Benchmark on the numerical simulation of a tube bundle vibration under cross flow

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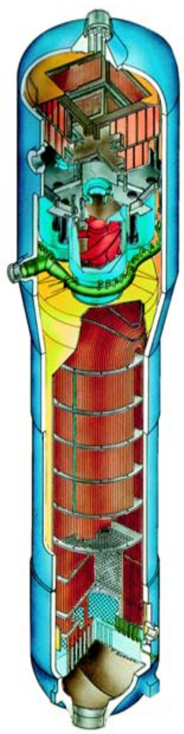
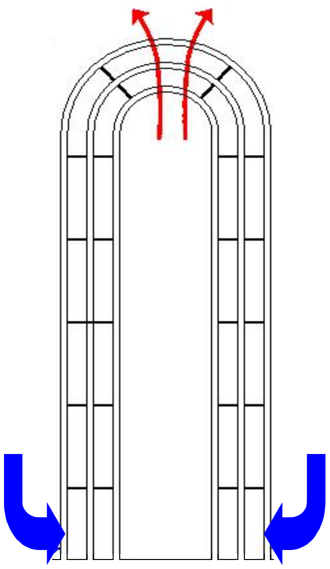
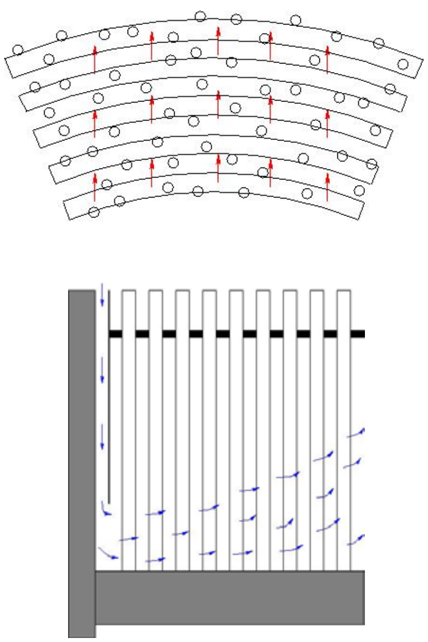
INTRODUCTION

CREATIF Program :

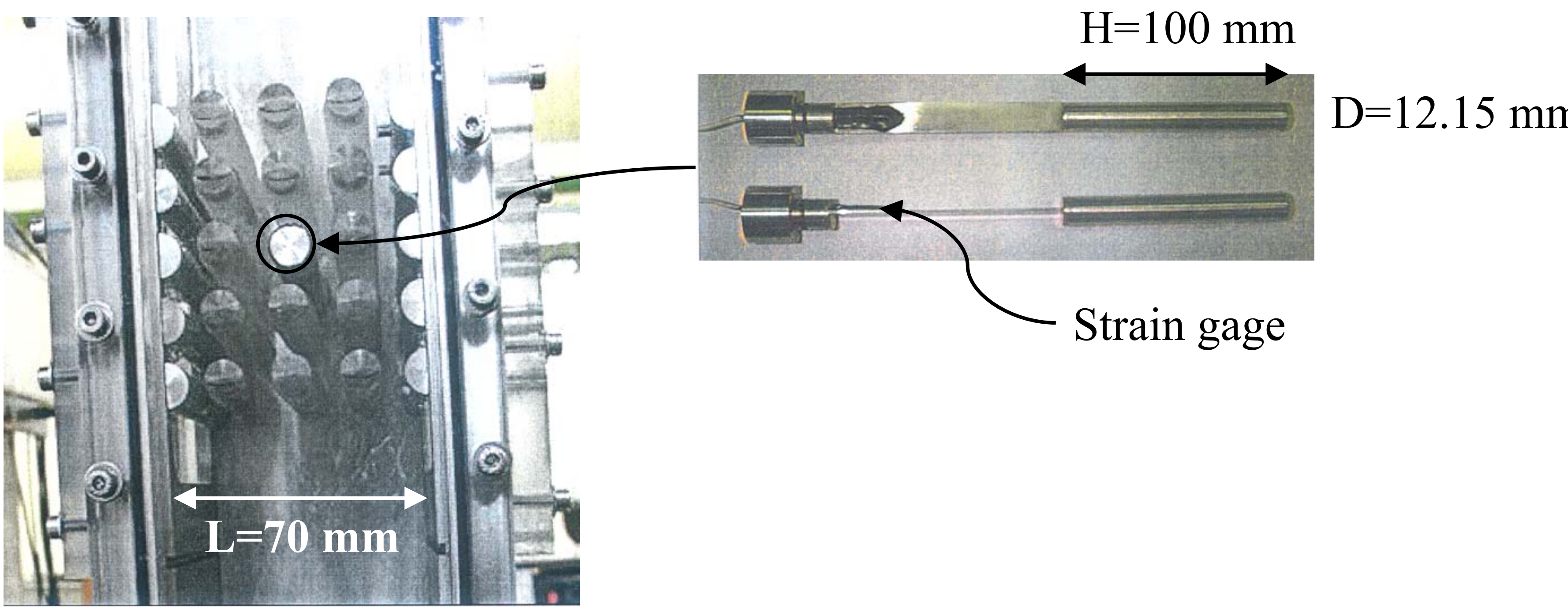
Comprehension of the vibratory Response of an Array of Tubes in Interaction with a Fluid.







