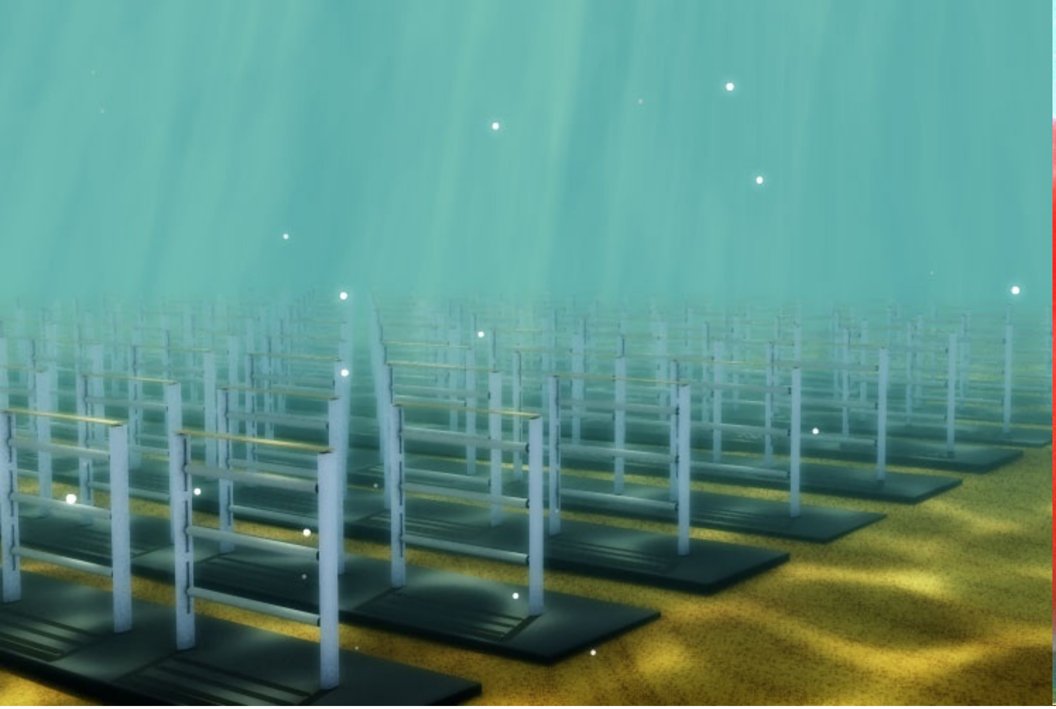
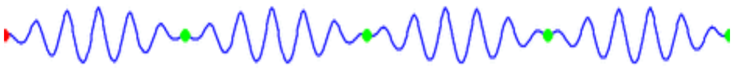


Tidal/current energy harvesting using the phenomenon of Vortex Induced Vibration (VIV)

By Andrei Metrikine (homepage.tudelft.nl/v5u5c/)

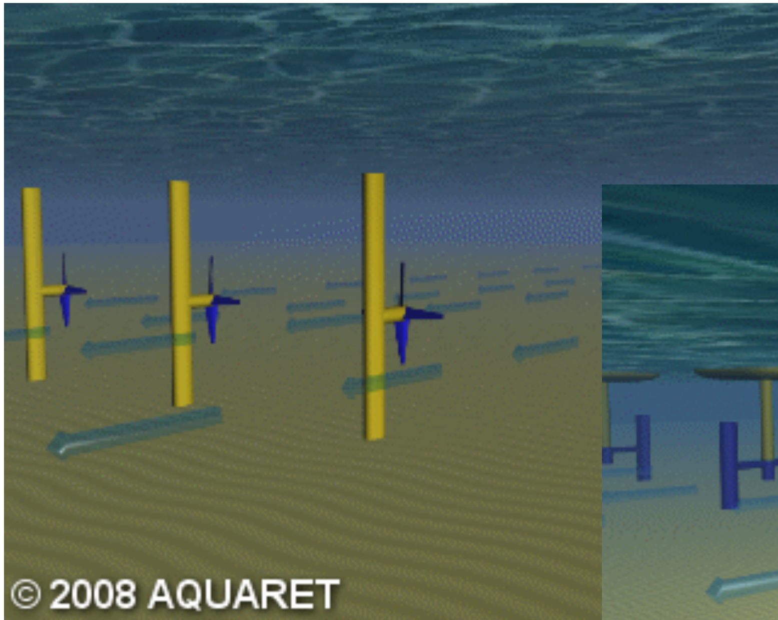


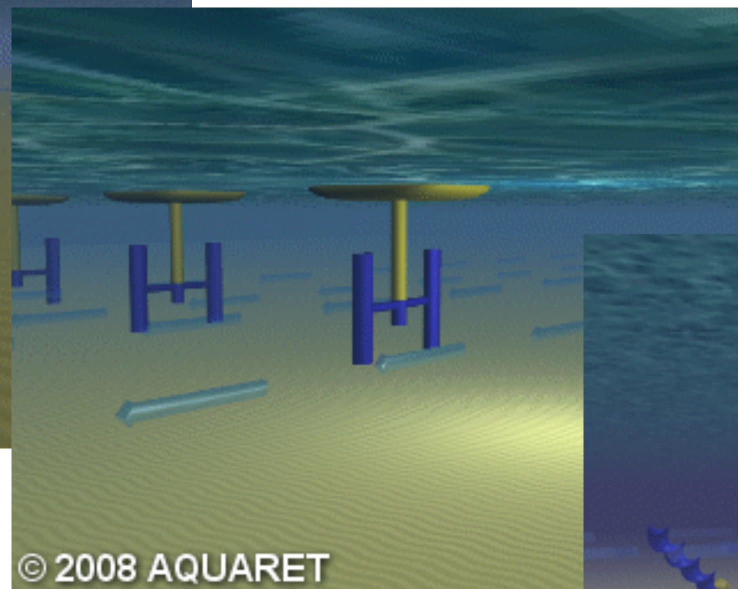
TU Delft Delft University of Technology

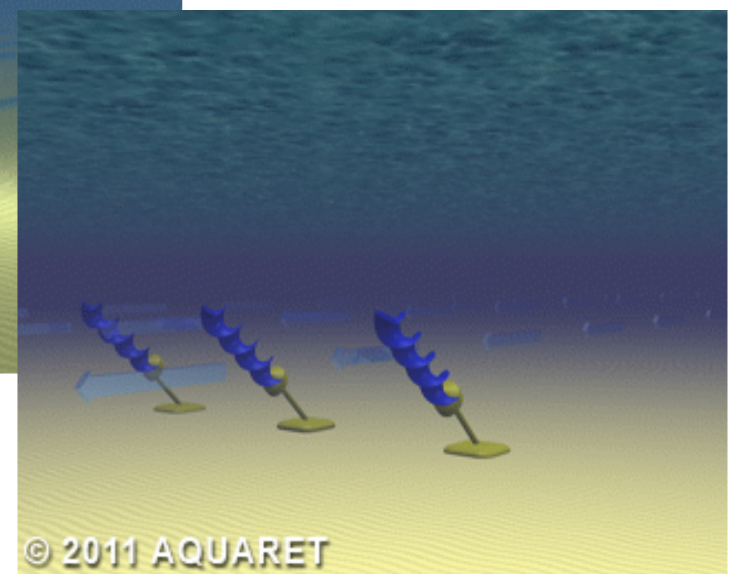
Content

1. Main types of current energy converters: uniform motions versus self-excited vibration.
2. VIVACE system (developed and patented by the University of Michigan)
3. Von Karman vortex street
4. The Vortex-Induced Vibration phenomenon
5. Pros and cons and a way forward.

