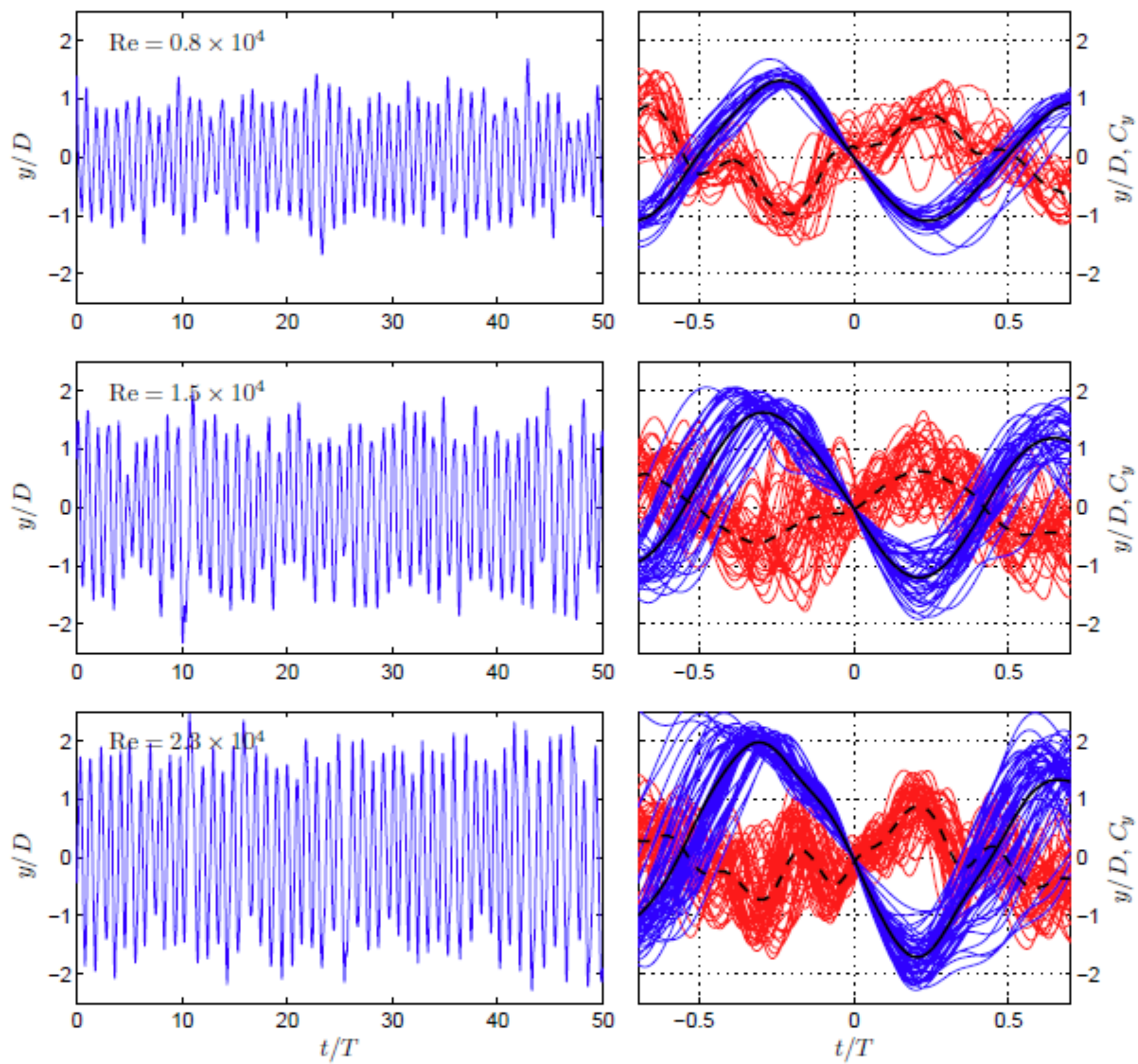


Without springs: $k = 0$



$$m\ddot{y} + c\dot{y} = C_y \frac{1}{2}\rho U^2 D$$

$$\frac{\hat{y}}{D} = \underbrace{\frac{1}{4\pi}\hat{C}_y \sin\phi}_{} \underbrace{\left(\frac{U}{Df}\right)}_{?} \underbrace{\left(\frac{\rho U D}{\mu}\right)}_{\mathrm{Re}} \underbrace{\left(\frac{\mu}{c}\right)}_{\mathrm{Cte}}$$


