Energy harvesting in a fluid flow using piezoelectric materials

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joint work with

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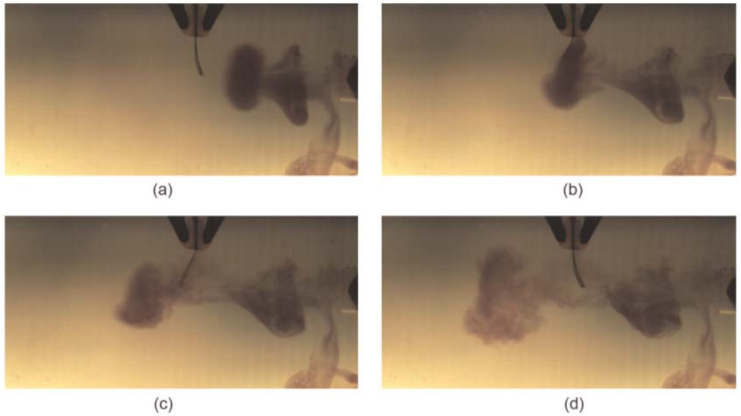
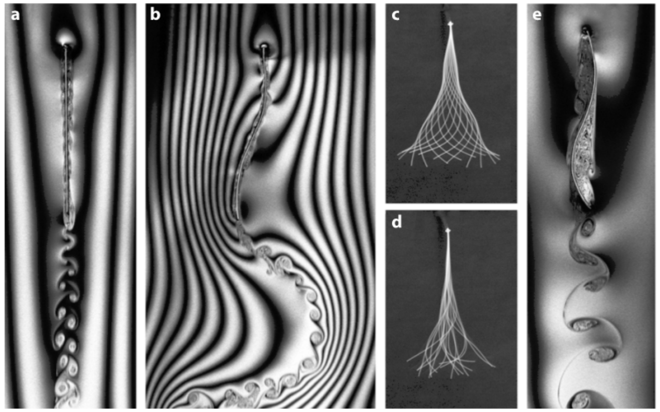
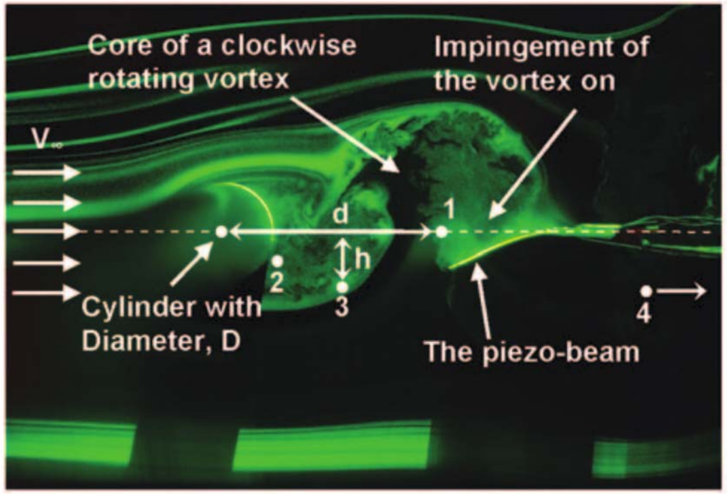
Solid vibrations in fluids



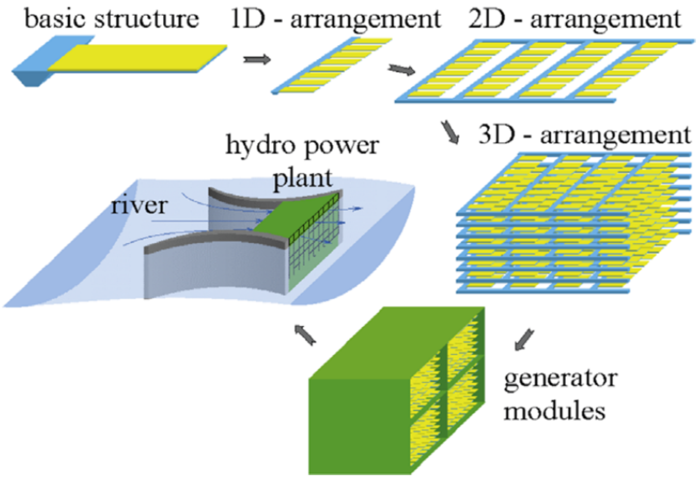
S.D. Peterson et al., J. of Intelligent Material Systems and Structures 23, (2012).



M.J. Shelley et al., Annu. Rev. Fluid Mech. 43, (2010).



H.D. Akaydin et al., J. of Intelligent Material Systems and Structures 21, (2010).