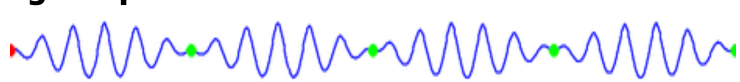
Horizontal- and vertical axis turbines



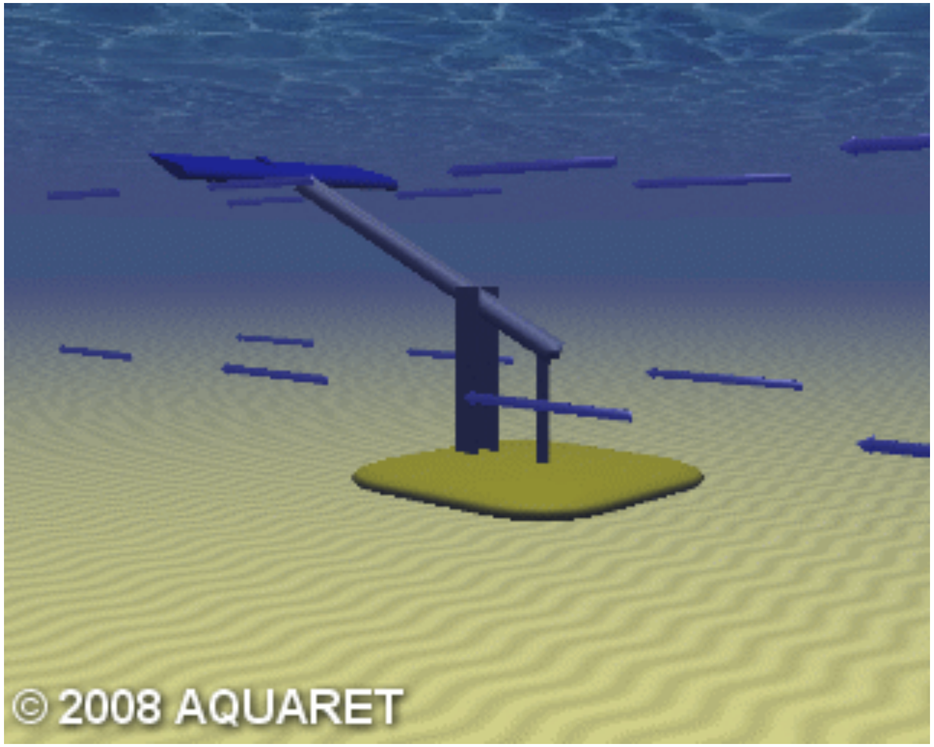


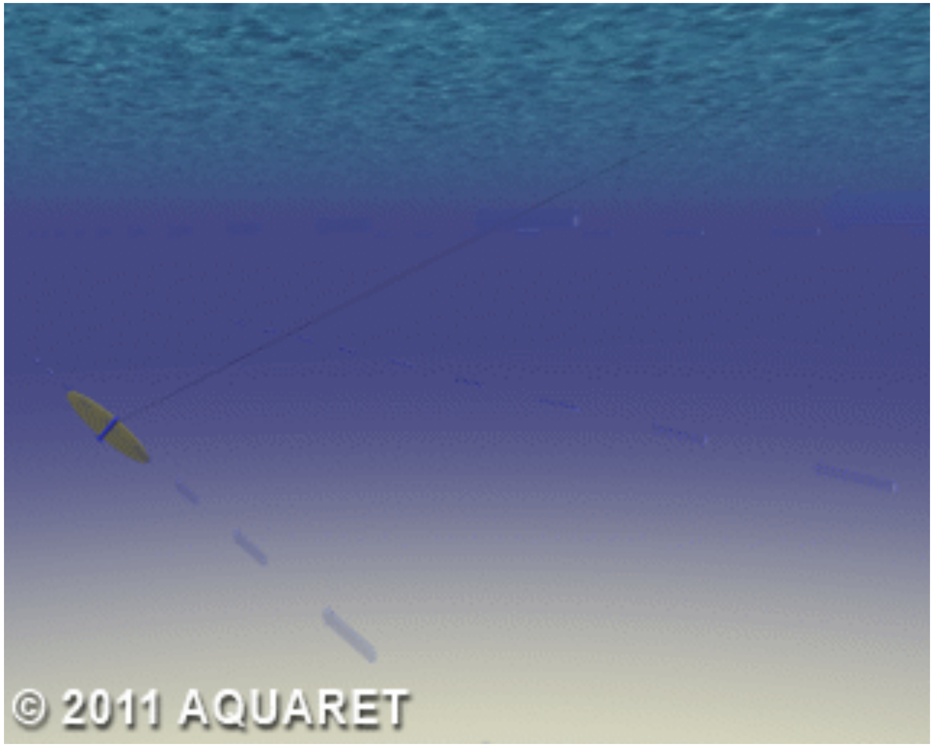


Uniform motion



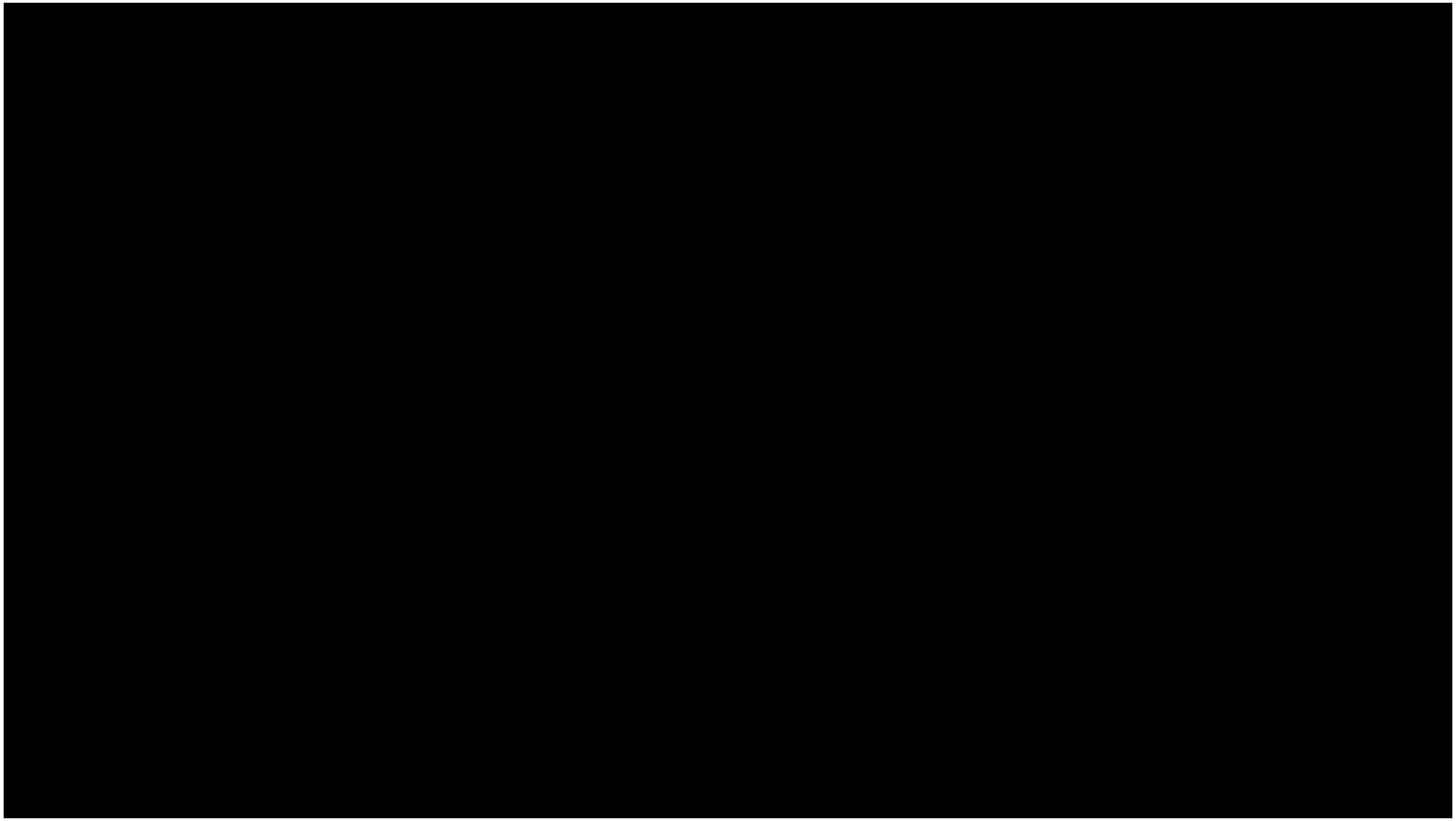