Experiment AMOVI (CEA)



- 24 fixed tubes (Plexiglas, f>300Hz)
- 1 moving tube (steel, f=14.3Hz)
- P/D = 1.44
- Single phase flow (flow rate from 0 to 5 $m^3.h^{-1}$)

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CONTENTS

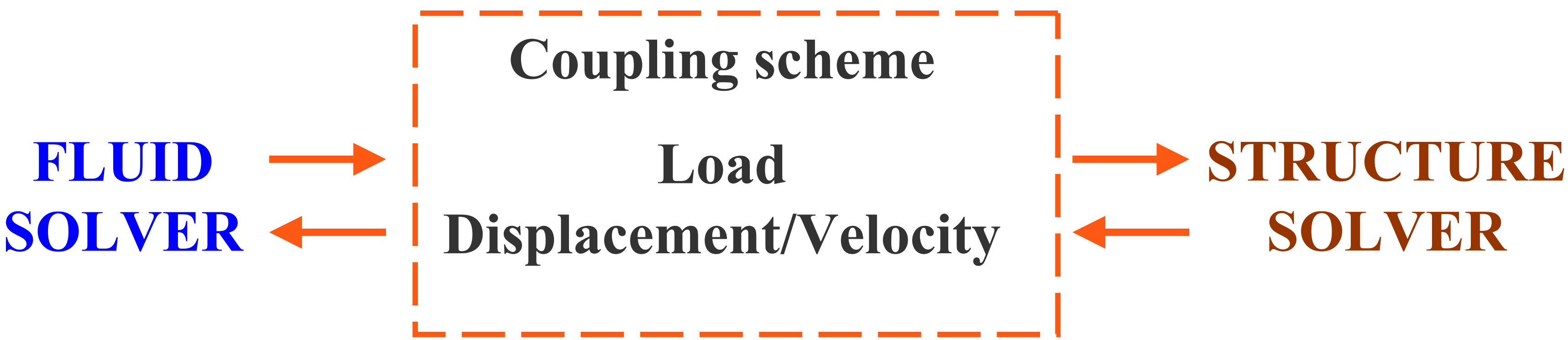
1

Methodology

Boundary conditions at fluid-structure interface

$$\begin{cases} \vec{u}_s = \vec{u}_f \\ \overline{\overline{\sigma}}_s \cdot \vec{n} = \overline{\overline{\sigma}}_f \cdot \vec{n} \end{cases}$$

Partitioned coupling



Structure solver (rigid body)

- 1 degree of freedom oscillator for EDF tool
- Finite element method with Lagrangian formulation for CEA tool

Fluid solver

- Finite volume method with Eulerian formulation (EDF tool)
- Finite element method with Eulerian formulation (CEA tool)

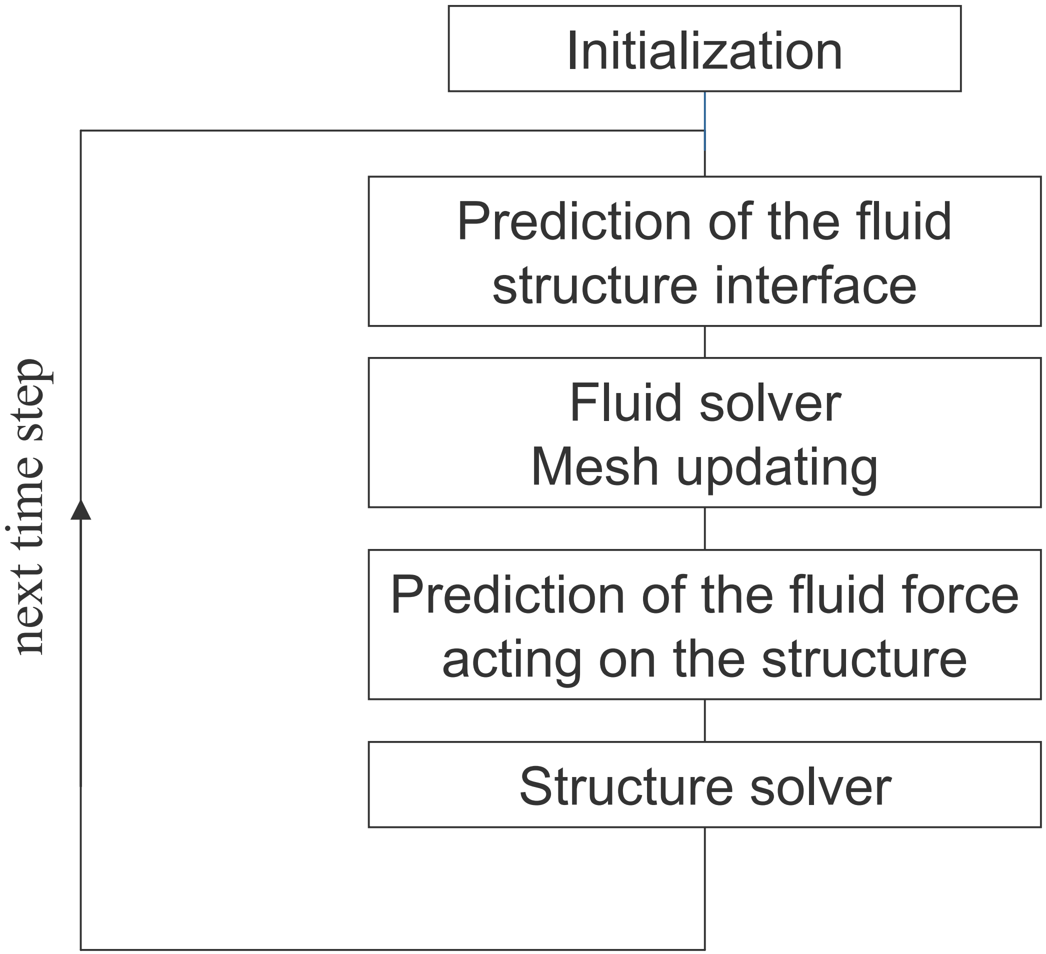
⇒ Use of an ALE technique to follow the structure interface (both cases)

Partitioned procedure

- Fluid solver needs structure data at time t^{n+1}
- Structure solver needs fluid data at time t^{n+1}

⇒ Prediction : the position of the structure interface at time t^{n+1}

1.3 Improved serial staggered procedure



$$X_{fluid}^{pred,n+1} = X_{structure}^{n} + \frac{\Delta t}{2} V_{structure}^{n}$$