Re = 0.8 × 10^4
Re = 1.5 × 10^4
Re = 2.3 × 10^4
y/D
y/D, C_y
t/T

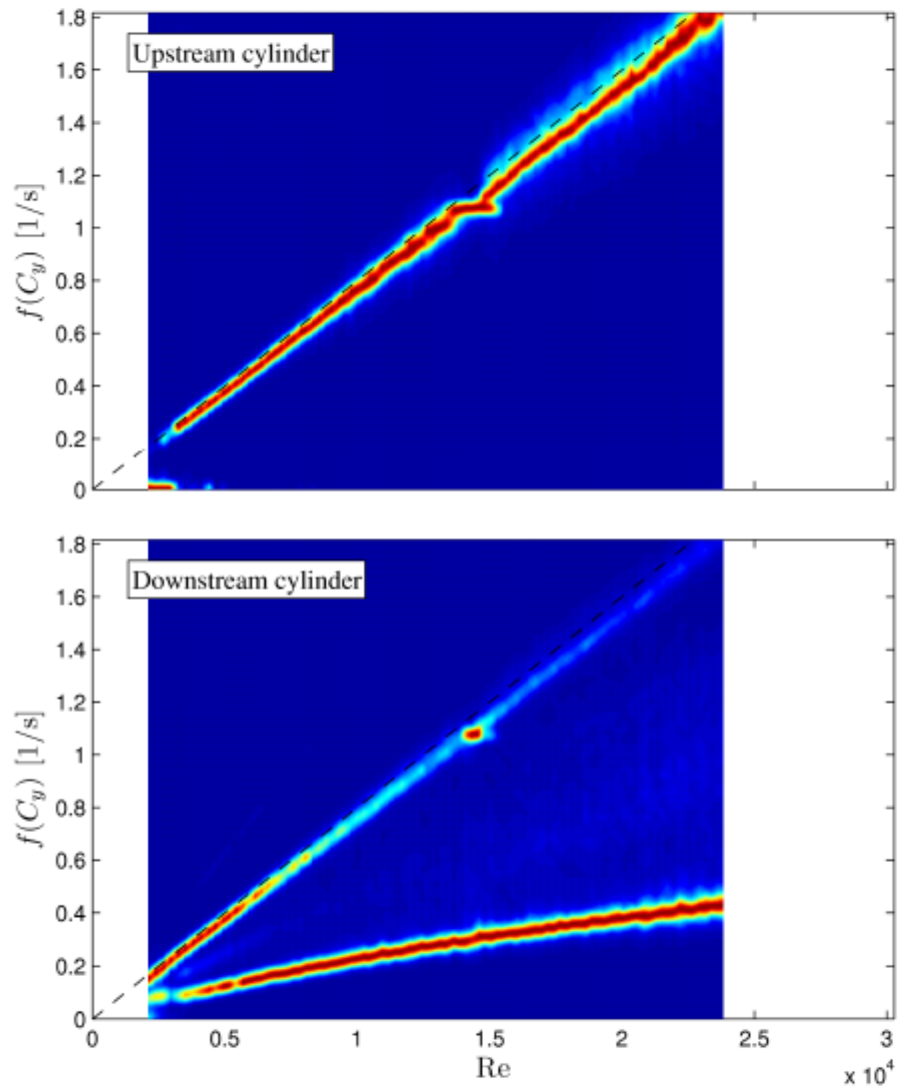
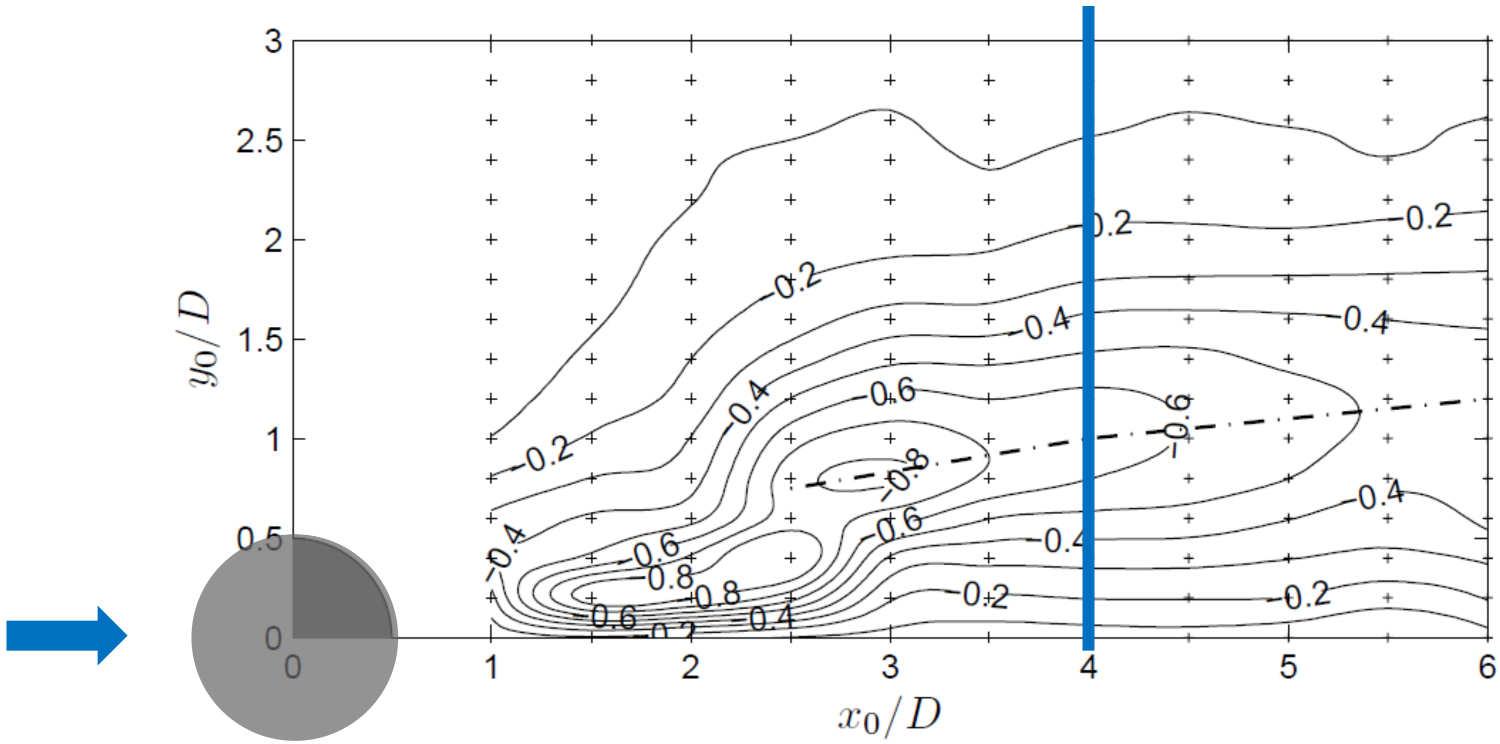
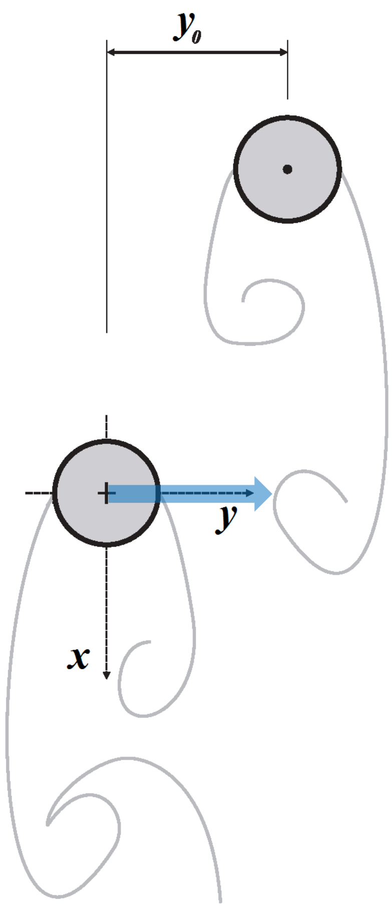