Hydrofoil and tidal kite





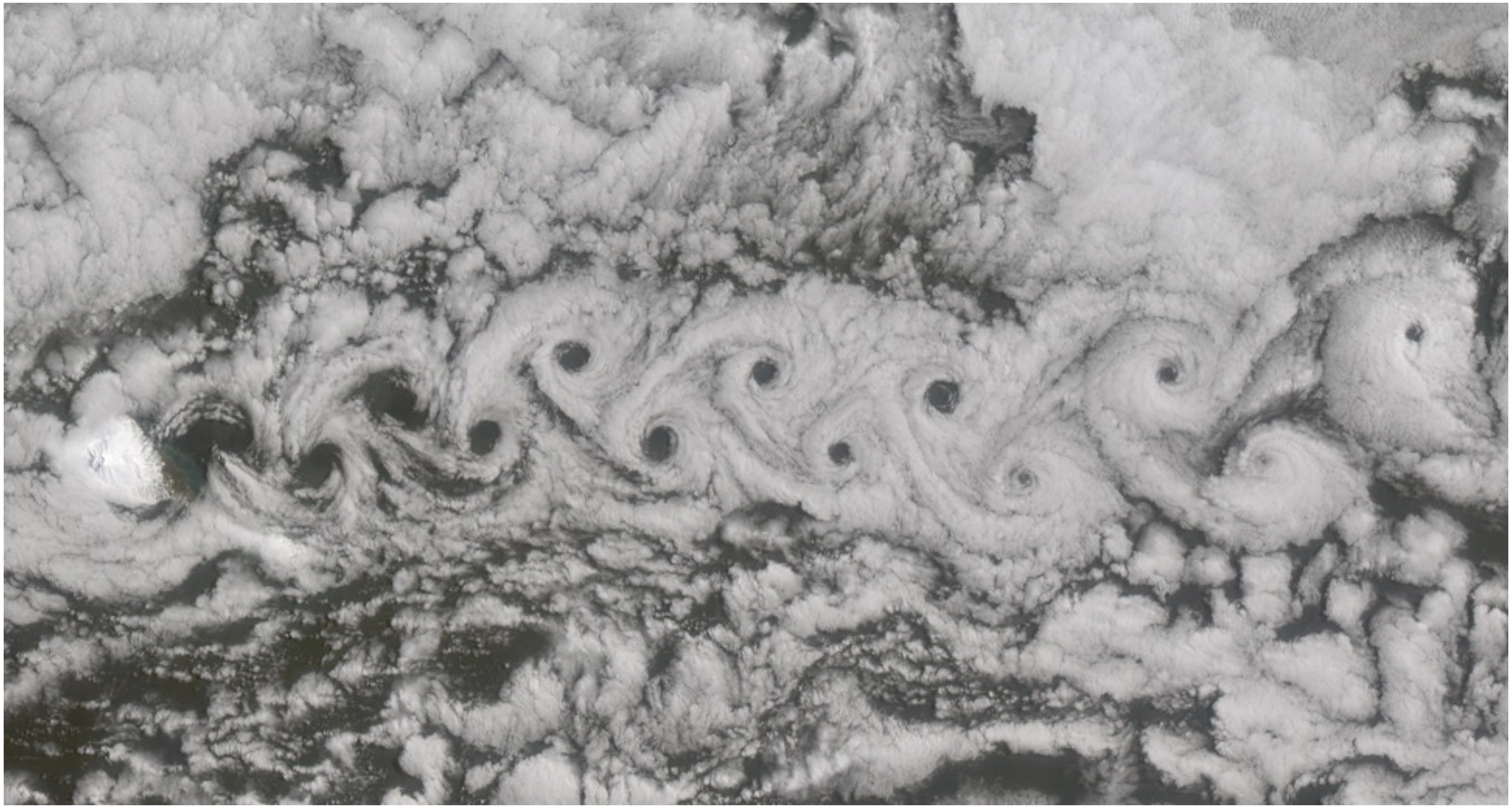
Self-excited vibration

VIVACE

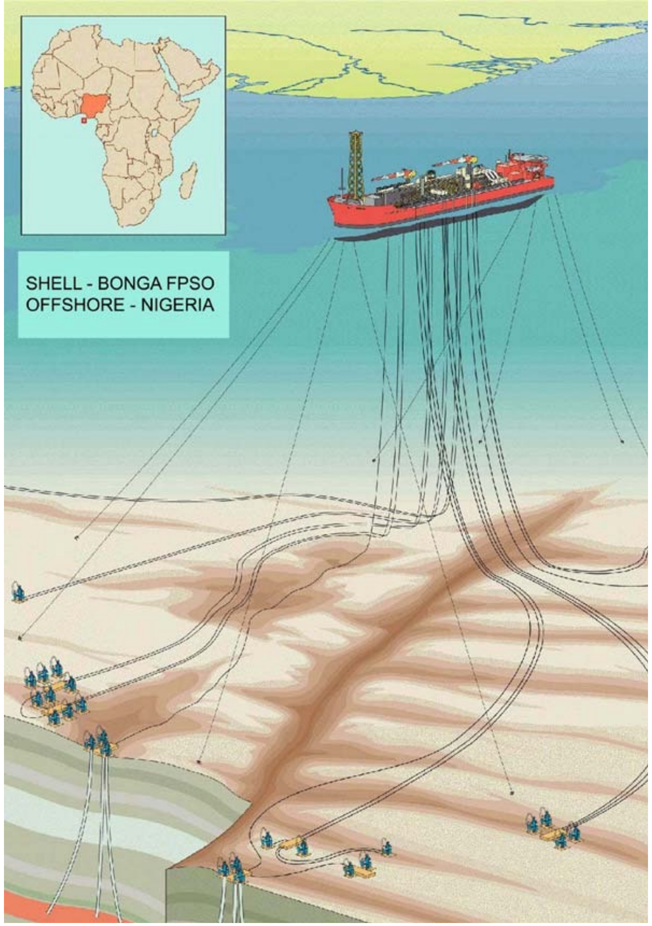


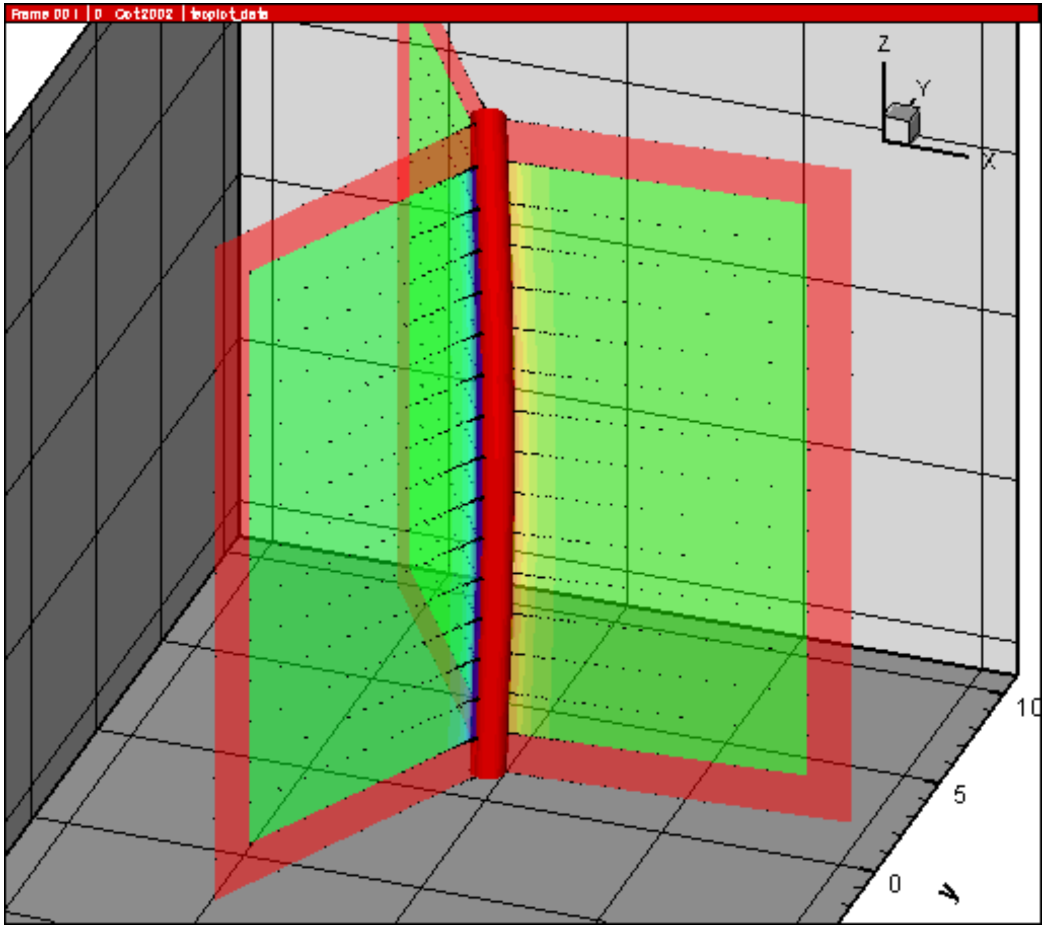
http://www.vortexhydroenergy.com

Von Karman vortex street