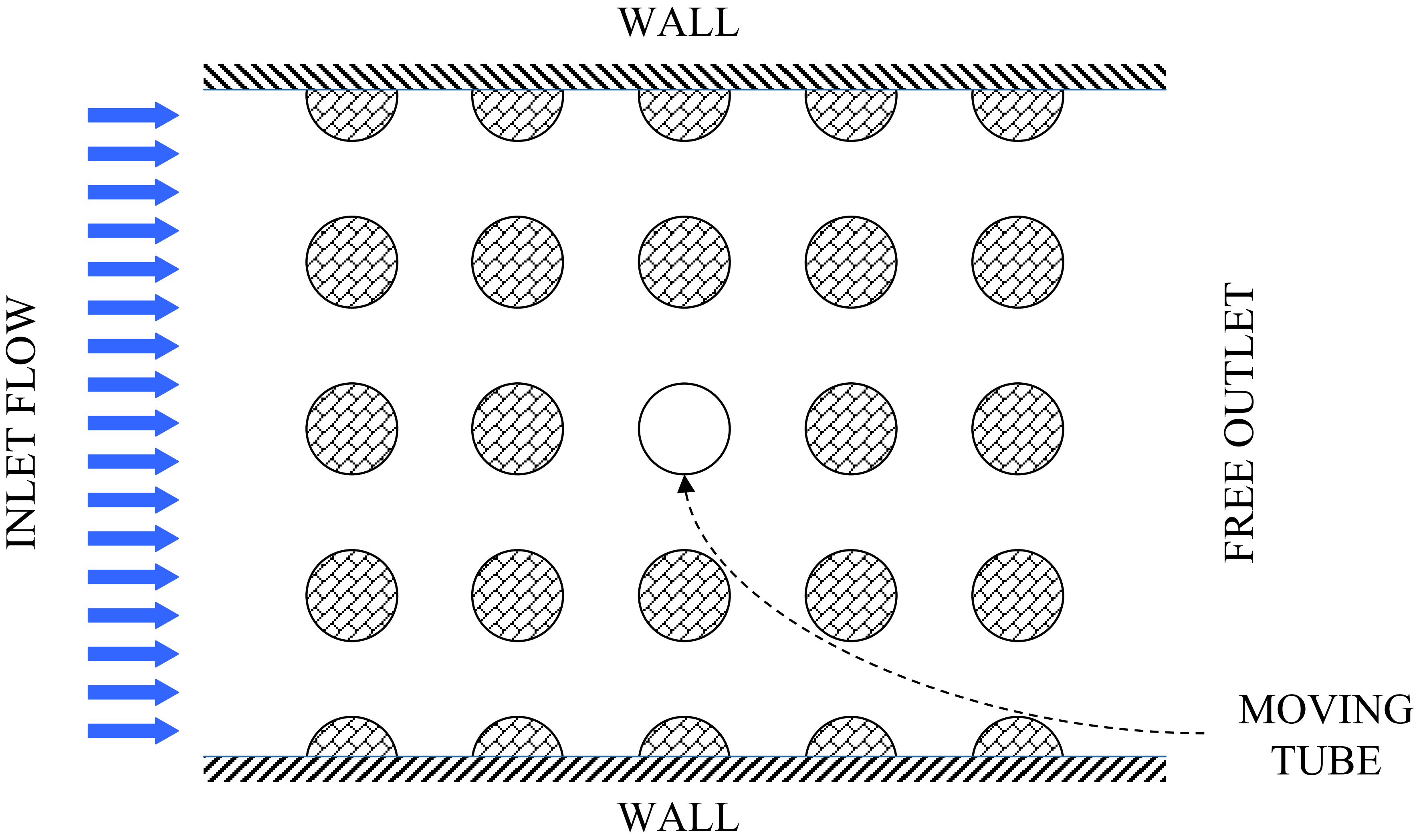
$$F_{structure}^{pred,n+1} = 2F_{fluid} - F_{structure}^{pred,n}$$

(Piperno et al. ,2001)