S. Pobering et al., Int. Conference oon MEMS, NANO and Smart Systems 00, (2004).

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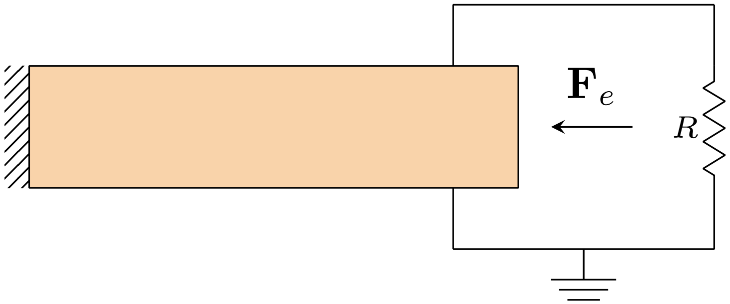
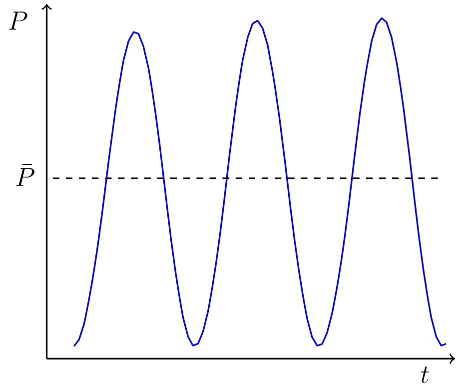
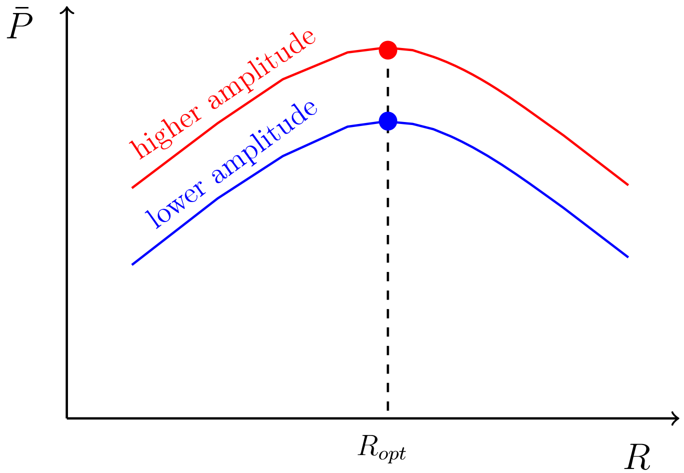
Piezoelectric materials

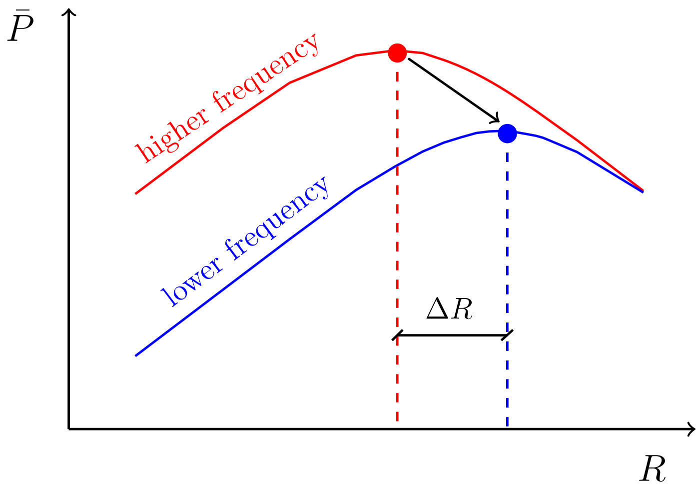
Piezoelectric solids develop an electric potential when compressed or stretched.





