Fluid-structure interaction modeling for wind energy harvesting in a Venturi tube

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Wind Actuated TENG (WATENG)

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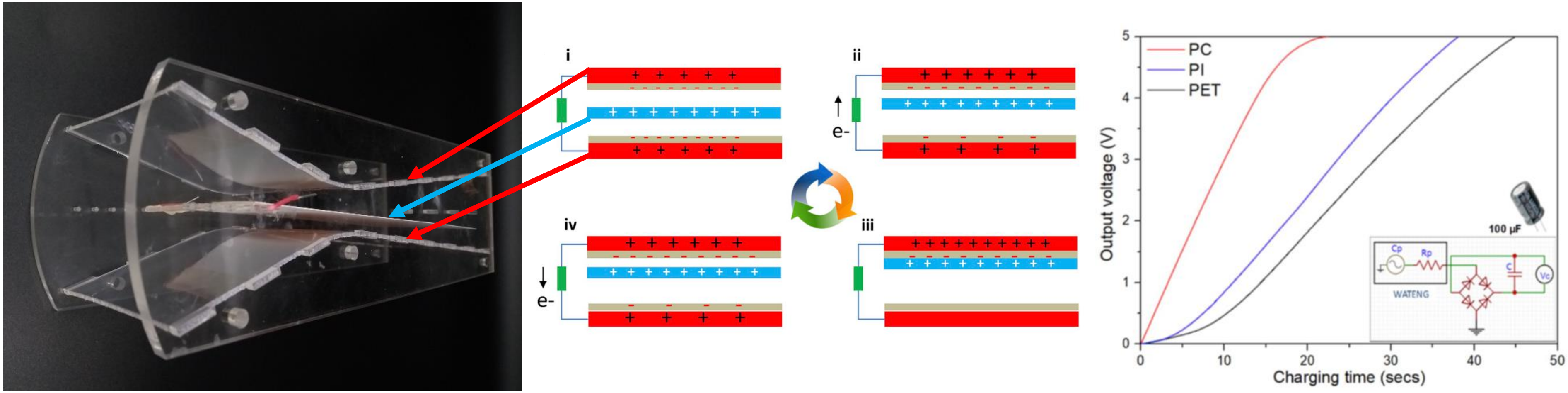
Triboelectric Nanogenerator (TENG)



The Venturi tube forces the oscillation of the flag.

Figure 1 : WATENG working principle and 100 µF capacitor charging performance across a full wave rectifier [1].

[1] A. N. Ravichandran *et al.*, *Nano Energy*, vol. 62, pp. 449–457, 2019

Wind Actuated TENG (WATENG)

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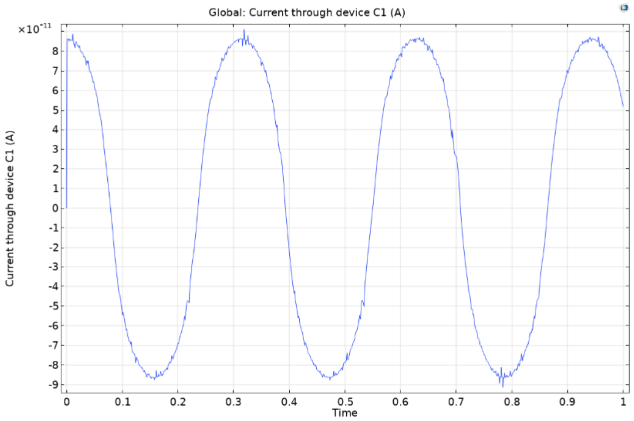
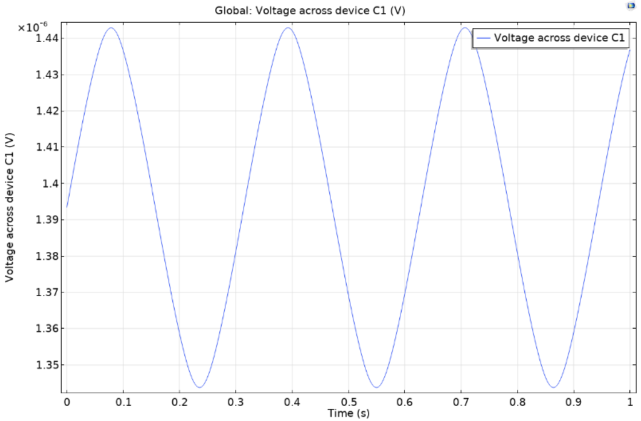
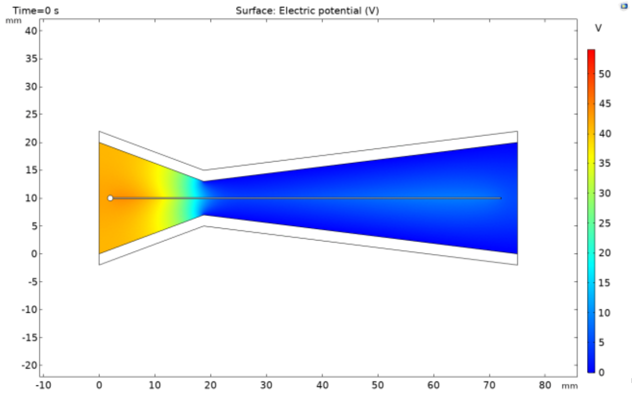
Physics :