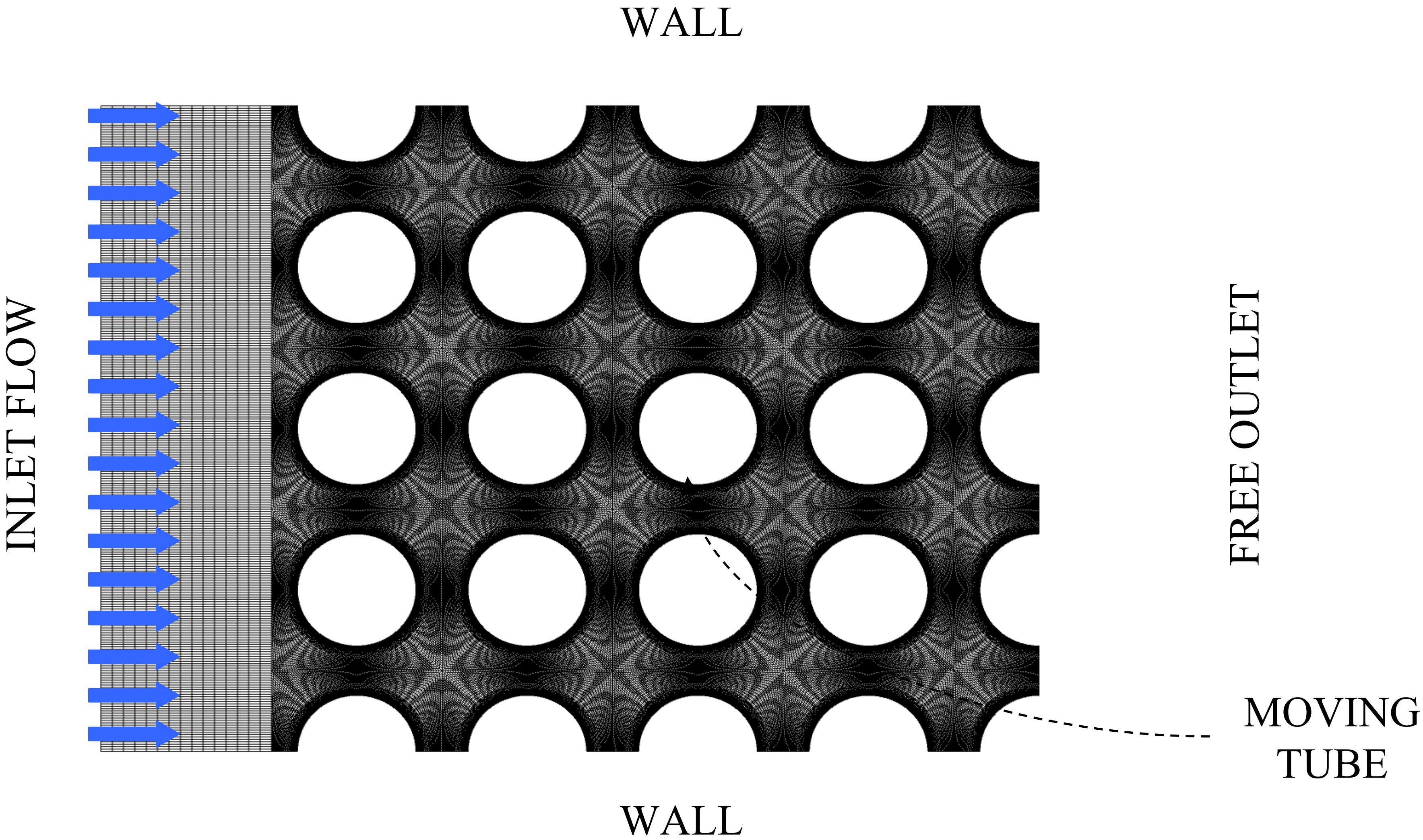
2

Real case (2D model)

2.1 Geometry (experiment AMOVI, CEA)



2.1 Geometry (experiment AMOVI, CEA)



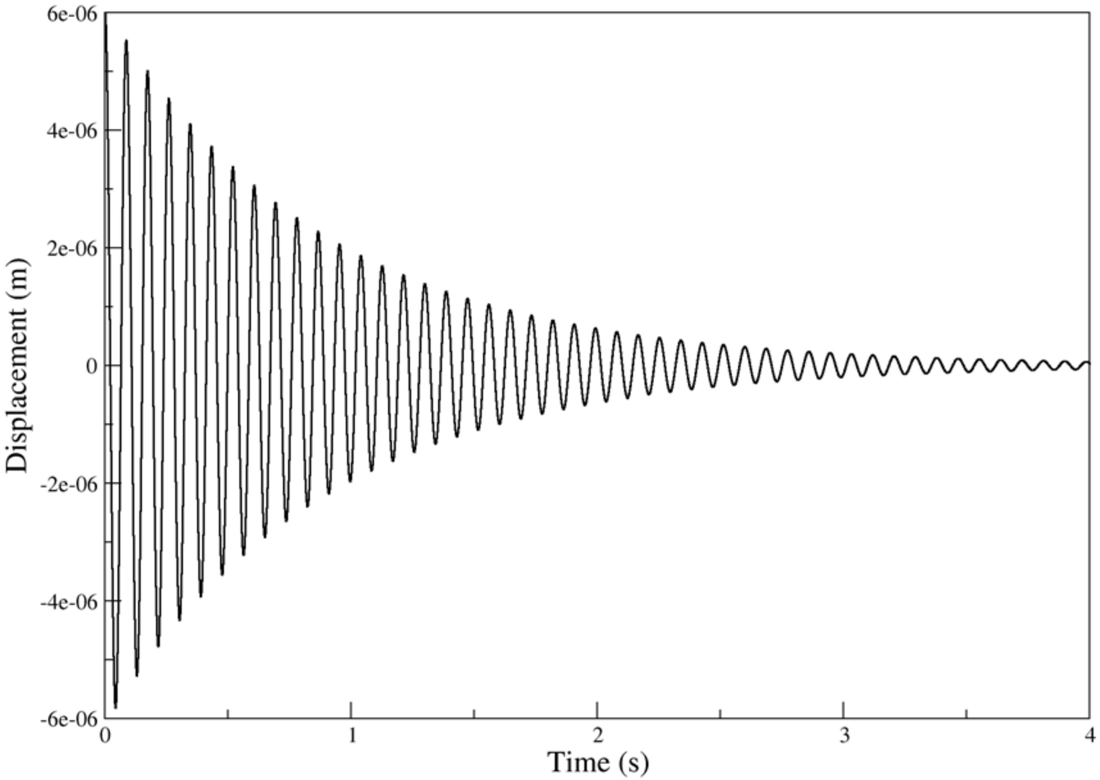
2.2 Parameters

Structure properties		
Natural frequency	(Hz)	14.3
Natural damping	(%)	0.25
Mass	($kg.m^{-1}$)	0.298
Diameter	(mm)	12.15

Fluid properties		
Density	($kg.m^{-3}$)	10^{3}
Dynamic viscosity	($kg.m^{-1}.s^{-1}$)	10^{-3}