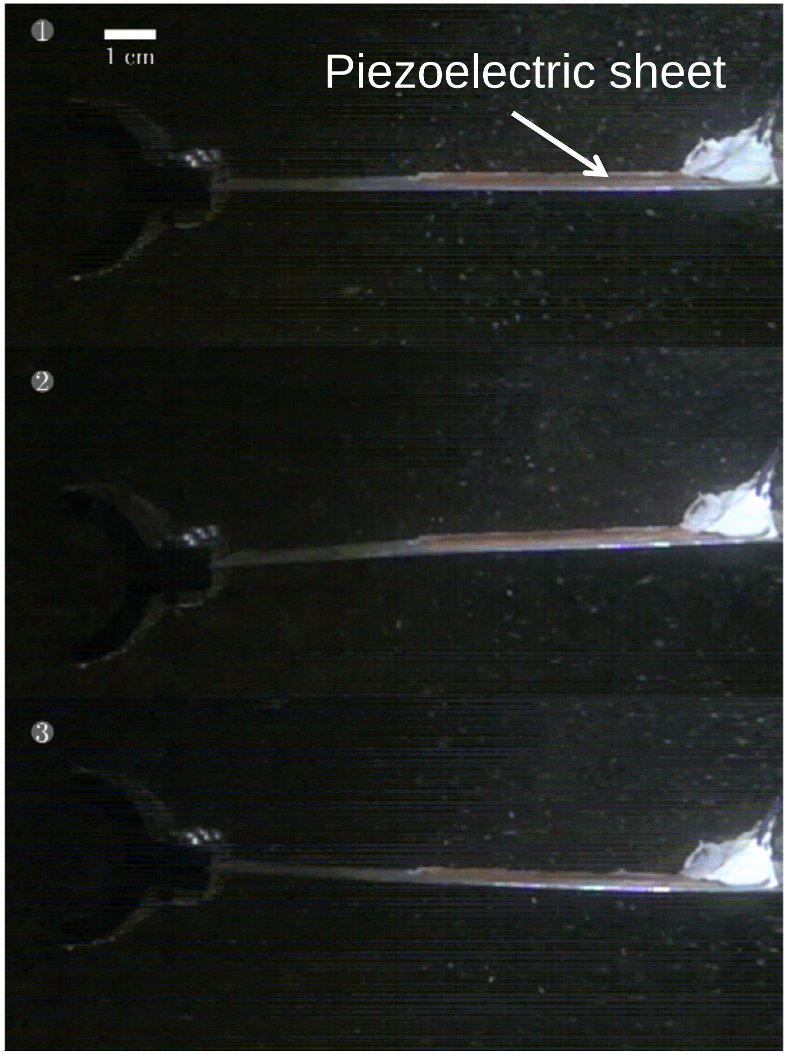
The optimal external load resistance depends on geometry and characteristics of force application.