- Solid Mechanics
- Electrostatics
- Electrical Circuit



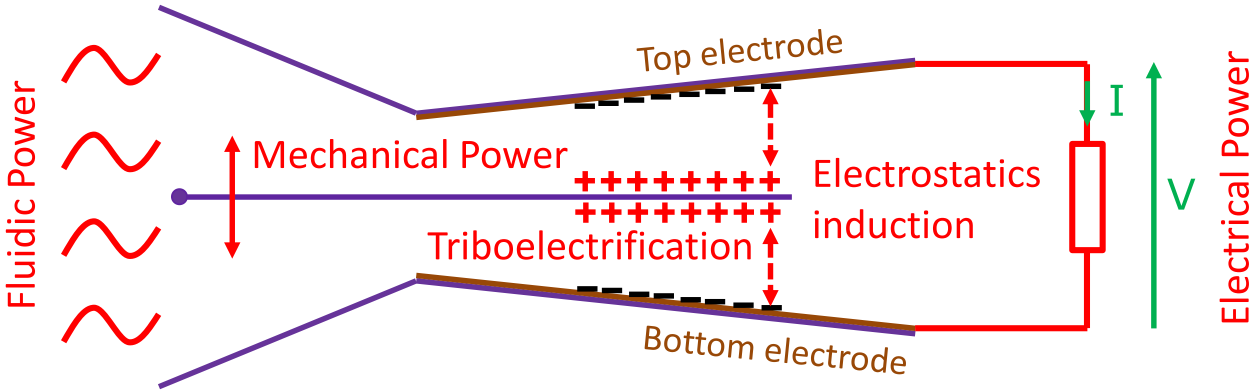


- 10E-9 C.m^{-2} surface charge density on the flag provided by triboelectrification.
- 100 µF capacitor between both electrodes.



Our objective

To maximize the efficiency in the transduction between fluidic and electrical power.



- Air flow (Fluid) / Flag (Mechanical structure)
- Flag (Mechanical structure) / Charged flag (Triboelectrification)
- Charged flag (Triboelectrification) / Electrodes (Electrical flow)
- Electrodes (Electrical flow) / Load (Electrical circuit)

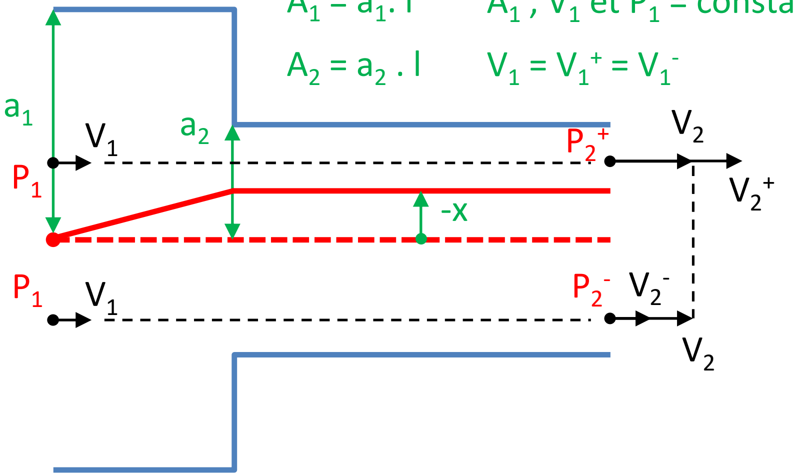
How can we convert fluid power into oscillating mechanical power ?

An air flow across a Venturi tube.

