Passive control of fluid-structure instabilities by means of piezo-shunts

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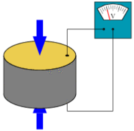
AEROFLEX project

ONERA
THE FRENCH AEROSPACE LAB

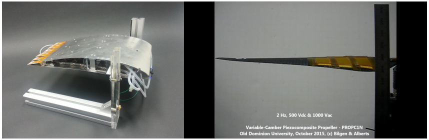
Piezo-electricity : a wide range of applications

> **Piezo-electricity :** *Electric response of certain materials to a mechanical stress due to their microscopic structure*



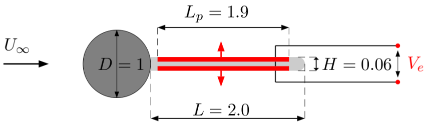
Sensing & Actuation from everyday life . . .

. . . to the **Aerospace Research**

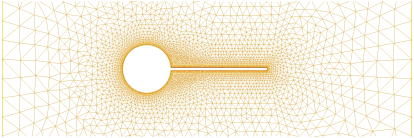


Our Goal : using piezos to control fluid-structure instabilities

2D Model problem



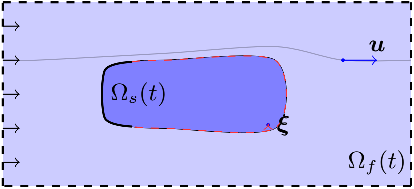
Fluid region



Solid region

- Rigid cylinder + elastic plate + piezo patches.
- $Re = U_\infty D/\nu = 80$, density ratio $m_\rho = 50$ and bending stiffness $K = 0.3$.
- Electro-mechanical coupling only acting for bending modes (*transverse effect + opposite poiling direction*).

Modelling framework



Arbitrary Lagrangian Eulerian approach

- Lagrangian for the solid.
- Eulerian description for the fluid.
- Eqs. in the underformed configuration

- Fully coupled nonlinear fluid-electro-mechanical system in compact form

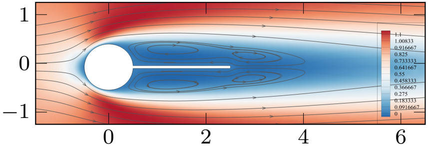
$$\mathcal{B}\frac{\partial \boldsymbol{q}}{\partial t} = \mathcal{R}(\boldsymbol{q}).$$

- **Linearization around a fixed equilibrium solution** $\boldsymbol{q}_B$, i.e. $\mathcal{R}(\boldsymbol{q}_B) = \boldsymbol{0}$, with $\boldsymbol{q}(\boldsymbol{x}, t) = \hat{\boldsymbol{q}}(\boldsymbol{x})e^{\lambda t}$

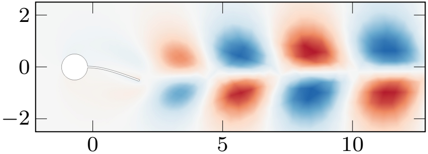
$$\lambda \mathcal{B}\hat{\boldsymbol{q}} = \left.\frac{\partial \mathcal{R}(\boldsymbol{q})}{\partial \boldsymbol{q}}\right|_{\boldsymbol{q}_B} \hat{\boldsymbol{q}},$$

which is a **Generalised Eigenvalue Problem**, for $\lambda = \sigma + \imath\omega \in \mathbb{C}$:

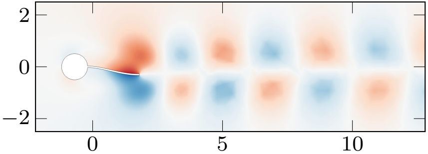
Base flow



No Piezos

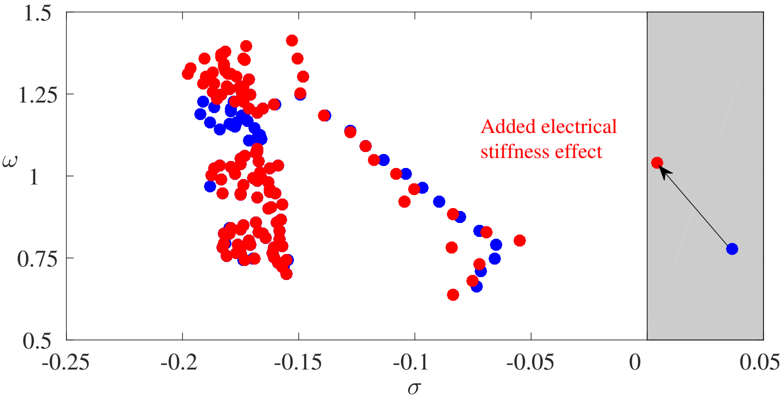


Piezos

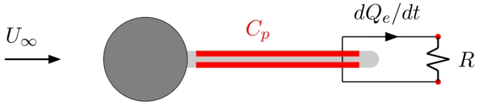


Global spectrum

Without vs With Piezos



Connecting a R-shunt circuit



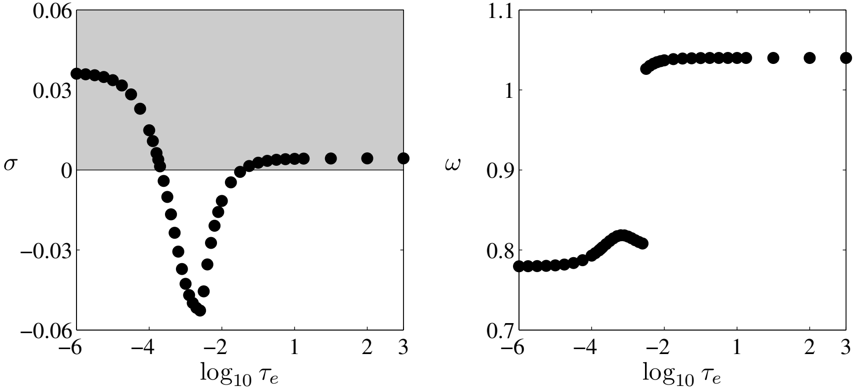
1st order electr. dynamics

$$\frac{dQ_e}{dt} + \frac{1}{RC_p} Q_e = 0,$$

- $\tau_e = RC_p$ is the *characteristic electrical time*.
- **Energy dissipation** by Joule's effect, $P_e = C_p V_e^2 / \tau_e$.
- For $\tau_e \to 0$, **electro-mechanical coupling** becomes **negligible** (short-circuit).
- For $\tau_e \to \infty$, **electro-mechanical coupling** becomes **maximal** (open-circuit).

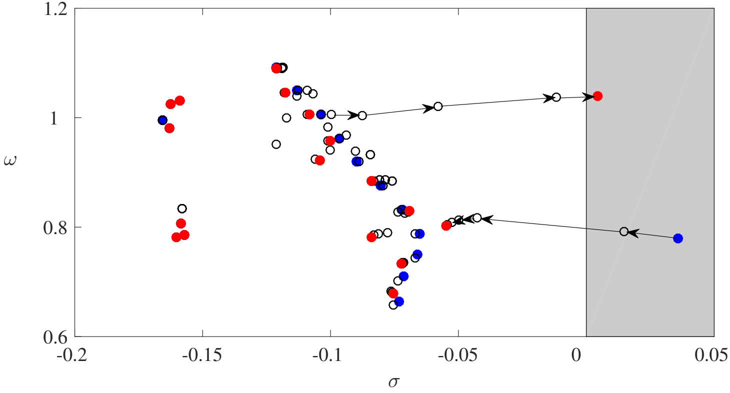
Varying the electrical resistance

Leading eigenvalue

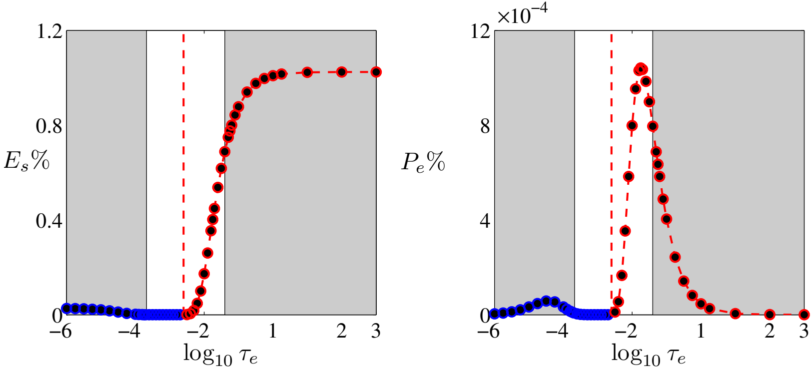


Varying the electrical resistance (continued)

Increasing τ_e



Leading mode



Conclusions

A *conjecture* on two possible distinct **stabilization mechanisms** :

- **Frequency desynchronization** by means of the added electric stiffness (*original flutter mode*).
- **Electrical damping** through Joule effect (*new selected flutter mode*).

Thanks for your attention.

(Any Questions?)