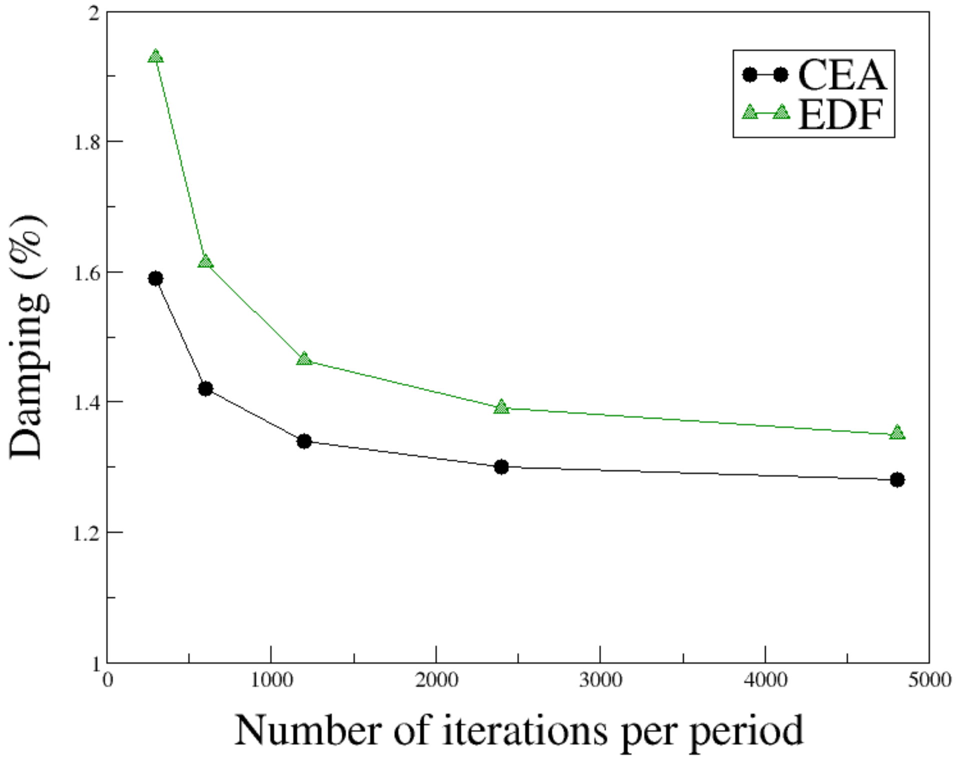
P/D	(-)	1.44
Inlet velocity	($m.s^{-1}$)	[0.03 ; 0.15]
Reduced velocity	(-)	[0.5 ; 2.8]
Reynolds number	(-)	[1200;6000]

2.3 Quiescent fluid : water frequency



	CEA	EDF	Analytical
Water frequency (Hz)	11.63	11.55	11.8

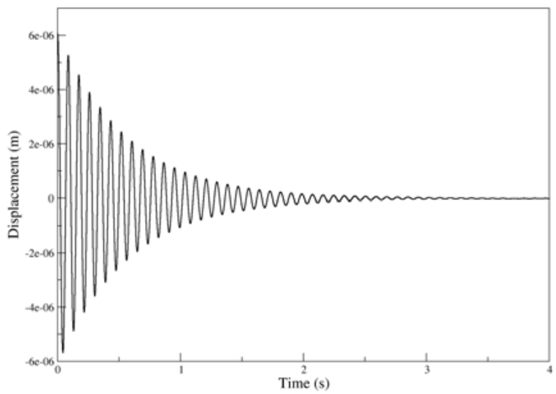
2.4 Quiescent fluid : water damping



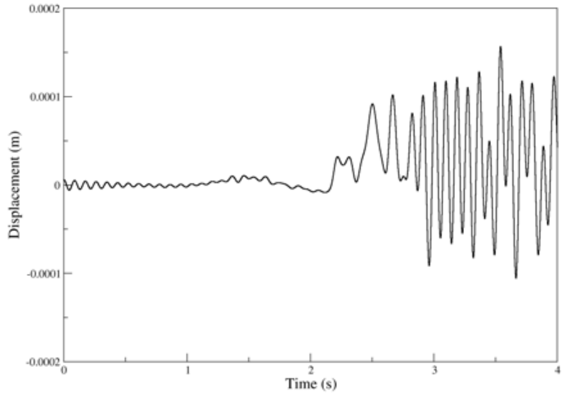
extrapolation	CEA	EDF	Analytical
Water damping (%)	1.216	1.215	1.18

2.5 Vibration under cross-flow

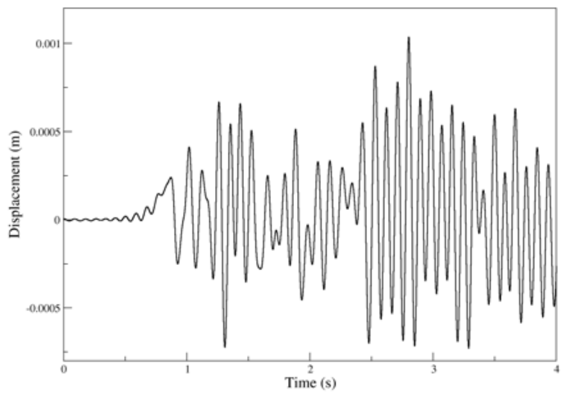
METHODOLOGY | REAL CASE (2D MODEL) | NUMERICAL CASE (2D MODEL) | REAL CASE (3D MODEL)



Re = 1200



Re = 3000



Re = 4800

- Numerical problem ?
- Physical problem ?

3

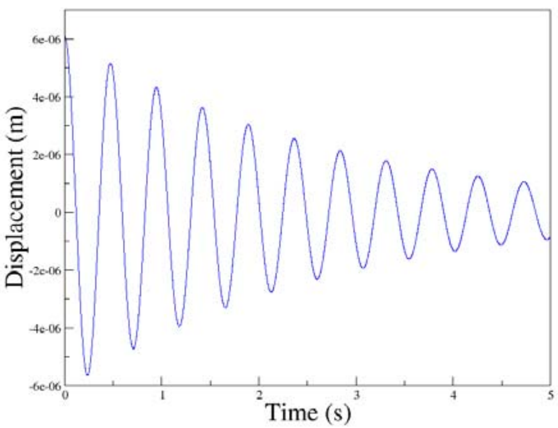
Numerical case (2D model)