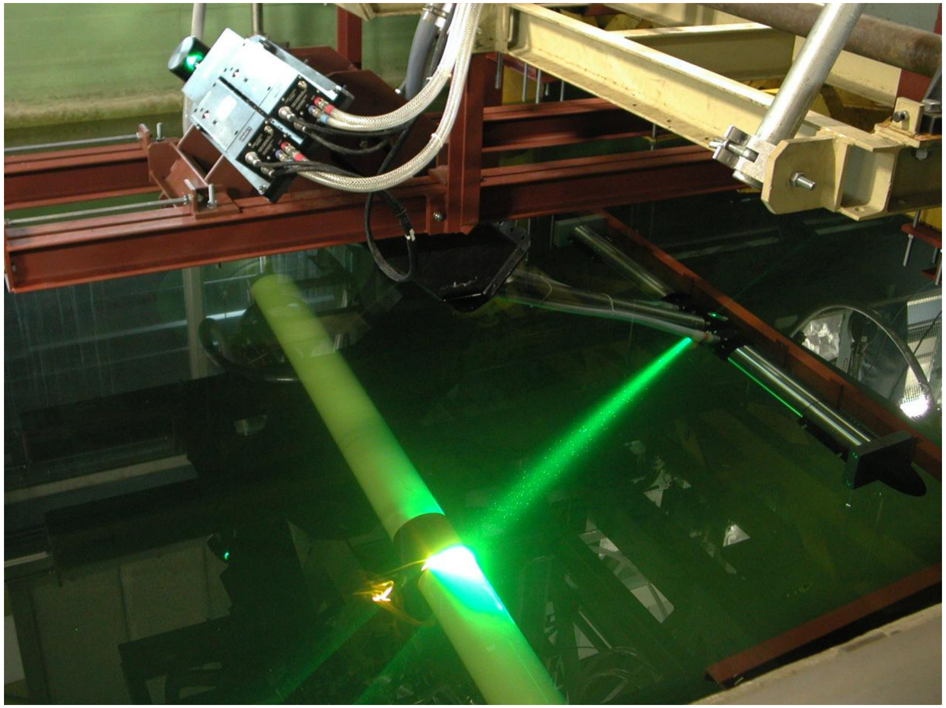
The origin of VIV studies in offshore engineering

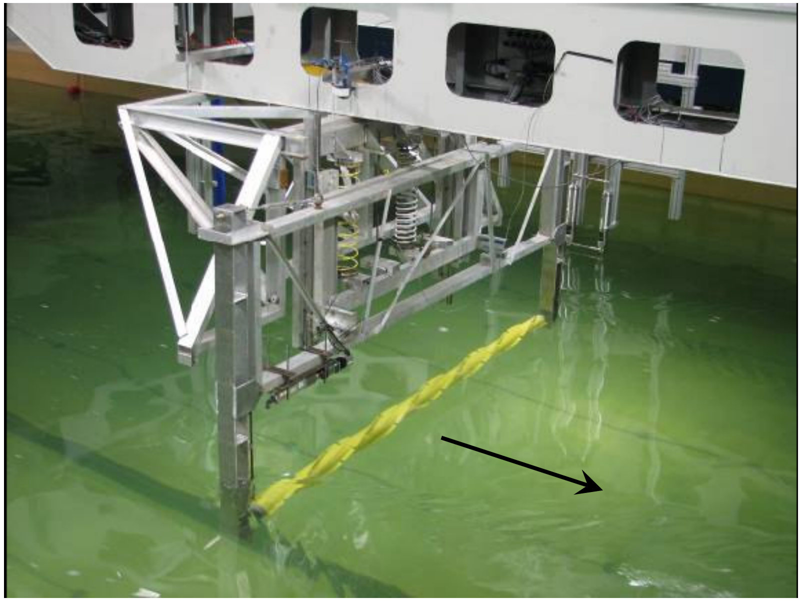




Power of VIV: full-scale impression

Experiments and countermeasures (when needed)