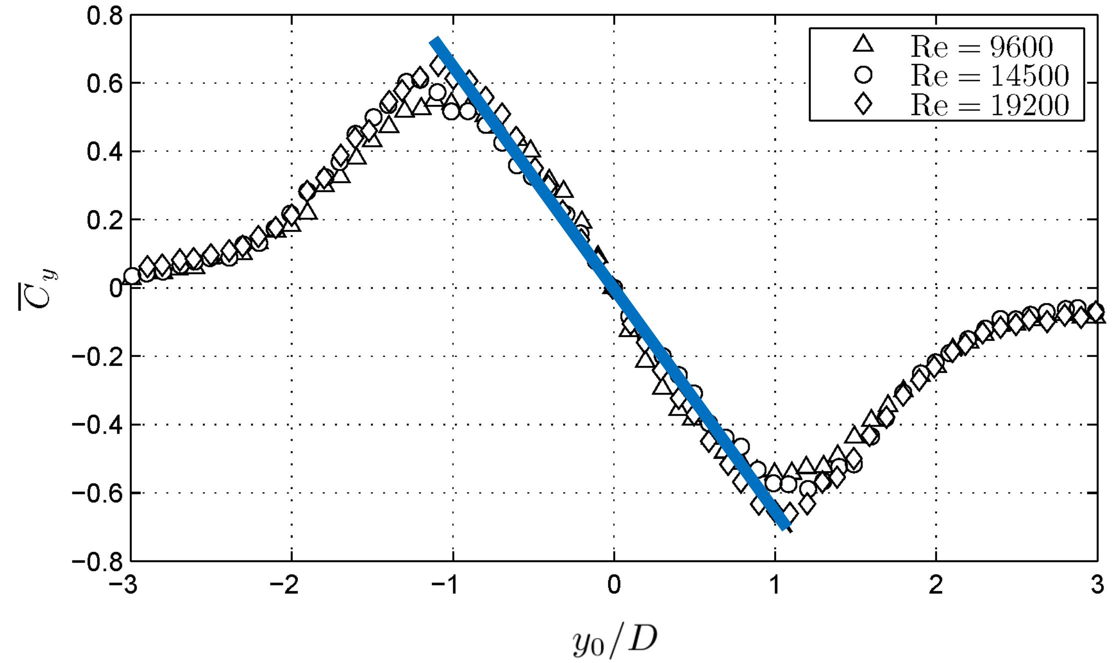
Fig. 7.5: Normalised PSD of lift force acting on the upstream static cylinder (top) and downstream cylinder without springs (bottom). Please refer to Appendix A.

Mean lift field: staggered cylinders



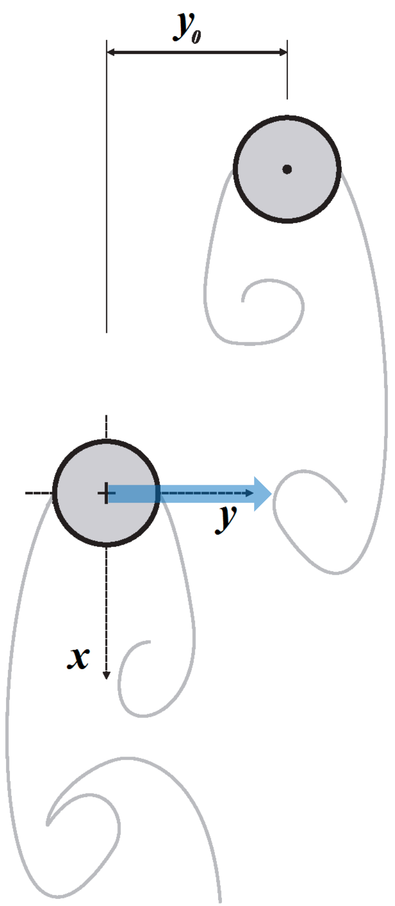
Staggered arrangement: Restoring force





$$\left| \frac{\partial \overline{C}_y}{\partial (y_0/D)} \right| = \alpha_{\overline{C}_y} = 0.65$$