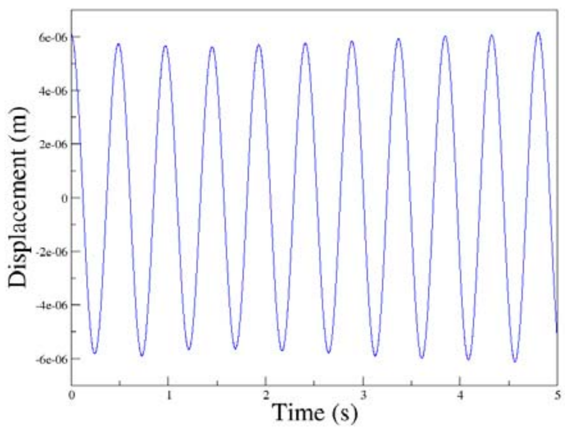
3.1 Parameters

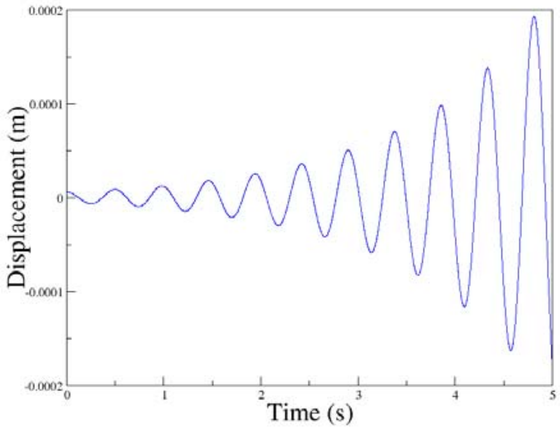
Structure properties		
Natural frequency	(Hz)	2.5
Natural damping	(%)	0.0437
Mass	(kg)	0.298
Diameter	(mm)	10.00

Fluid properties		
Density	($kg.m^{-3}$)	10^3
Dynamic viscosity	($kg.m^{-1}.s^{-1}$)	10^{-3}

P/D	(-)	1.44
Inlet velocity	($m.s^{-1}$)	[0.001 ; 0.035]
Reduced velocity	(-)	[0.1 ; 4.5]
Reynolds number	(-)	[30 ; 1200]







$$v_{inlet} = 0.001 \text{ m.s}^{-1}$$
$$v_{red} = 0.13 \, (-)$$

$$v_{inlet} = 0.02 \text{ m.s}^{-1}$$
$$v_{red} = 2.62 \, (-)$$

$$v_{inlet} = 0.03 \text{ m.s}^{-1}$$
$$v_{red} = 3.93 \, (-)$$

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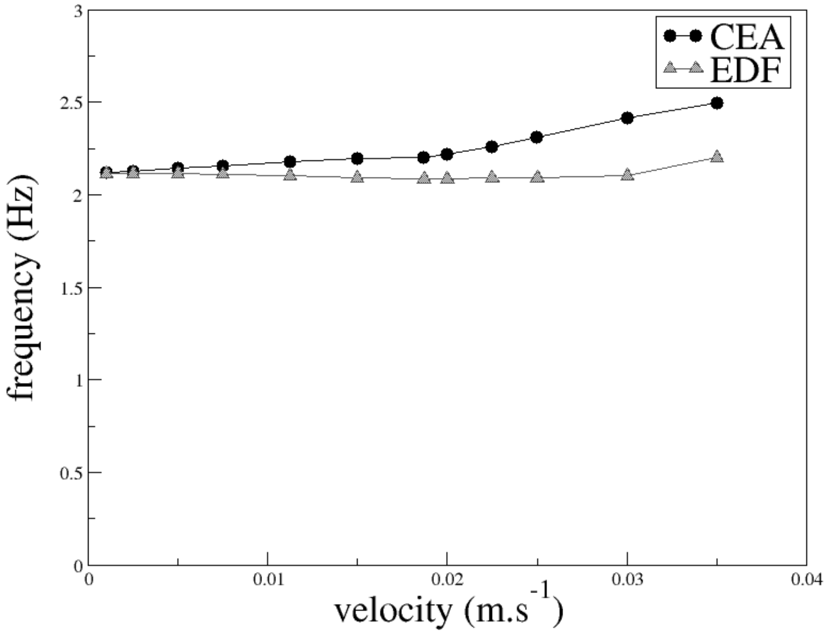
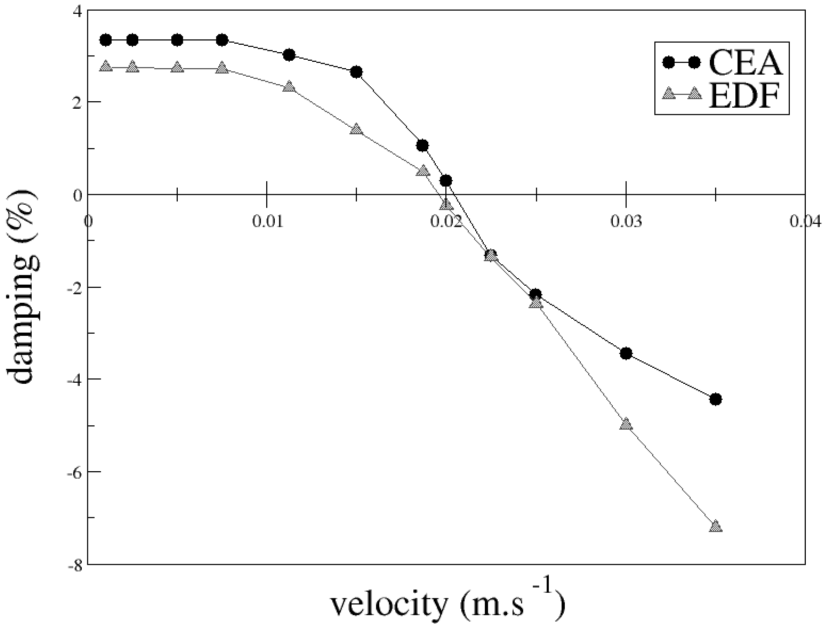
3.3 Frequency and damping