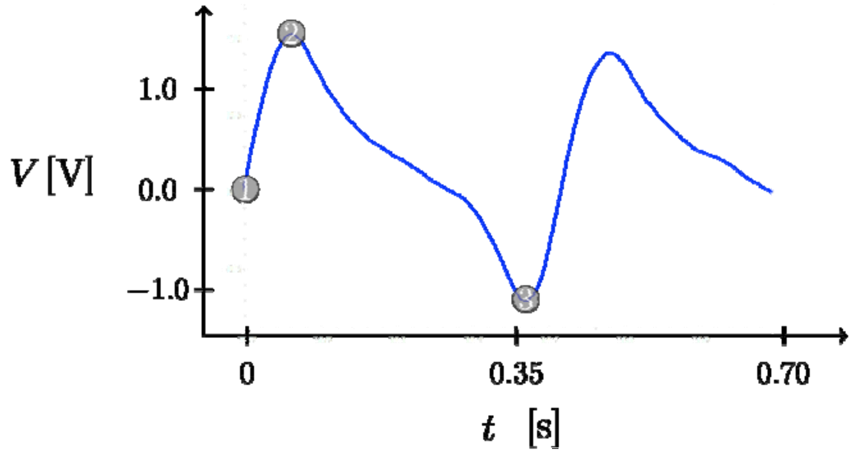


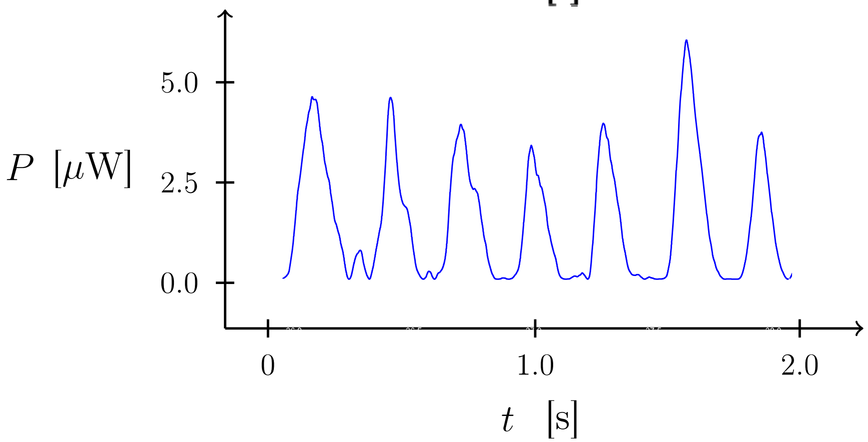
Energy harversting in fluid flows

Energy harversting in fluid flows



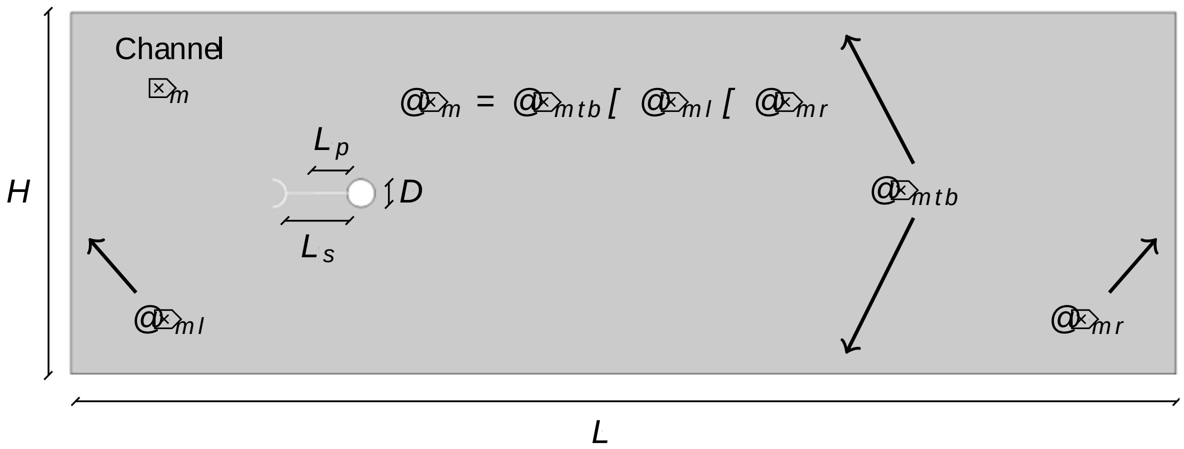
The solid vibrates due to the fluid flow and generates an electrical potential which is harvested on an electrical load resistance.



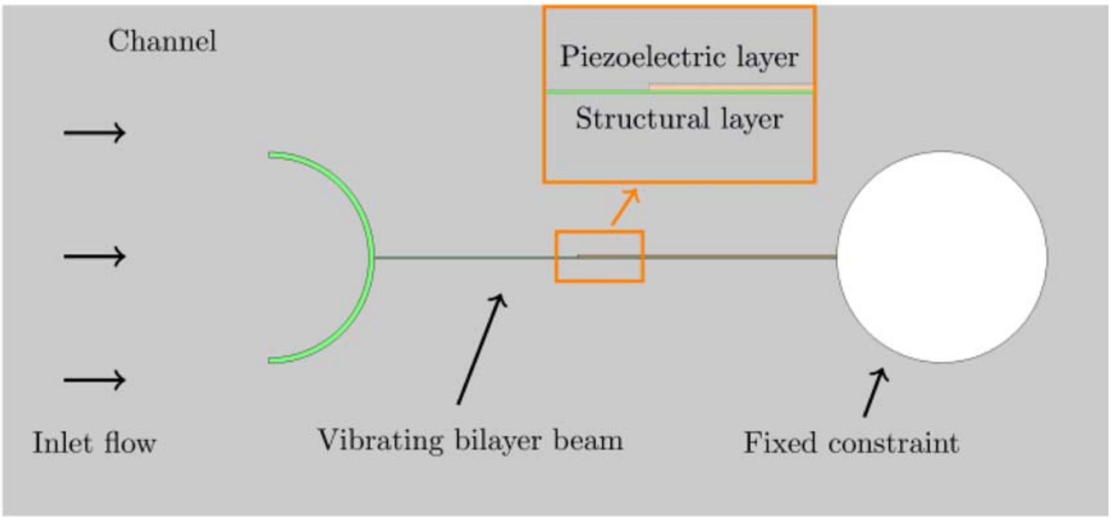


Modeling FSI

a)



b)



Modeling FSI

Momentum and mass conservation for the fluid

$$\rho_f \, \dot{\mathbf{v}}_f + \rho_f \, (\nabla \mathbf{v}_f)\,(\mathbf{v}_f - \dot{\mathbf{u}}_m) = \operatorname{div} \boldsymbol{\Gamma} + \mathbf{f}$$

$$\operatorname{div} \mathbf{v}_f = 0$$

Solid balance of forces

$$\rho \, \ddot{\mathbf{u}} = \operatorname{div} \mathbf{S}$$

Gauss's law

$$\operatorname{div} \mathbf{D} = \rho_v$$

Moving mesh

$$\operatorname{div}(\mathbb{A} \nabla \mathbf{u}_m) = 0$$

Constitutive prescriptions

The fluid is assumed incompressible and linearly viscous:

$$\Gamma = -p\mathbf{I} + 2\mu_f(\mathrm{sym}\nabla\mathbf{v}_f) - \frac{2}{3}\mu_f(\mathrm{div}\,\mathbf{v}_f)\mathbf{I}$$