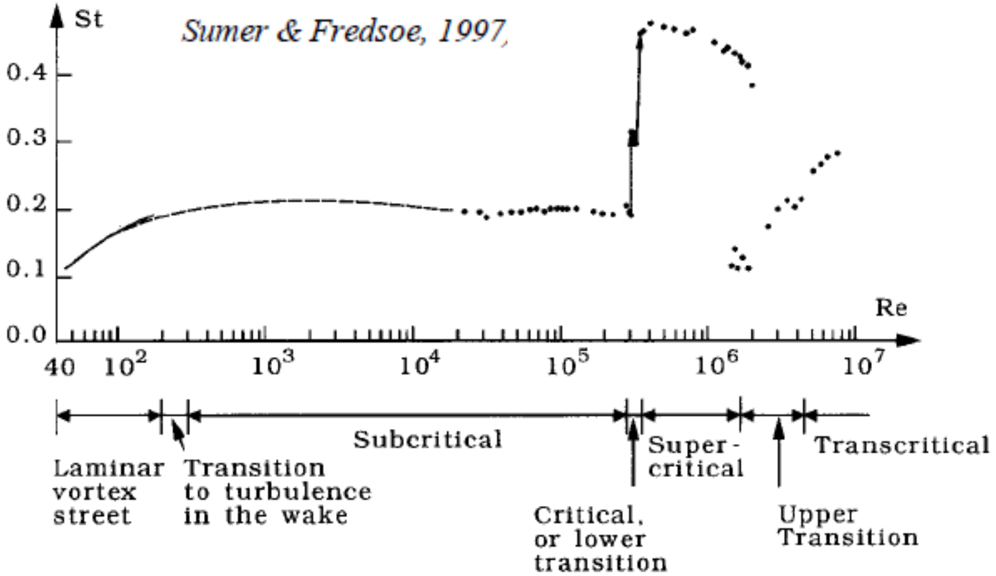
The Strouhal frequency

$$f_s = \frac{St}{D} V$$

f_s is the vortex shedding frequency of a stationary cylinder

D is the diameter of the cylinder

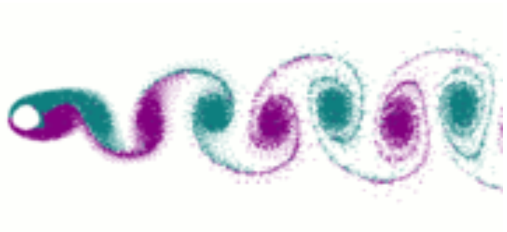
V is the flow velocity

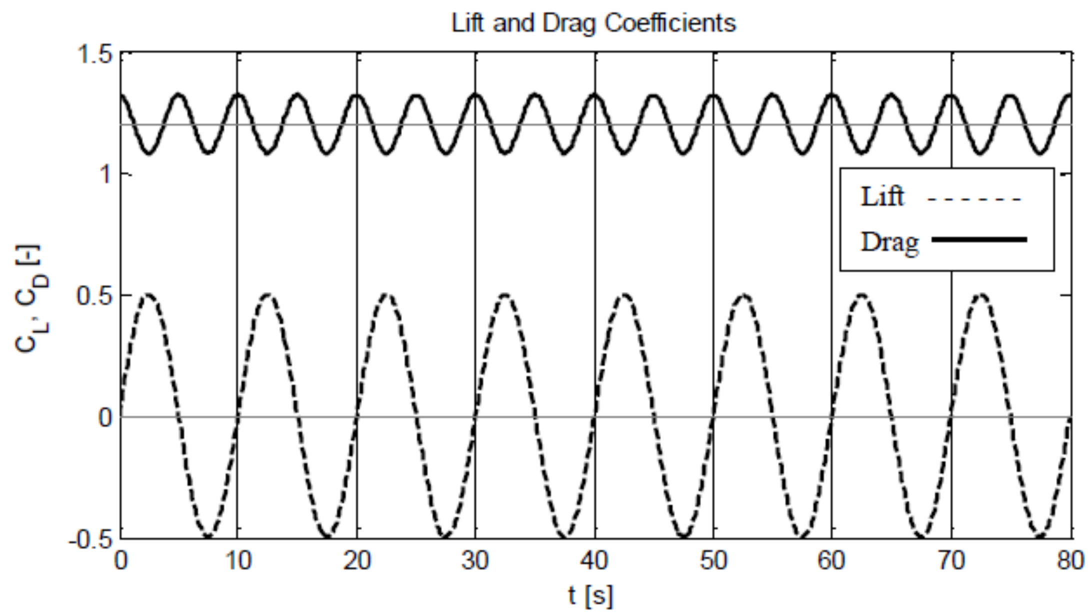


The lift and drag coefficients for stationary cylinders

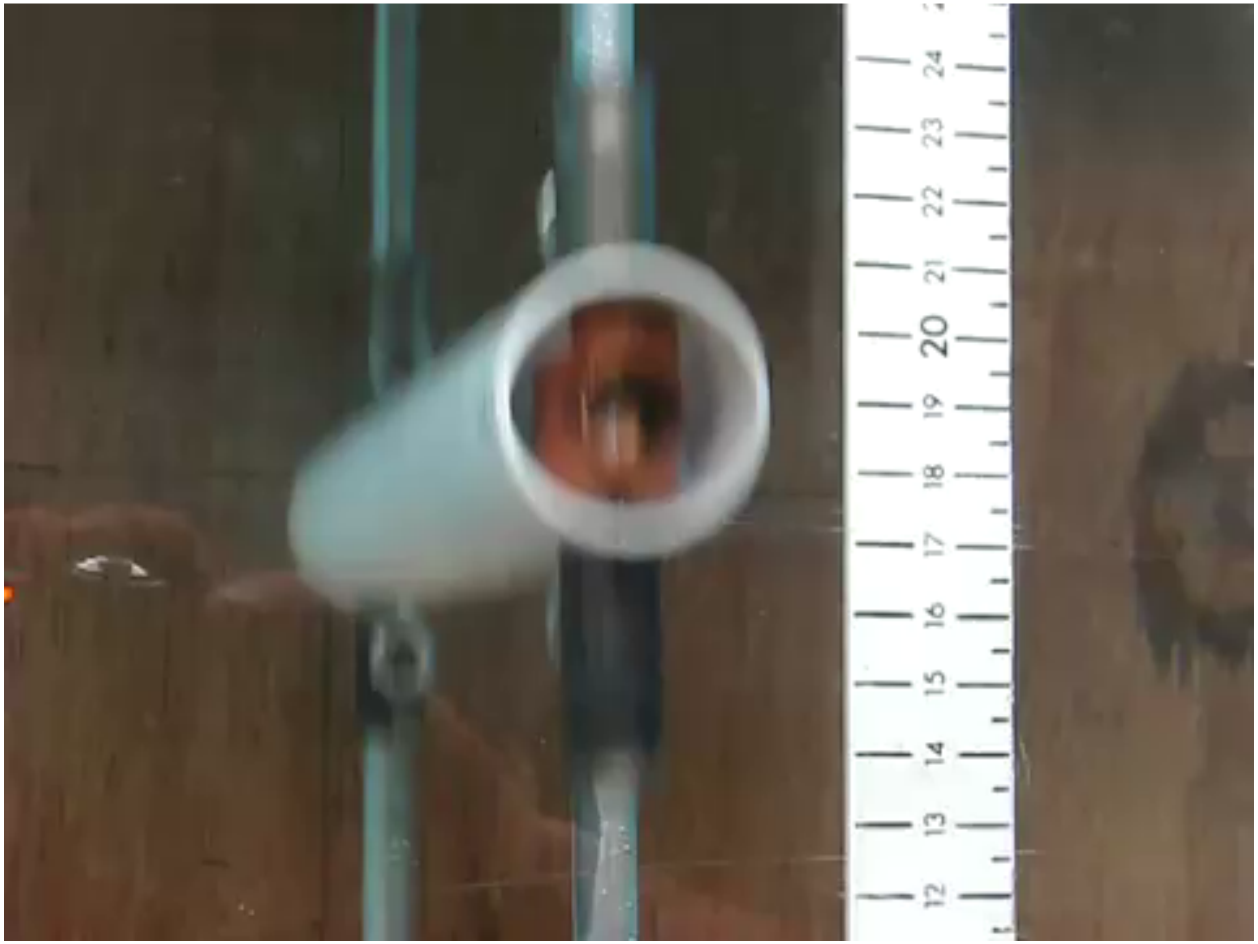
The lift coefficient: $C_L = \dfrac{F_L}{0.5\rho D L V^2}$

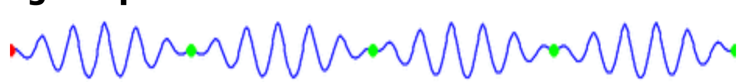
The drag coefficient: $C_D = \dfrac{F_D}{0.5\rho D L V^2}$



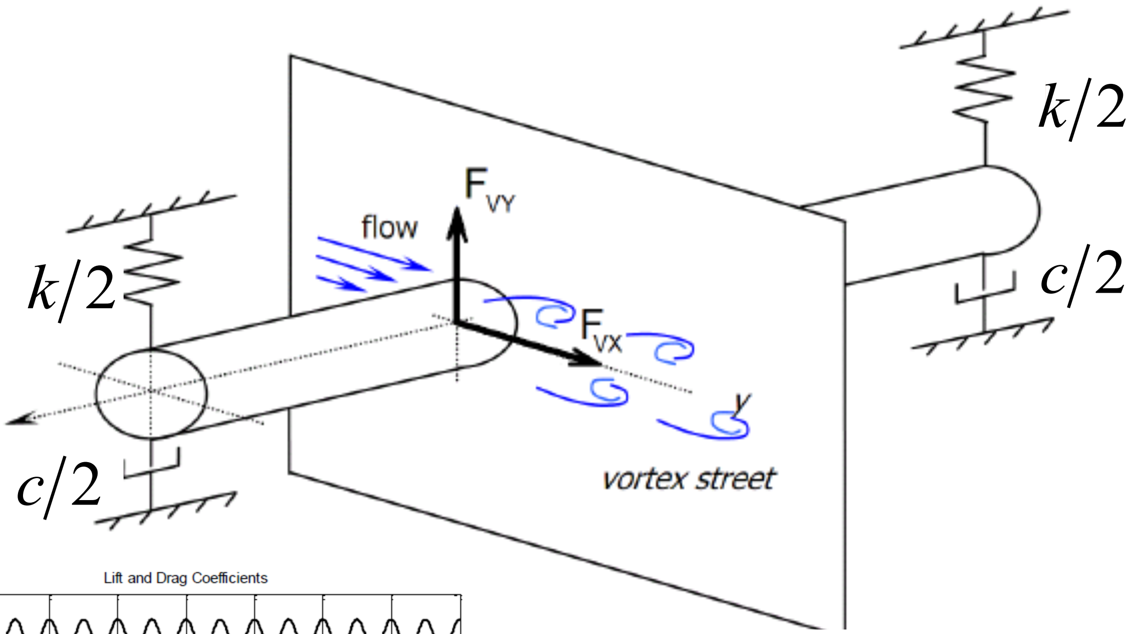


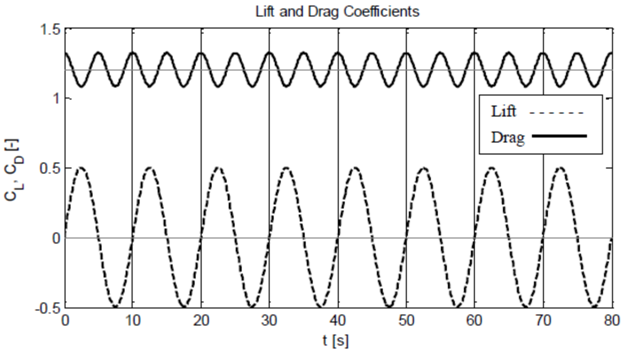
VIV of an elastically supported cylinder