The wake stiffness concept

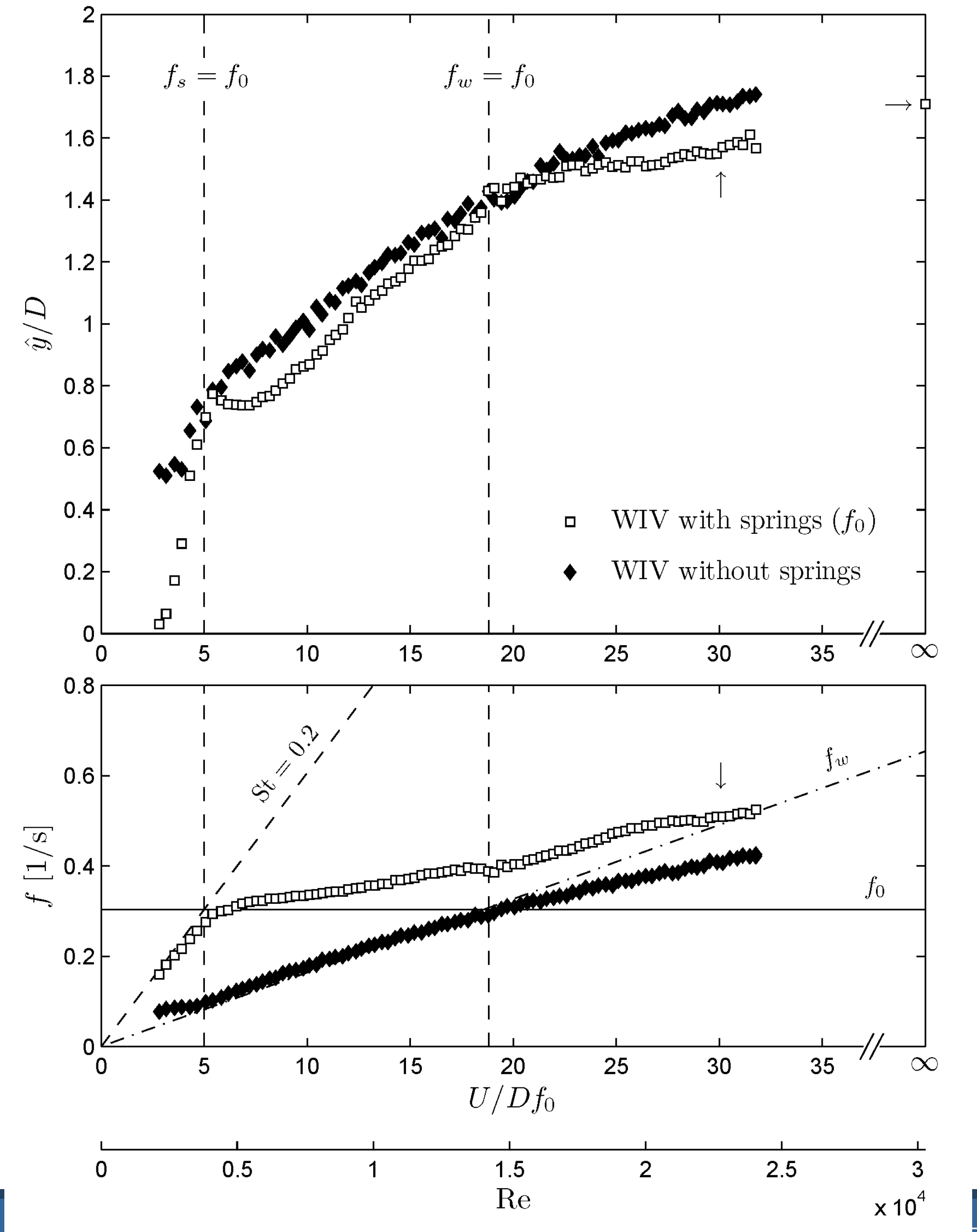


$$k_w = \alpha_{\overline{C}_y} \frac{1}{2} \rho U^2$$

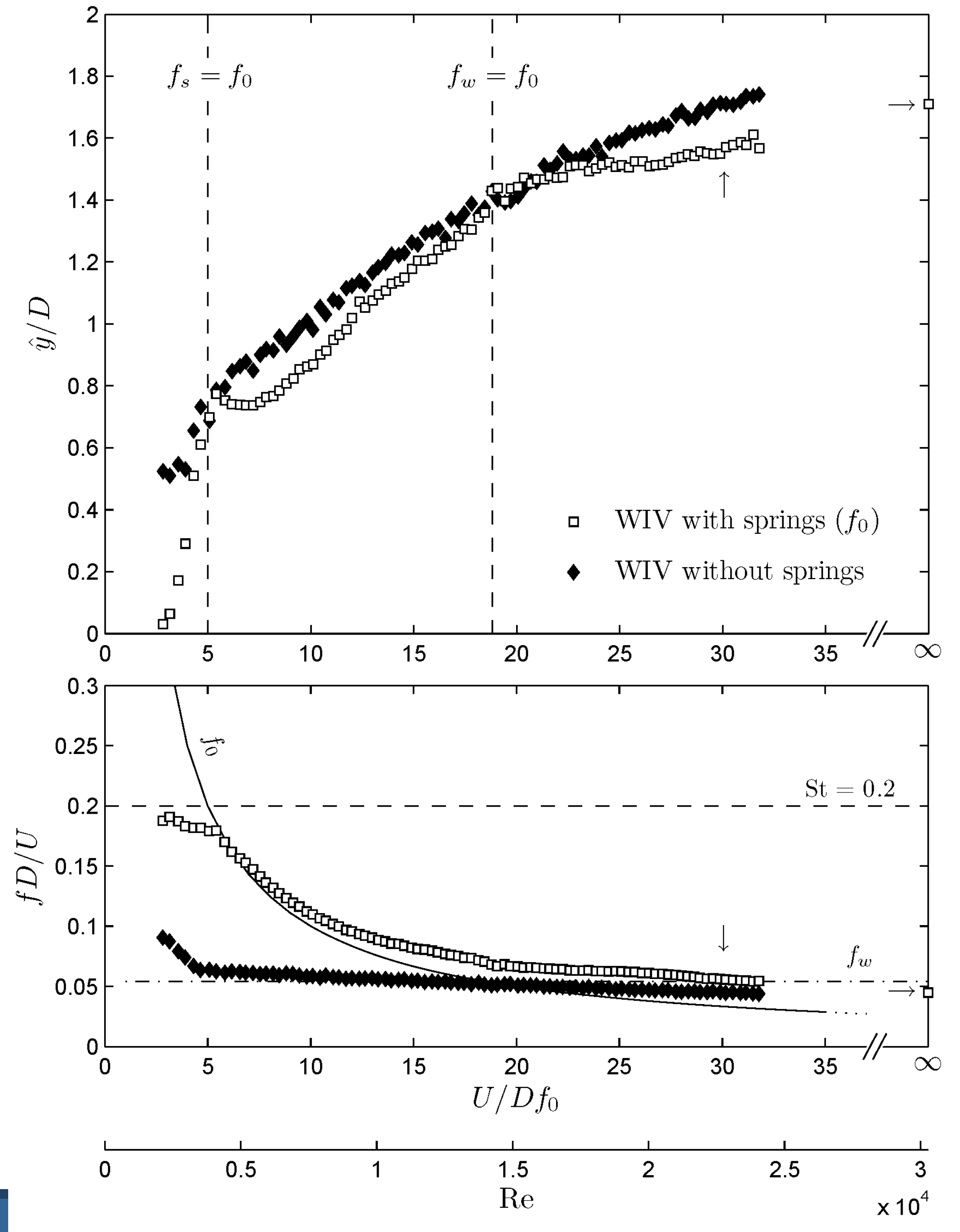
$$f_w = \frac{1}{2\pi} \sqrt{\frac{k_w}{(m^* + C_a)\rho \frac{\pi D^2}{4}}}$$

$$\underbrace{\frac{f_w D}{U}}_{\text{Cte}} = \frac{1}{2\pi} \sqrt{\frac{2}{\pi} \frac{\cancelto{0.65}{\alpha_{\overline{C}_y}}}{(\cancelto{2.6}{m^*} + \cancelto{1.0}{C_a})}} = 0.054$$