Both structural and piezoelectric solid are assumed to be linear elastic:

$$\mathbf{S}^e = \frac{Y_s}{1+\nu_s}\mathbf{E} + \frac{Y_s\,\nu_s}{(1+\nu_s)(1-2\,\nu_s)}\mathrm{tr}(\mathbf{E})\,\mathbf{I}$$

$$\mathbf{S}^e = \mathbb{C}\mathbf{E} - \mathbf{e}^T\mathbf{E}_{el}$$

The electric displacement in the piezoelectric solid:

$$\mathbf{D} = \mathbf{e}\mathbf{E} + k_o\,\mathbf{k}\,\mathbf{E}_{el}$$

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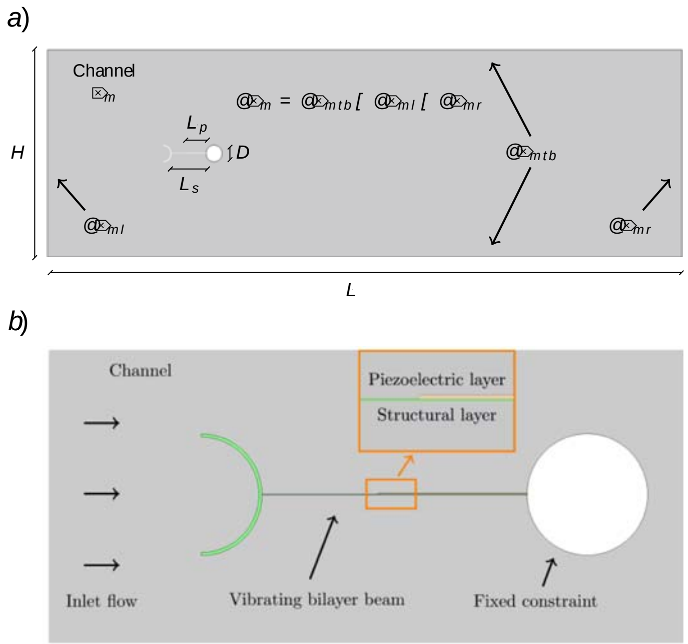
Principal boundary conditions



At the fluid-solid interface we assign:

$$\mathbf{T}\mathbf{n} = -\Gamma\mathbf{n}, \quad \mathbf{v}_f = \dot{\mathbf{u}}_m = \dot{\mathbf{u}}_s \quad \text{on } \partial\Omega_{sm} \times \mathscr{T}$$

At the channel walls the mesh is fixed:

$$\mathbf{u}_m = 0 \quad \text{on } \partial\Omega_m \times \mathscr{T}$$

A inlet condition on the left wall of the channel:

$$\mathbf{v}_f = (1 - \exp(-t/\tau))Uf(Y)\mathbf{e}_1 \quad \text{on } \partial\Omega_{ml} \times \mathscr{T}$$

At the top boundary of the piezoelectric solid we assign an electrical $V = \tilde{V}$:ial n such that it holds:

$$\int_{\partial\Omega_{spt}} \dot{\mathbf{D}} \cdot \mathbf{n}\, ds = \frac{\tilde{V}}{R}$$