VIV of an elastically supported cylinder



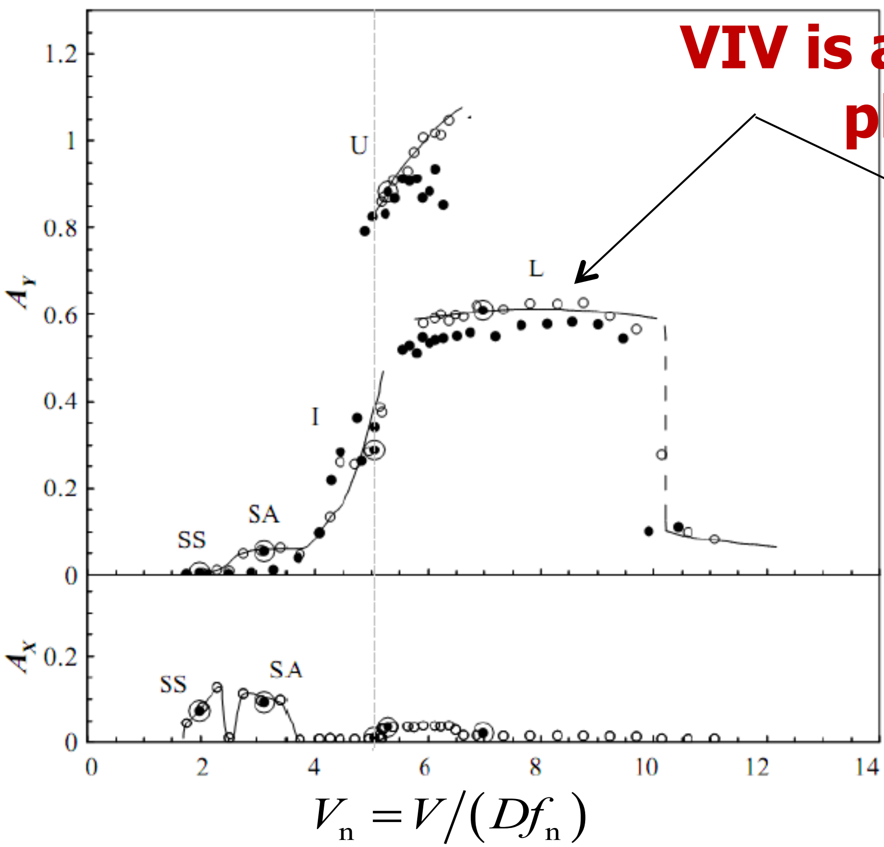


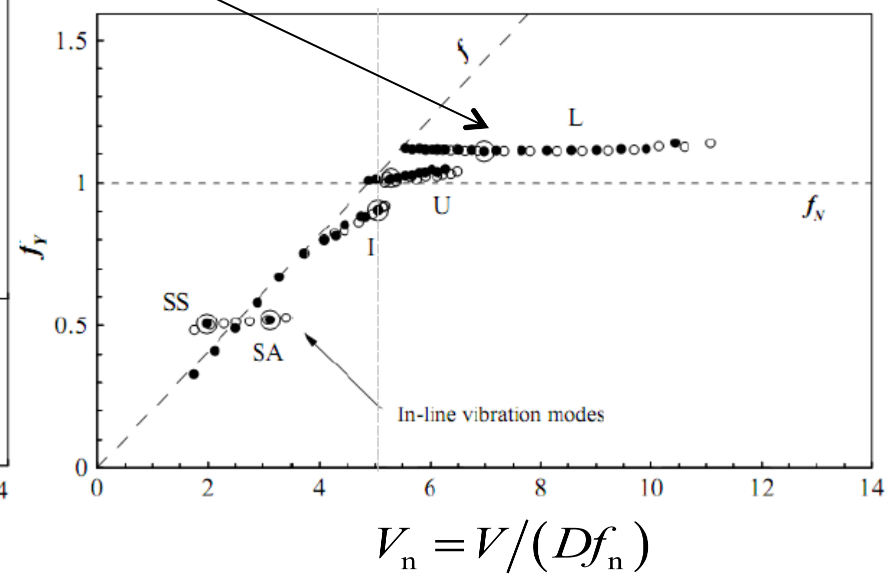
$$m^* = \frac{M}{\frac{\pi D^2}{4} L\rho} = \frac{m}{\frac{\pi D^2}{4}\rho} \frac{(Mass\ of\ the\ system)}{(Mass\ of\ displaced\ fluid)}$$

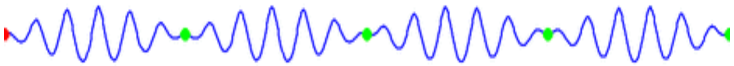
Results of the free vibration experiment

VIV is a synchronization phenomenon

$$A_x = X_{max}/D$$
$$A_y = Y_{max}/D$$
$$f = f_{cyl}/f_n$$

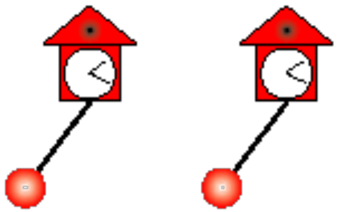




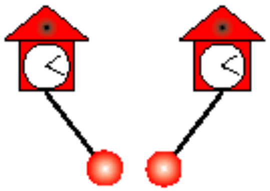


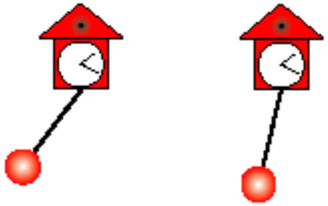
The synchronization phenomenon

in-phase synchronization

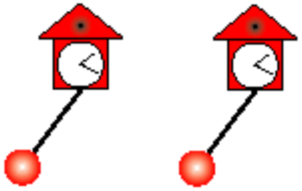


anti-phase synchronization

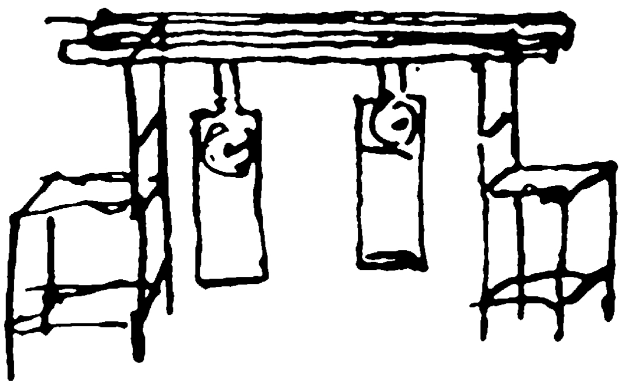




synchronization with an arbitrary phase shift



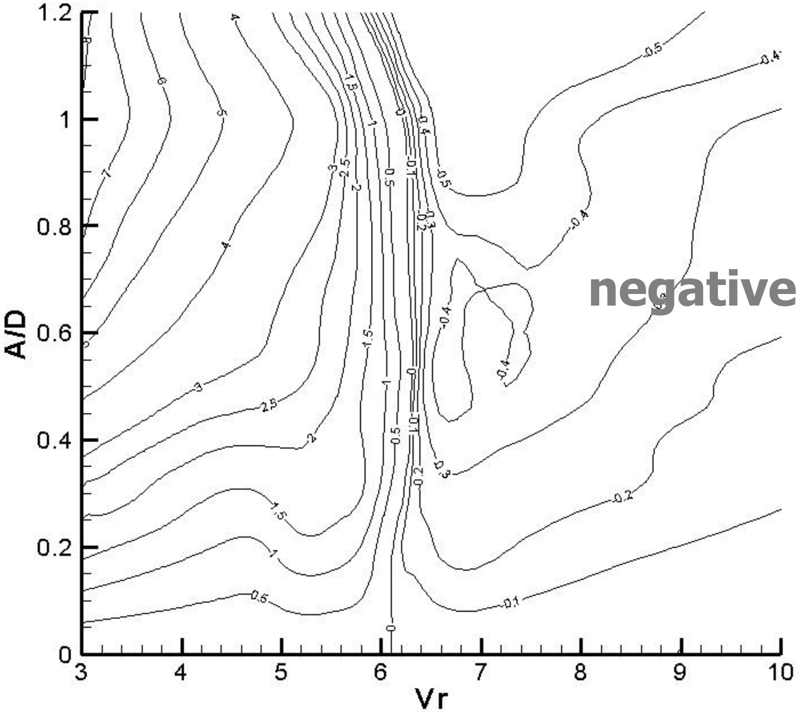
no synchrony



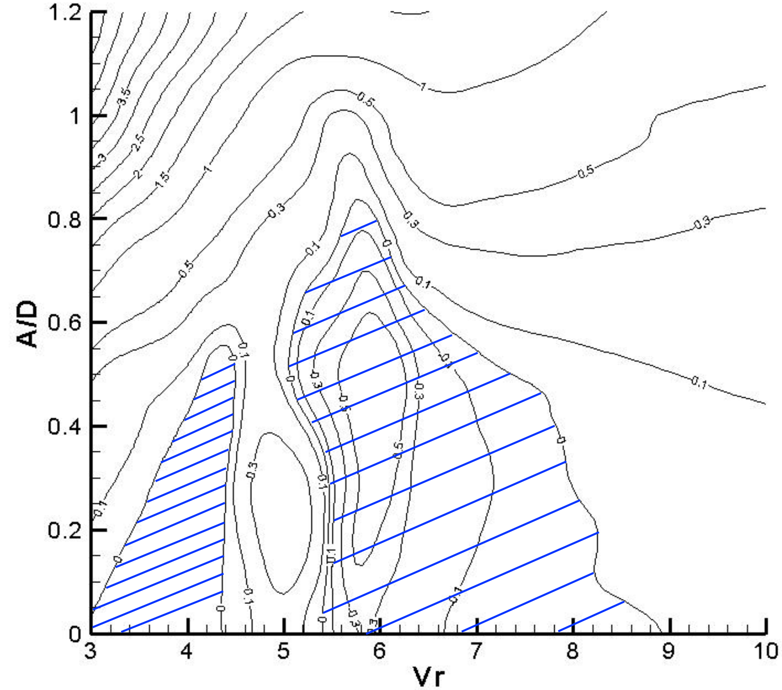
An original drawing by Christiaan Huygens illustrating his experiments with pendulum clocks (17th sentury)

http://www.scholarpedia.org/article/Synchronization

The forced vibration experiment



Added Mass

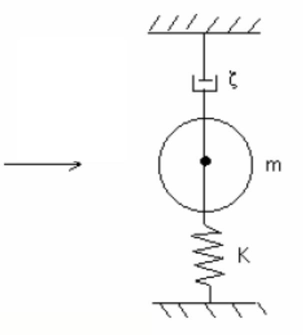


Added Damping

The wake oscillator model: idea

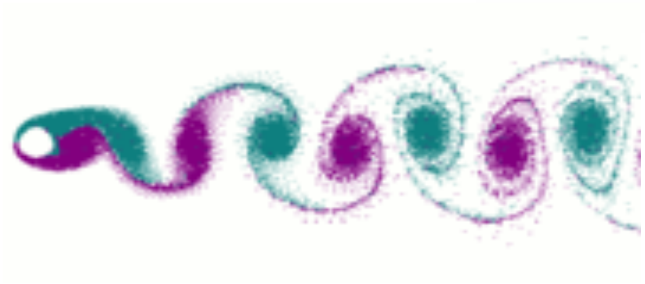
Equation of Motion of the Structure:

$$\ddot{y} + \left(2\zeta\Omega_n + M\left(\overline{\mathrm{St}}\right)^{-1} \hat{C}^0_{x0} \right)\dot{y} + \Omega_n^2 y = M\left(\overline{\mathrm{St}}\right)^{-2} \hat{C}^0_{y1} q,$$