WIV response

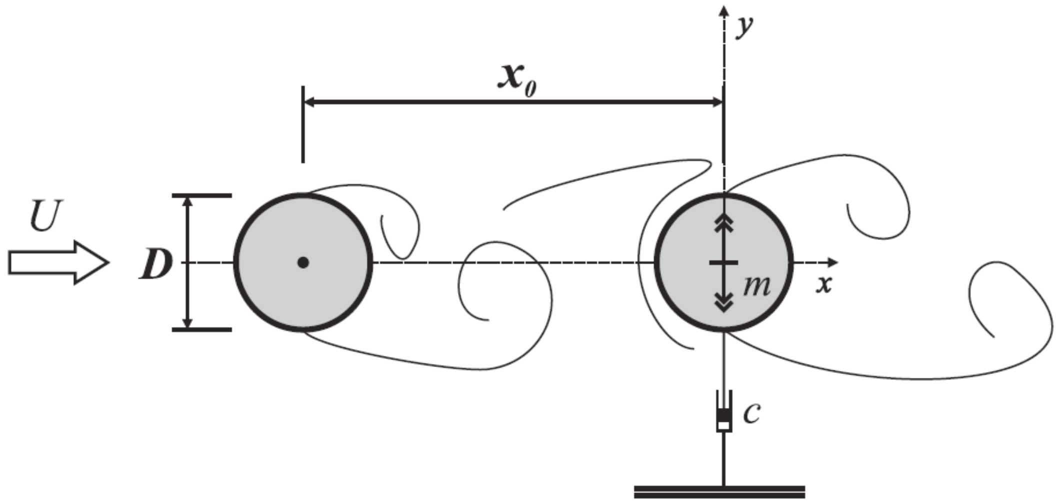


WIV response



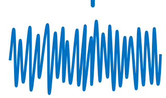
$$\frac{f_w D}{U} = 0.054$$