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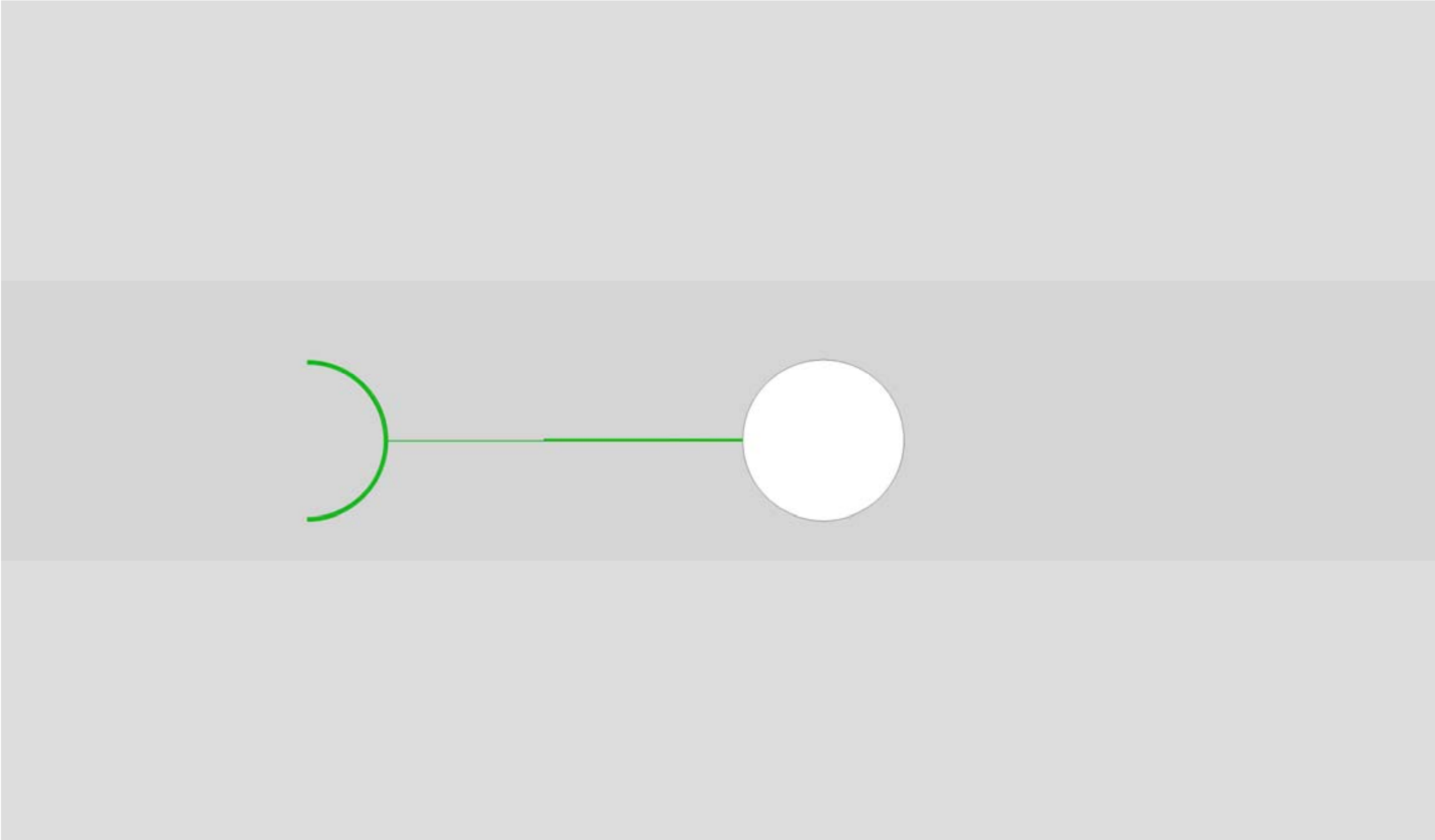