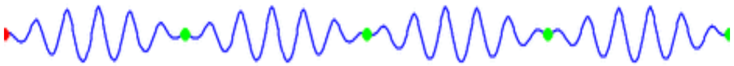
Oscillator:

$$\ddot{q} + \varepsilon(q^2 - 1)\dot{q} + q = A\ddot{y}$$



Tuning parameters: A, ε

Model by Facchinetti et al. (2004)



Generalization to large angles

Model by Facchinetti et al. (2004)

$$\ddot{y} + 2\zeta\Omega_n\dot{y} + \Omega_n^2 y = M\left(\overline{\mathrm{St}}\right)^{-2}\left(-\dot{y}\,\overline{\mathrm{St}}\,\hat{C}_{x0}^{0} + q\hat{C}_{y1}^{0}\right)$$

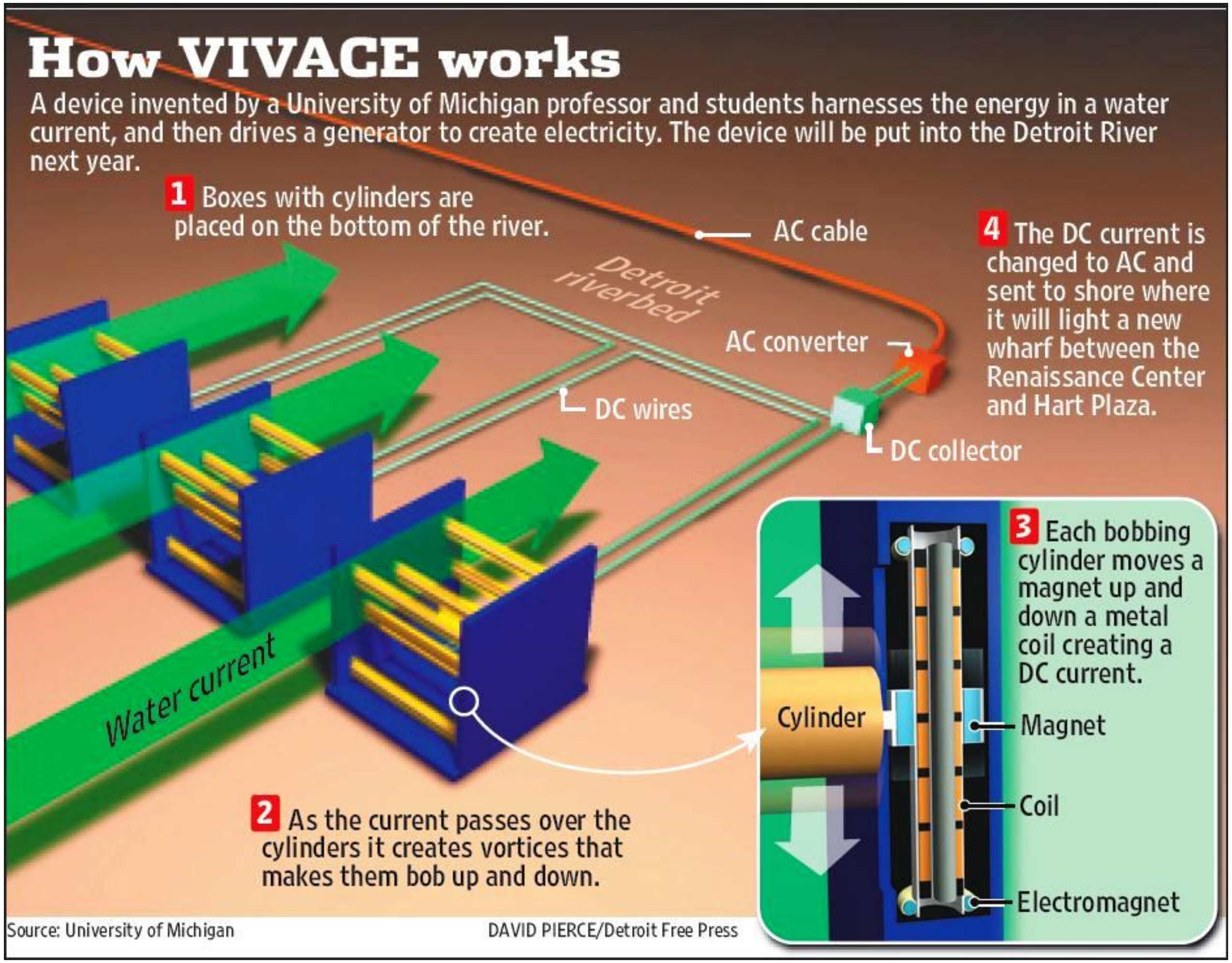
$$\ddot{q} + \varepsilon(q^2 - 1)\dot{q} + q = A\ddot{y}$$

Model by Ogink & Metrikine (2010)

$$\ddot{y} + 2\zeta\Omega_n\dot{y} + \Omega_n^2 y = M\left(\overline{\mathrm{St}}\right)^{-2}\left(-\dot{y}\,\overline{\mathrm{St}}\,\hat{C}_{x0}^{0} + q\hat{C}_{y1}^{0}\right)\sqrt{1 + \left(\overline{\mathrm{St}}\right)^2 \dot{y}^2 / 4},$$