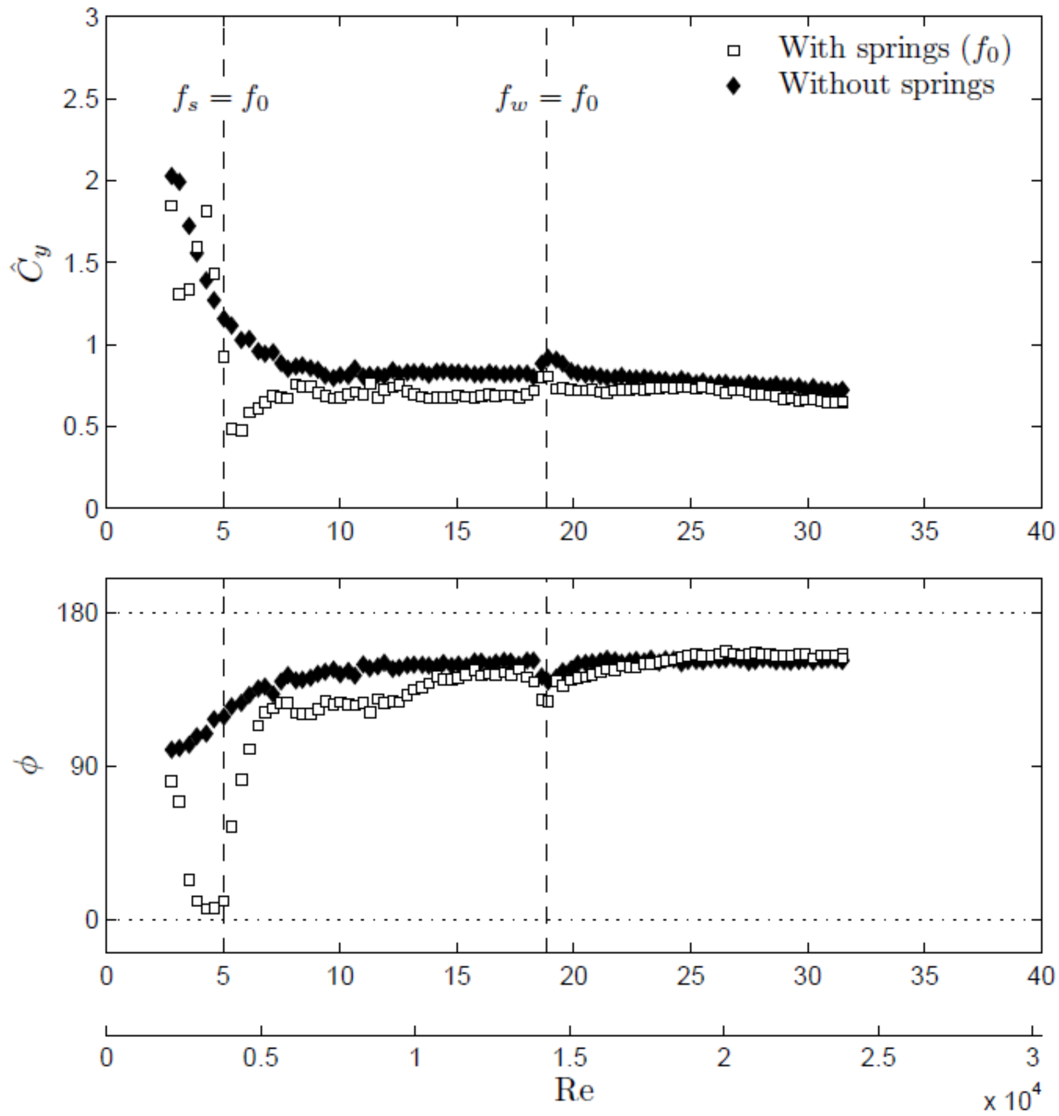
Without springs: $k = 0$



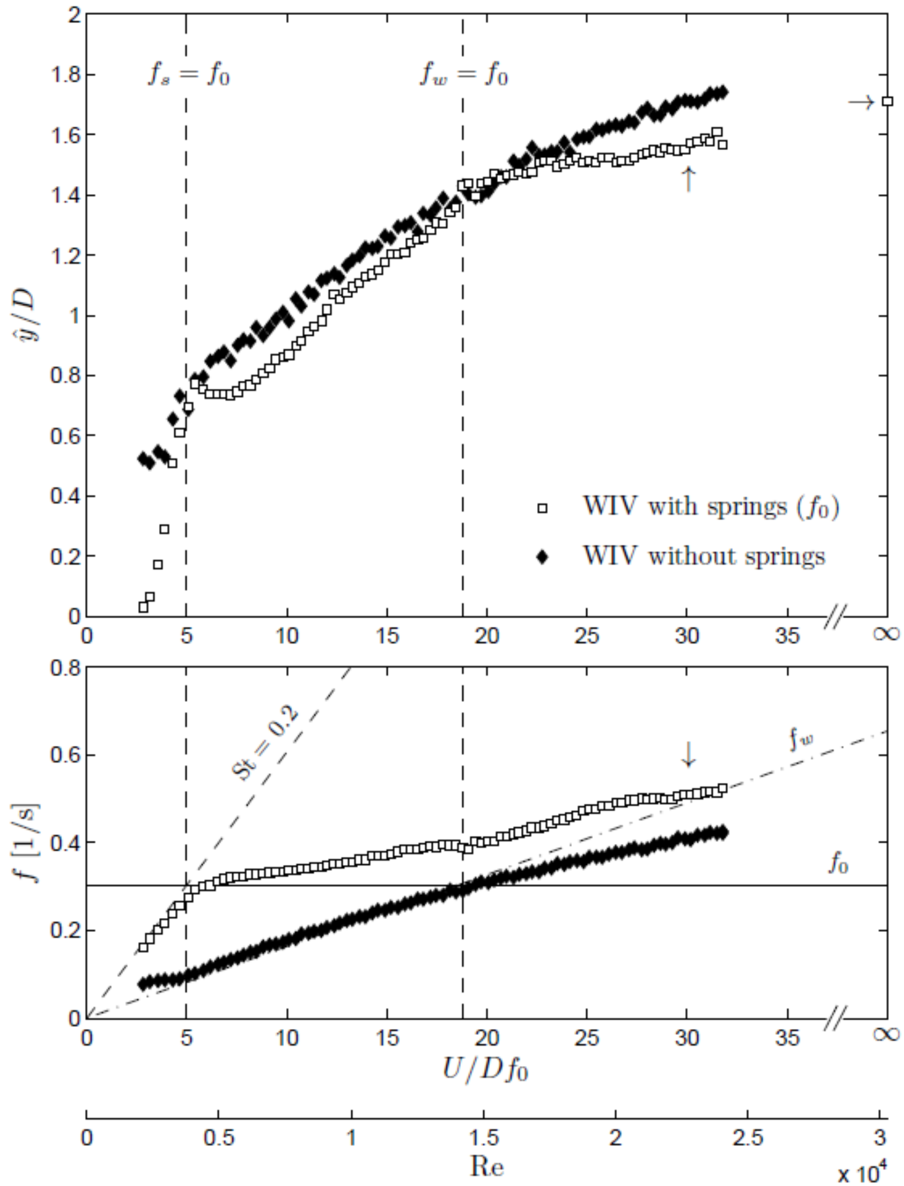
$$m\ddot{y} + c\dot{y} = C_y \frac{1}{2}\rho U^2 D$$