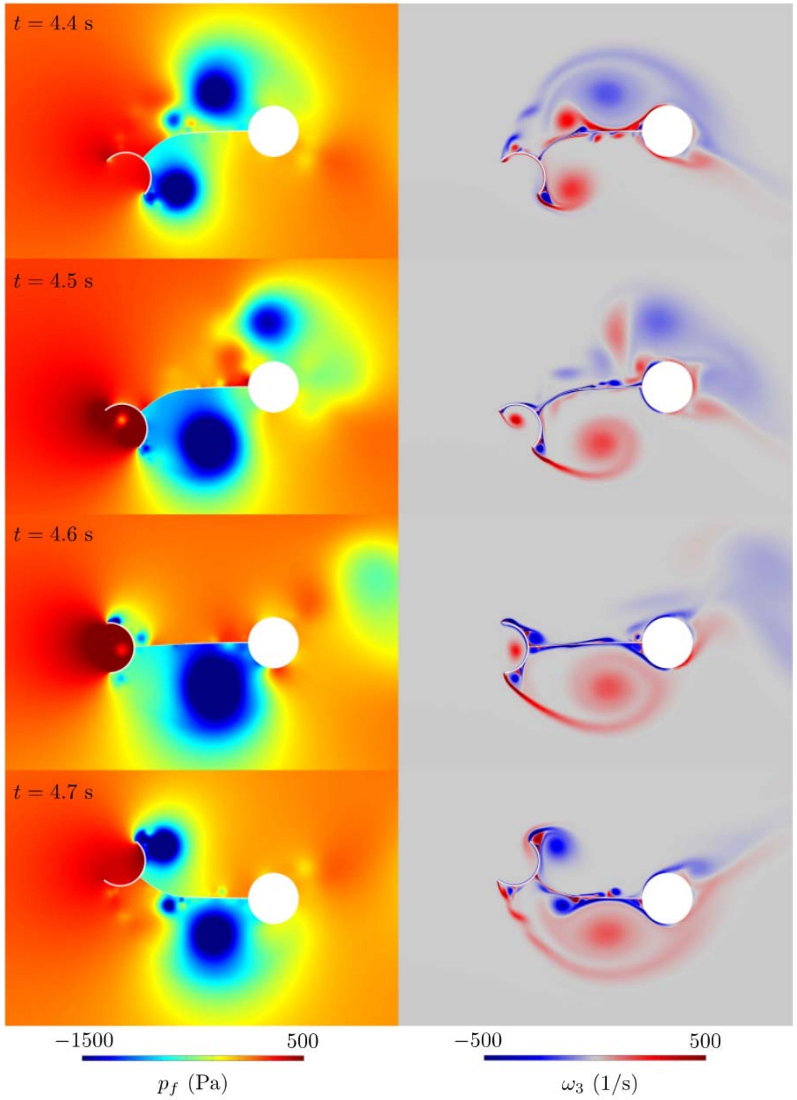
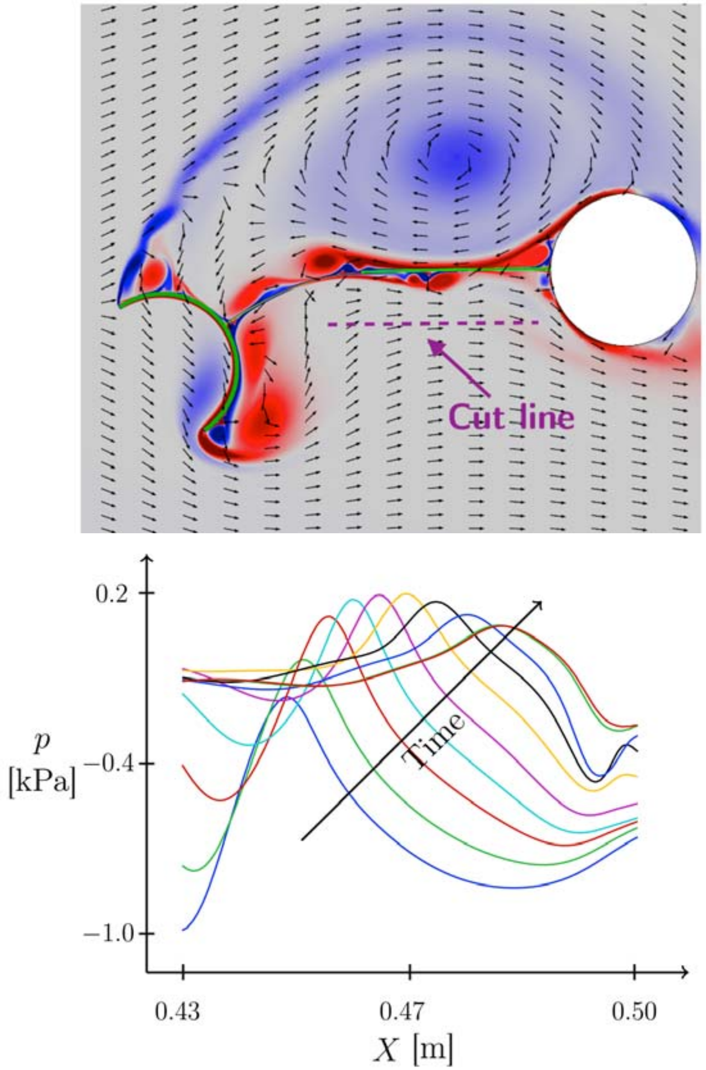
Results of simulations