The suction effect

$A_1 = a_1 . l$ $\quad$ A_1, V_1 et P_1 = constant

$A_2 = a_2 . l$ $\quad$ $V_1 = V_1^+ = V_1^-$



$P_2^+ \ll P_2^-$

$V_2^+ \gg V_2^-$

I. A light unbalance from the center position of the flag initiates the suction effect.

II. The closest is the flag to the wall, the highest is the depression.

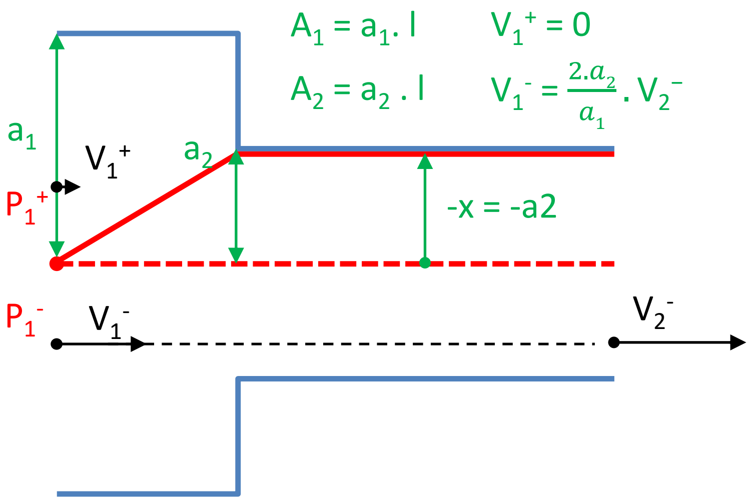
III. The flag speeds up to the wall until it reaches it.

A Steady state and an incompressible flow.

Flow conservation, $A_1 . V_1 = A_2 . V_2$

Bernoulli's equation, $\frac{P_2}{\rho} + g.z + \frac{1}{2} . V_2 = \frac{P_1}{\rho} + g.z + \frac{1}{2} . V_1$

The overpressure effect



P1+ >> P1-

I. The flag locks the air flow.

II. The pressure in the convergent section increases until the flag goes down under the resulting force.

III. When the flag exceeds the center position, it is attracted by the wall.

A Steady state and an incompressible flow.

Flow conservation, $A_1 . V_1 = A_2 . V_2$

Bernoulli's equation, $\frac{P_2}{\rho} + g.z + \frac{1}{2} . V_2 = \frac{P_1}{\rho} + g.z + \frac{1}{2} . V_1$

The theory explains the oscillating mechanical movement observed in practice.

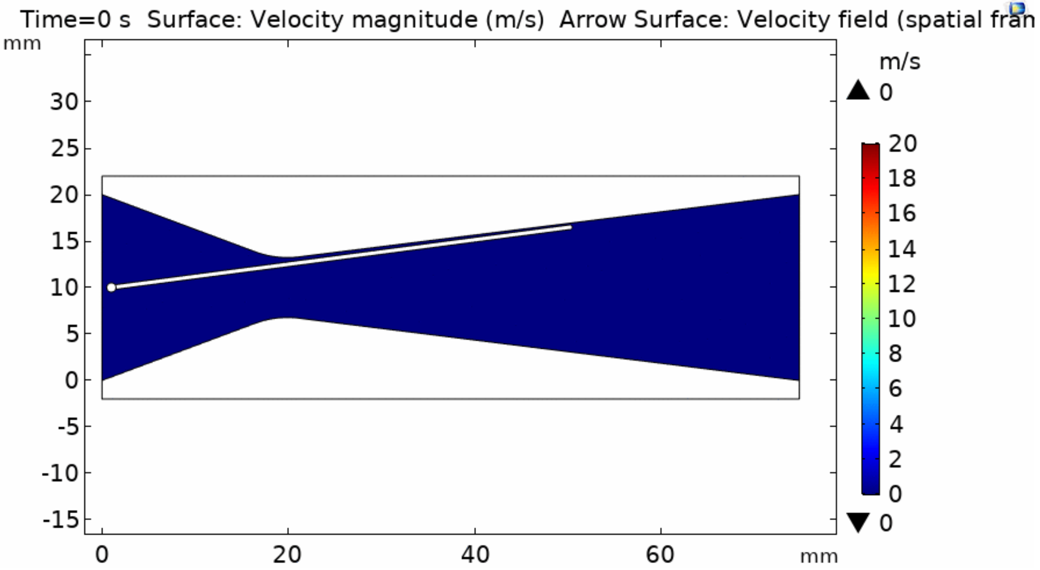
Can we model this behavior under COMSOL Multiphysics® ?