$$\frac{\hat{y}}{D} = \frac{1}{4\pi}\hat{C}_y \sin\phi \underbrace{\left(\frac{U}{Df}\right)}_{\textbf{Cte}} \underbrace{\left(\frac{\rho U D}{\mu}\right)}_{\text{Re}} \underbrace{\left(\frac{\mu}{c}\right)}_{\text{Cte}}$$

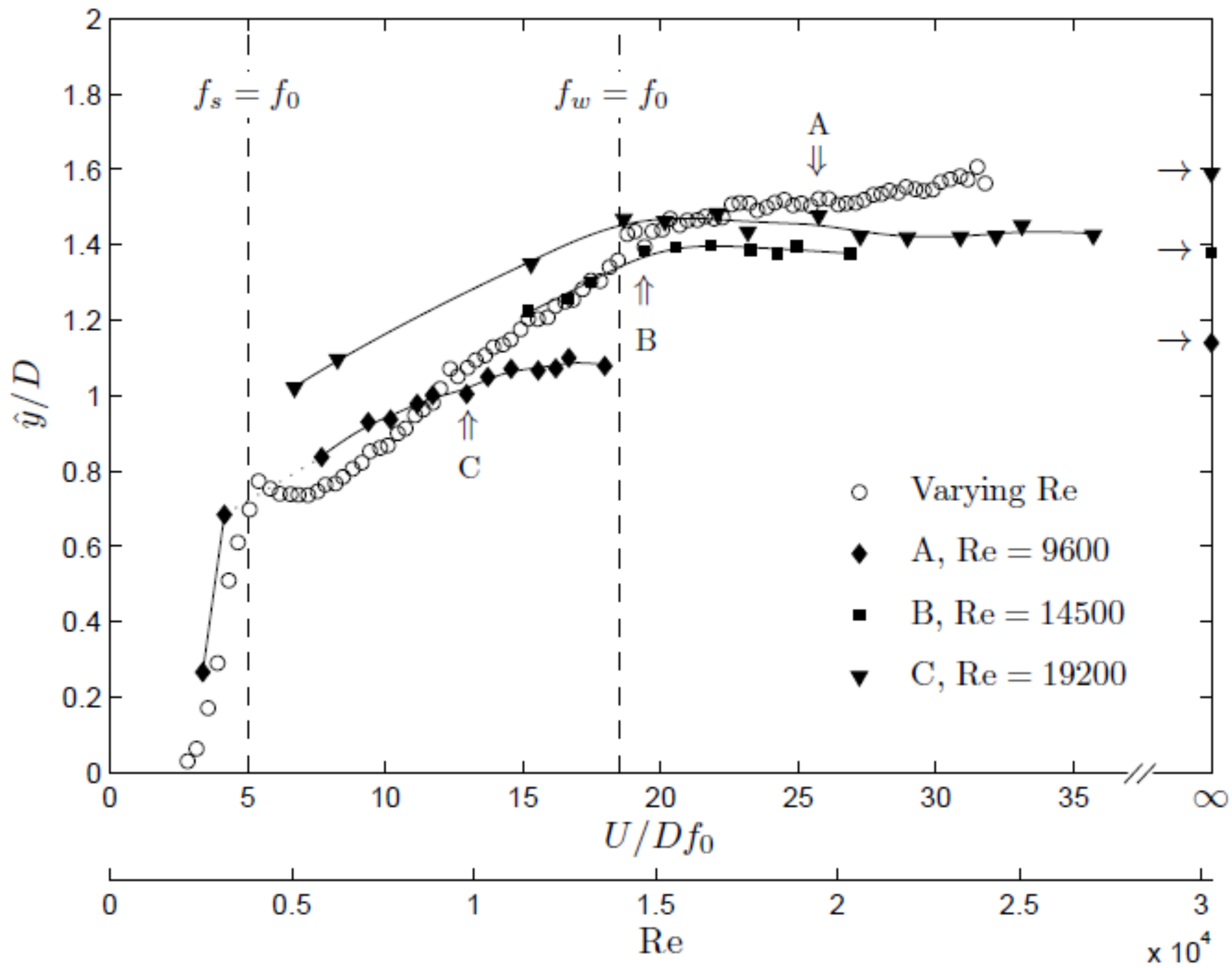




$f_s = f_0$
$f_w = f_0$
With springs (f_0)
Without springs
$\hat{C}_y$
ϕ
Re
x 10^4