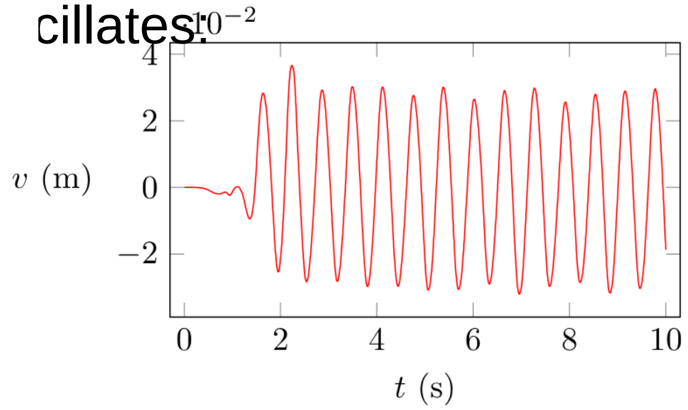
Results of simulations



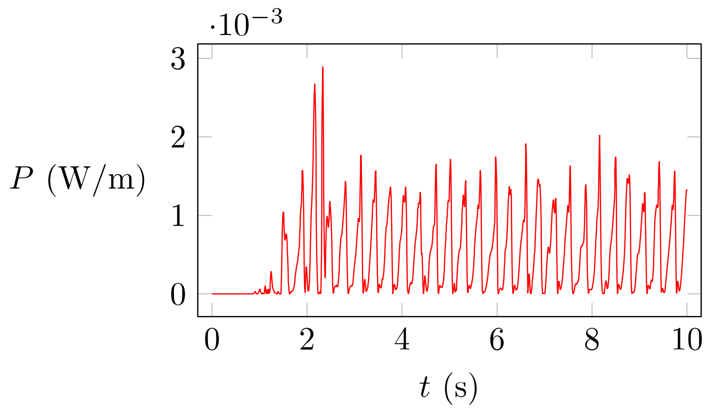


Results of simulations

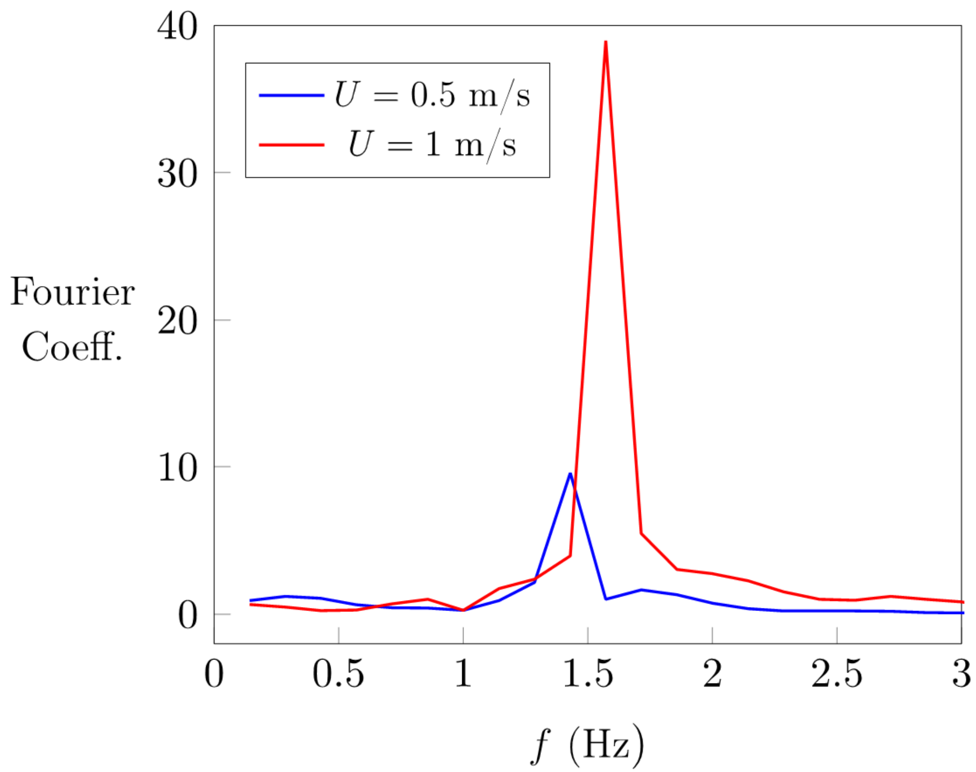
Vertical tip displacement of the solid which periodically cillates:



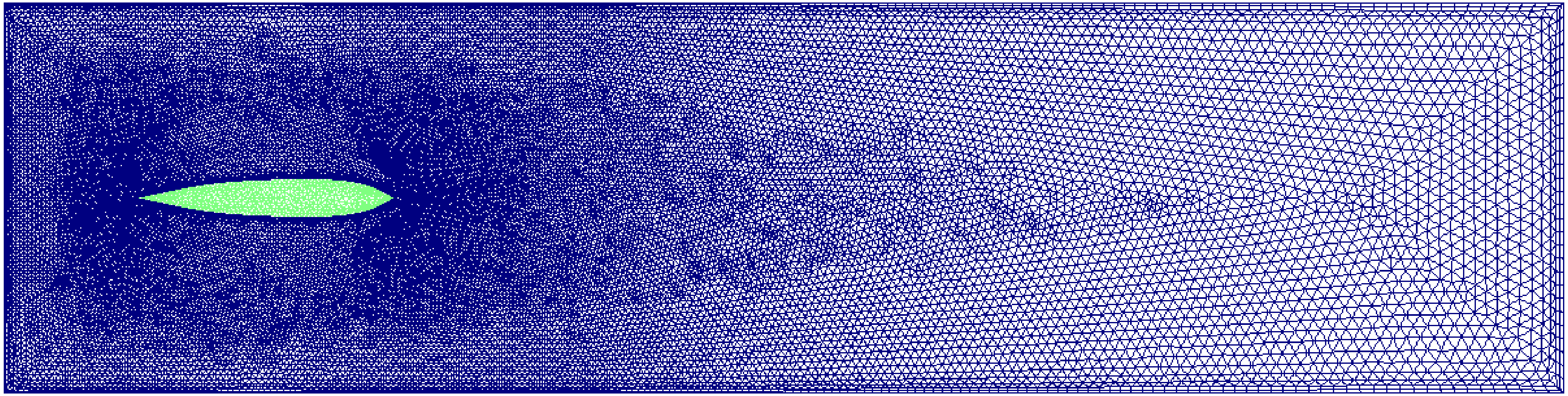
The harvested electrical power is:



Frequency spectrum of the vertical tip displacement at different inlet fluid velocities:



Remeshing



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- M. Curatolo and L. Teresi. Modeling and simulation of fish swimming with active muscles. *Journal of Theoretical Biology*, (2016).
- https://www.comsol.com/blogs/studying-the-swimming-patterns-of-fish-with-simulation/
- Download and play with the model! https://www.comsol.it/community/exchange/501/

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Remeshing

We need both moving mesh to solve the FSI for short time intervals, and re-meshing to track the long swimming path we aim at simulating.