METHODOLOGY | REAL CASE (2D MODEL) | NUMERICAL CASE (2D MODEL) | REAL CASE (3D MODEL)





4

Real case (3D model)

cea
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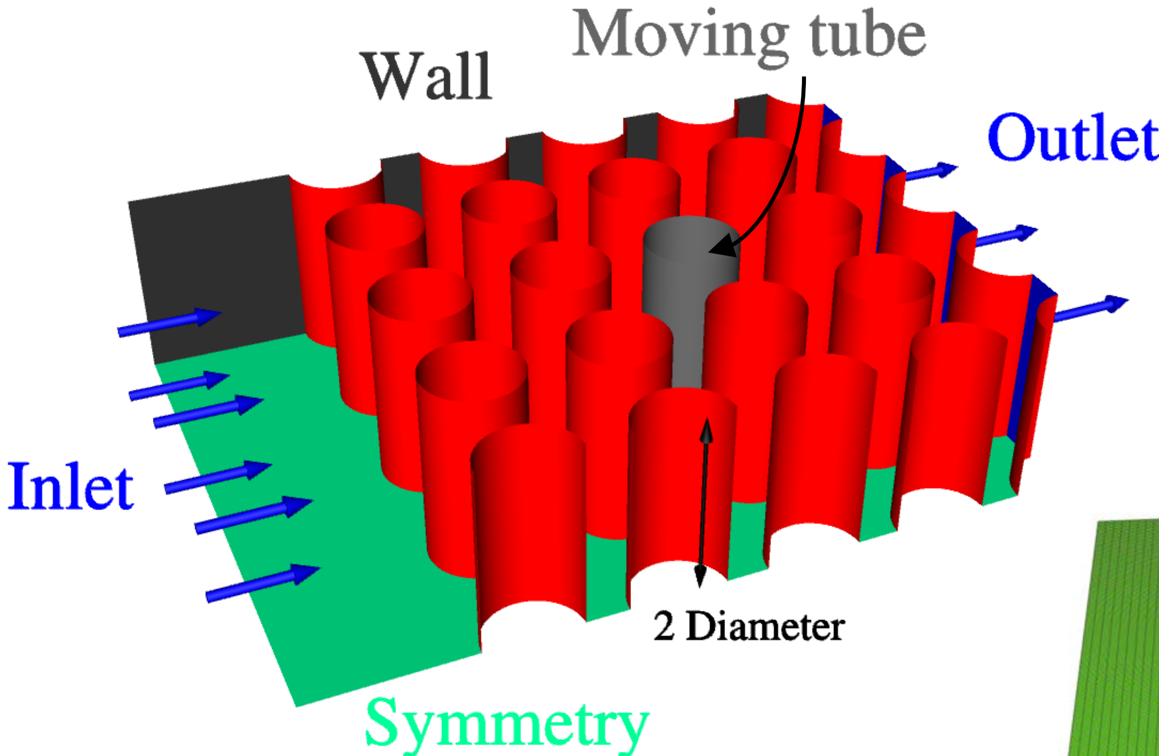
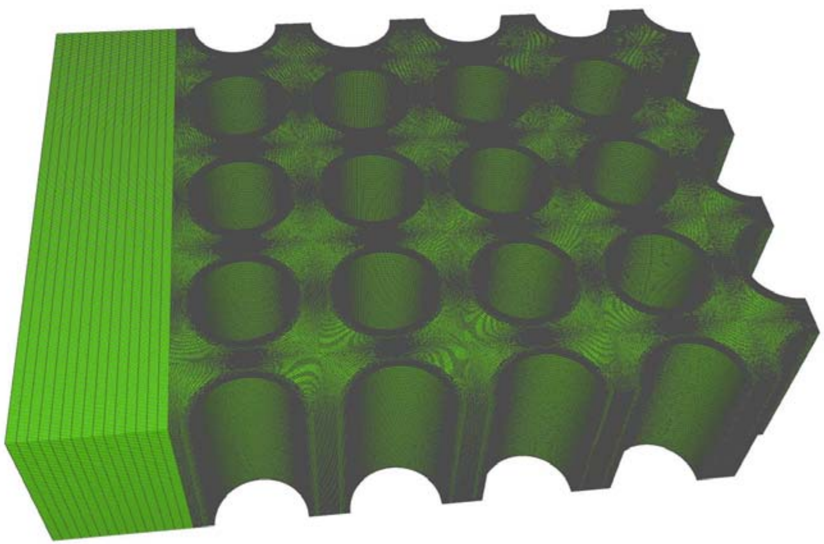
eDF R&D