$f_s = f_0$
$f_w = f_0$
$\hat{y}/D$
WIV with springs (f_0)
WIV without springs
St = 0.2
f_w
f_0
f [1/s]
U/Df_0
Re
x 10^4



$\hat{y}/D$
$f_s = f_0$
$f_w = f_0$
A
B
C
Varying Re
A, Re = 9600
B, Re = 14500
C, Re = 19200
U/Df_0
Re
x 10^4

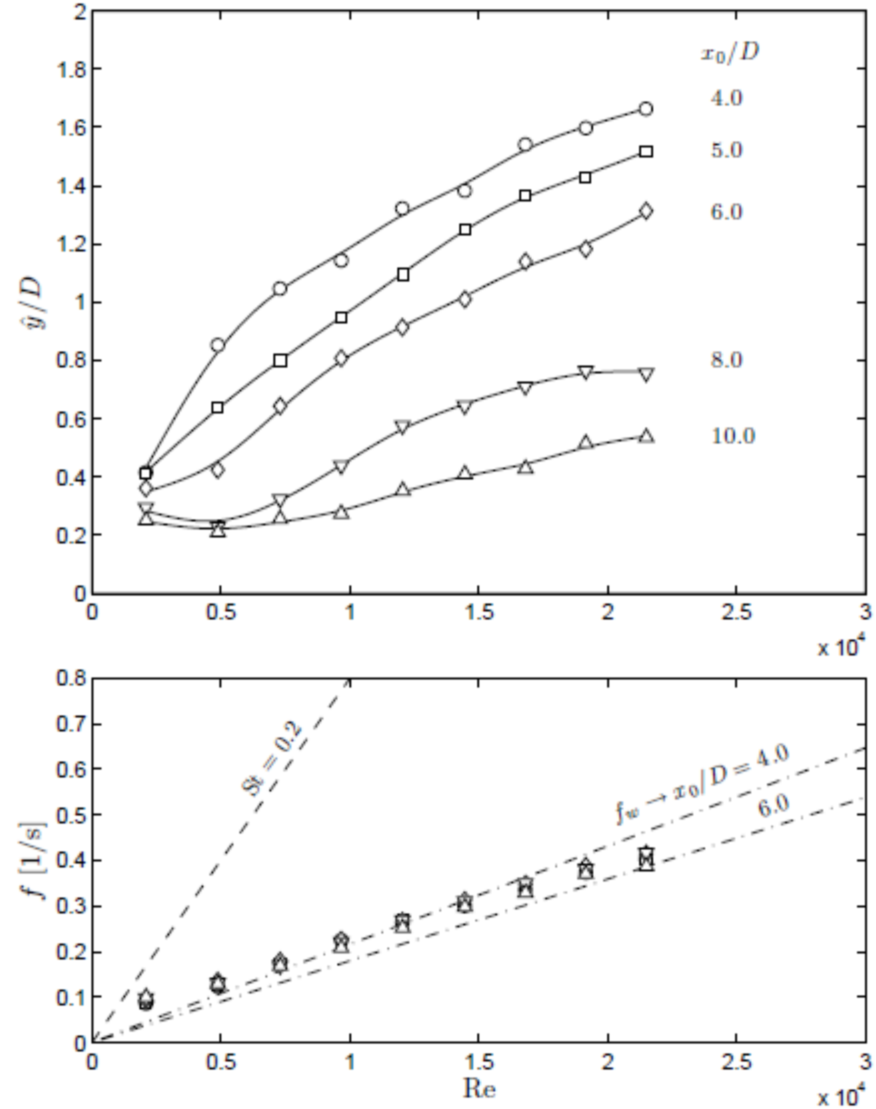


Fig. 7.8: WIV response of a downstream cylinder mounted without springs at various x_0 separations. Top: displacement; bottom: dominant frequency of oscillation.

PROF GUSTAVO ASSI
g.assi@usp.br

THANK YOU

$$m\ddot{y} + c\dot{y} = C_y \frac{1}{2}\rho U^2 D$$

$$\frac{\hat{y}}{D} = \frac{1}{4\pi}\hat{C}_y \sin\phi \frac{\rho U^2}{cf}$$

$$\frac{\hat{y}}{D} = \frac{1}{4\pi}\hat{C}_y \sin\phi \left(\frac{U}{Df}\right)\left(\frac{\rho U D}{\mu}\right)\left(\frac{\mu}{c}\right)$$

$$\left|\frac{\partial \overline{C}_y}{\partial (y_0/D)}\right| \equiv \Delta_{\overline{C}_y} \approx 0.65$$

$$k_w = \Delta_{\overline{C}_y} \frac{1}{2}\rho U^2$$

$$f_w = \frac{1}{2\pi}\sqrt{\frac{k_w}{(m^* + C_a)\rho\frac{\pi D^2}{4}}}$$