$$\ddot{q} + \varepsilon(q^2 - 1)\dot{q} + q = A\ddot{y}$$

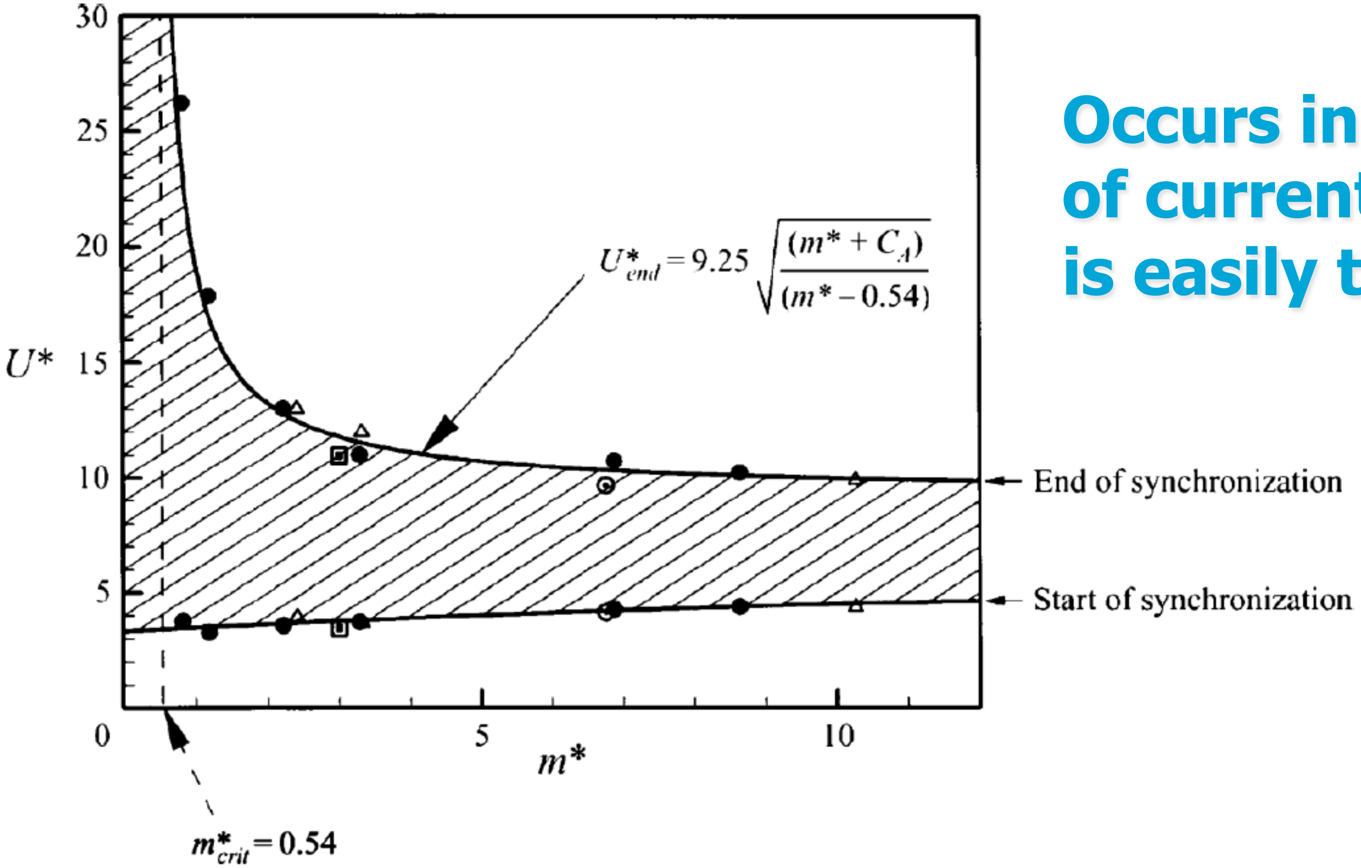
Back to VIVACE



Back to VIVACE

- The VIVACE converter is a transformational technology.
- It taps into a vast new source of clean and renewable energy, that of water currents as slow as 1 to 2 m/s, previously off limits to conventional turbine technology.
- The vast majority of river/ocean currents are slower than 1.5 m/s.

VIV energy generation: strong point

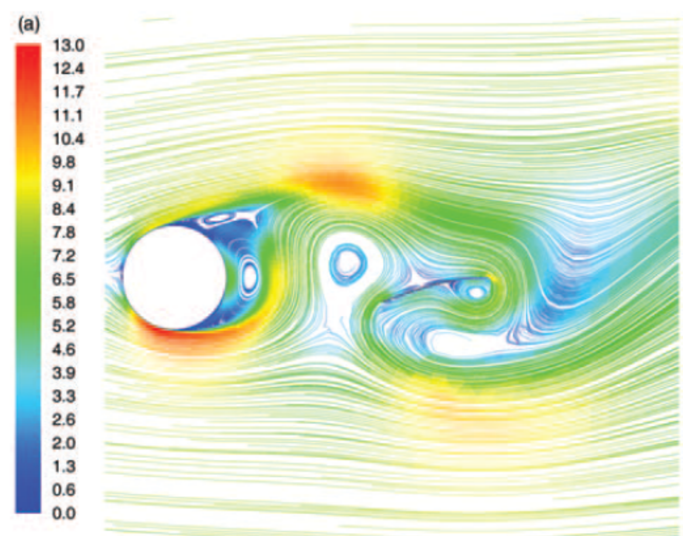


Occurs in a large range of current velocities and is easily tuneable.

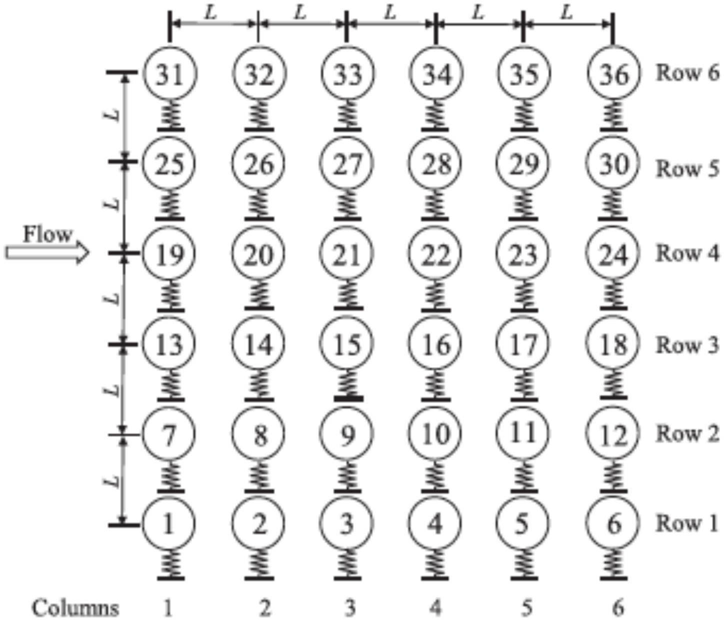
VIV energy generation: weak point

Currently captures moderate amount of kinetic energy of currents

Obvious solution: arrays and use of the wake-induced vibration



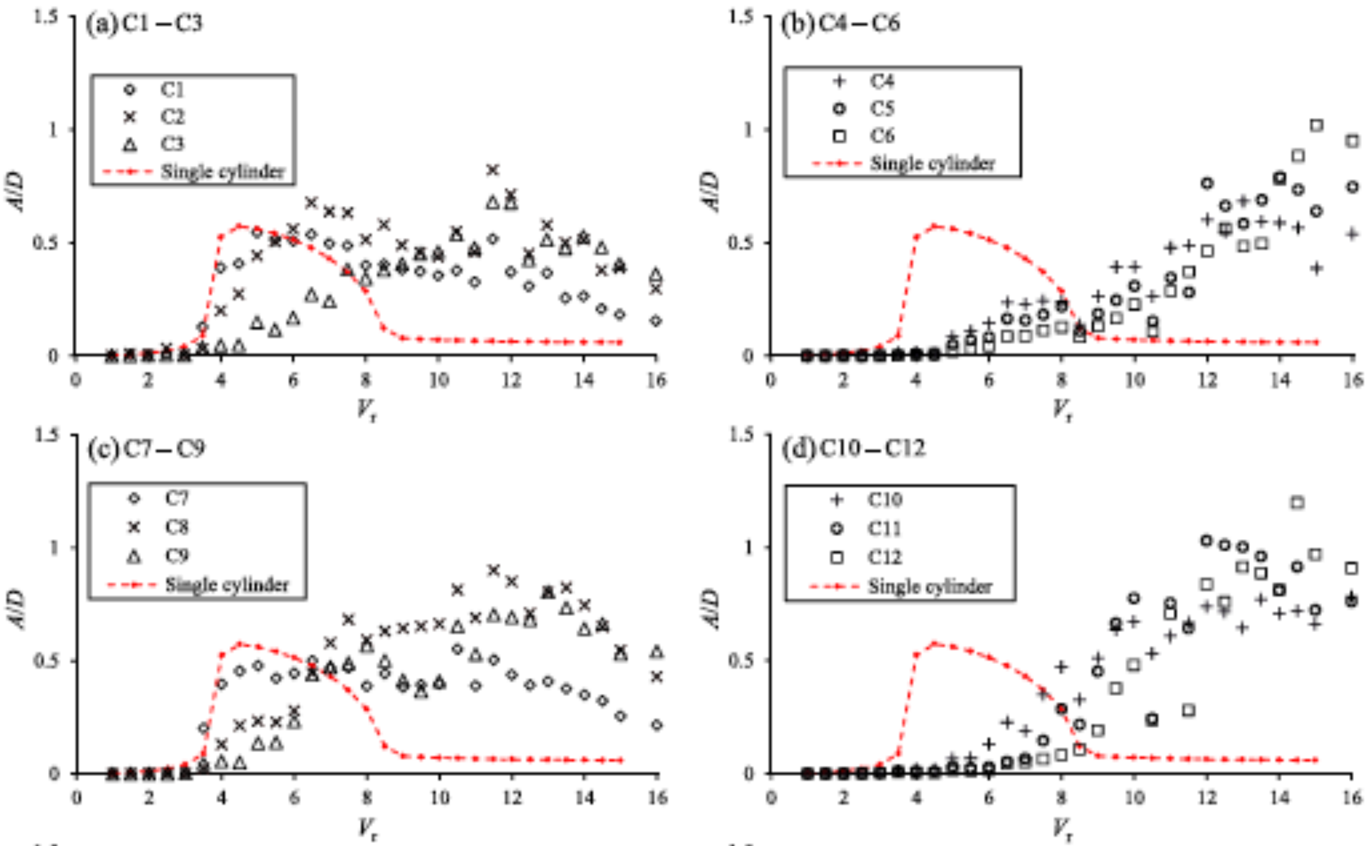
Recent theoretical findings



Flow and flow-induced vibration of a square array of cylinders in steady currents

Ming Zhao[1], Liang Cheng[2], Hongwei An[2] and Feifei Tong[2]

Recent theoretical findings



The synchronization range can be expanded and as much as needed kinetic energy can be captured

Thank you for your attention