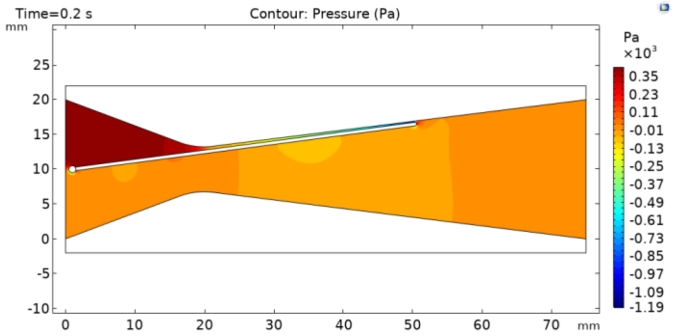
FSI simulations

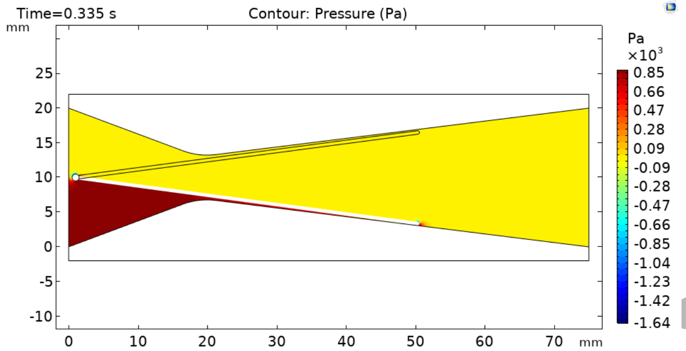
Fluid:
- Inlet velocity at steady state = 2 $m.s^{-1}$
- Density = 1.204 $kg.m^{-3}$
- Dynamic viscosity = 1.85E-5 Pa.s

Flag:
- Rigid domain
- Mass = 0.04 kg

Physics:
- Laminar Flow
- Solid Mechanics

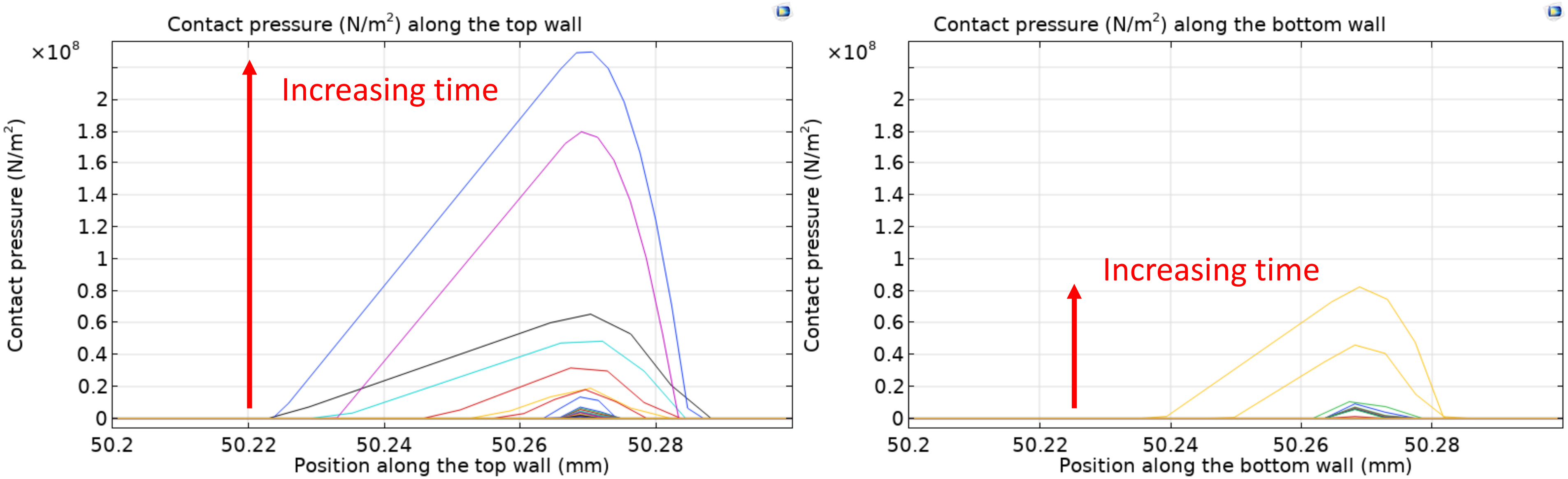






Can we estimate the flag contact pressure on the wall ?

FSI simulations



Conclusion

FSI simulations:

- ✓ Reproduction of an oscillating movement of the flag on COMSOL Multiphysics®.
- ✓ Evaluation of the flag contact pressure on the wall.

- ➢ Implementation of a turbulent model is being under study.
- ➢ Planning an experiment with a rigid flag into a WATENG in order to confirm our simulations results.

Electrostatics simulations:

- ✓ Evaluation of the available energy after triboelectrification.

- ➢ Coupling with the results of the FSI simulations.
- ➢ Extraction a SPICE model of the WATENG electrical output.

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Thank you

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