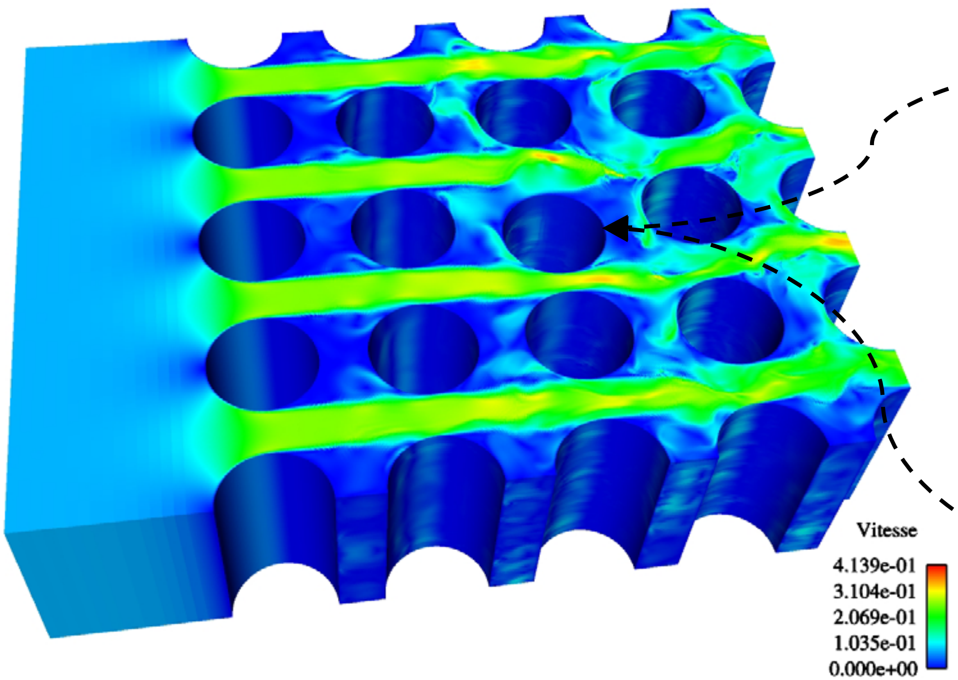
4.1 Geometry

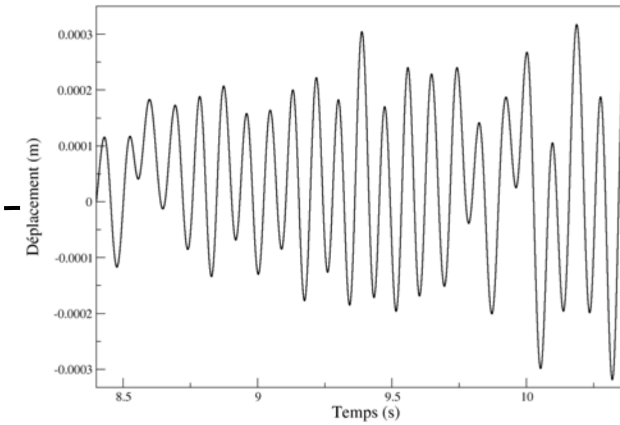


- 7.5 Millions of elements
- 2048 processors

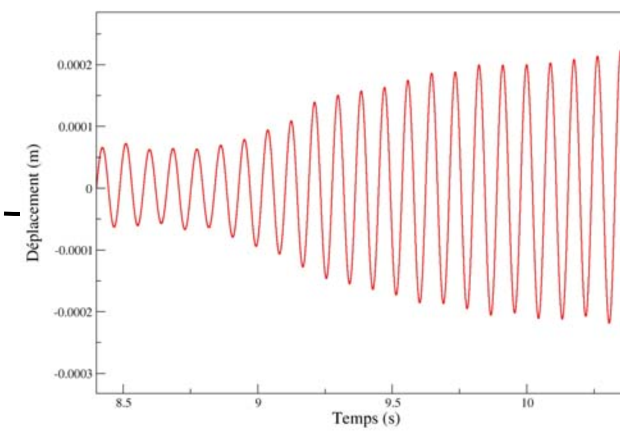


Reynolds = 3000 and DNS



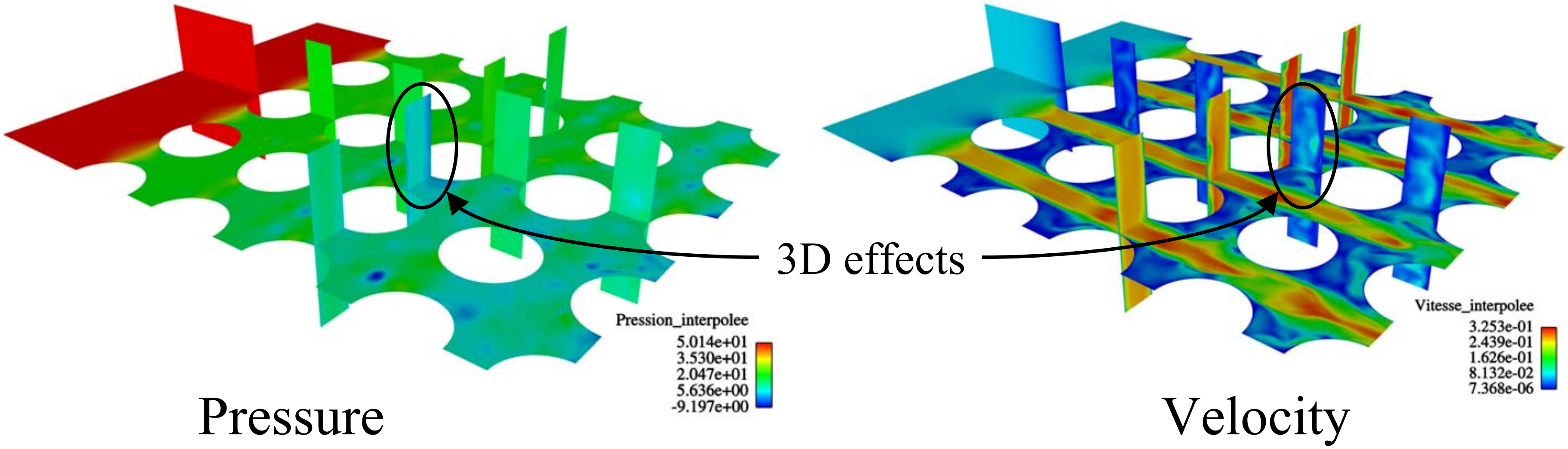


Displacement with 2D simulation



Displacement with 3D simulation

4.3 3D effect


3D effects
Pression_interpolee
5.014e+01
3.530e+01
2.047e+01
5.636e+00
-9.197e+00
Pressure
Vitesse_interpolee
3.253e-01
2.439e-01
1.626e-01
8.132e-02
7.368e-06
Velocity

CONCLUSION

- ✓ Catch the 3 behaviors of the structure
- ✓ Used of an extrapolation method for the damping
- ✓ Over-estimation of force fluid with 2D simulation (3D simulation is required)

- ➢ 3D simulation for numerical case
- ➢ 3D simulation with turbulent model for real case
- ➢ Comparison of the real case to the experiment AMOVI (CEA)