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Simulation of the AMOVI experiment on flow-induced vibrations with a Rigid Body FSI approach

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Outline

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- Motivation
- AMOVI experimental facility
- CAD modelling and mesh generation
- FSI: Rigid body solution method
- First numerical analysis
- Summery and further steps

Motivation

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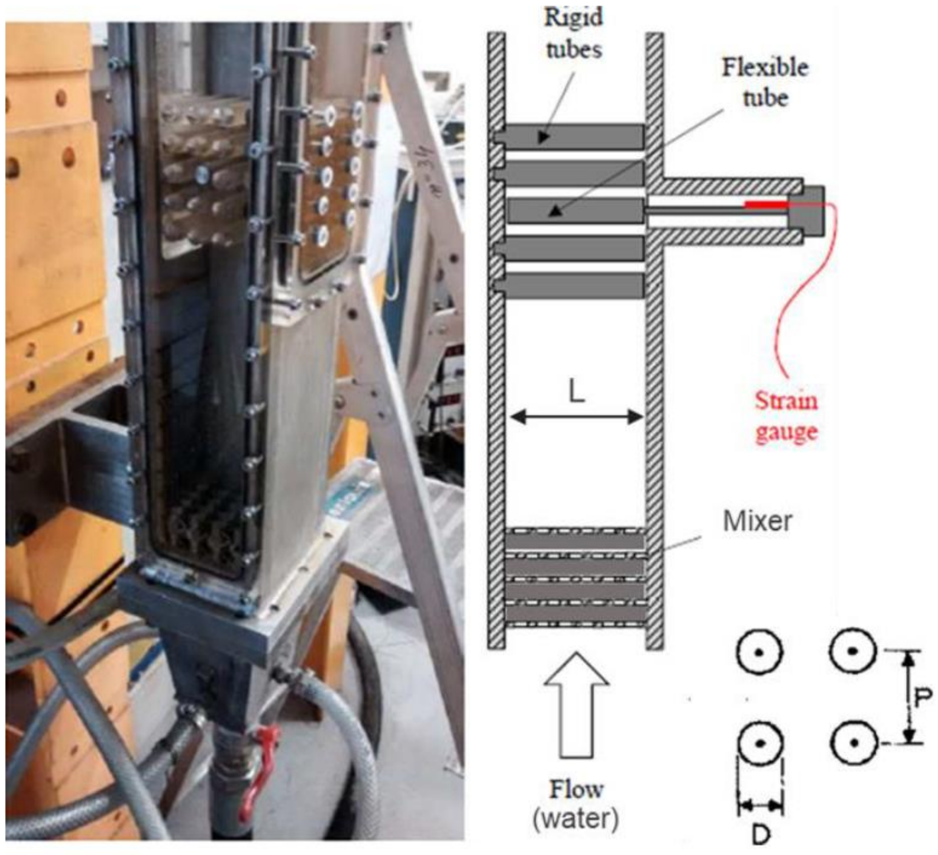
- The interaction between fluid and solid structures (rods, tubes) in nuclear power plants may lead to flow-induced vibrations (FIV), causing material fatigue, wear, and eventually component damage.
- Within the GO-VIKING project ("**G**athering expertise **O**n **V**ibration **I**mpa**K**t **I**n **N**uclear power **G**eneration"), the experimental and numerical investigation are performed to improve the understanding of FIV in reactor cores and steam generators (SG).
- The objective of WP3 is to develop, implement, and validate different FSI methods for the analysis of FIV in SG geometries.
- CEA provided experimental data on the vibration of a flexible tube in a channel and in a tube bundle, both configurations being exposed to single phase cross-flow.

AMOVI experiment

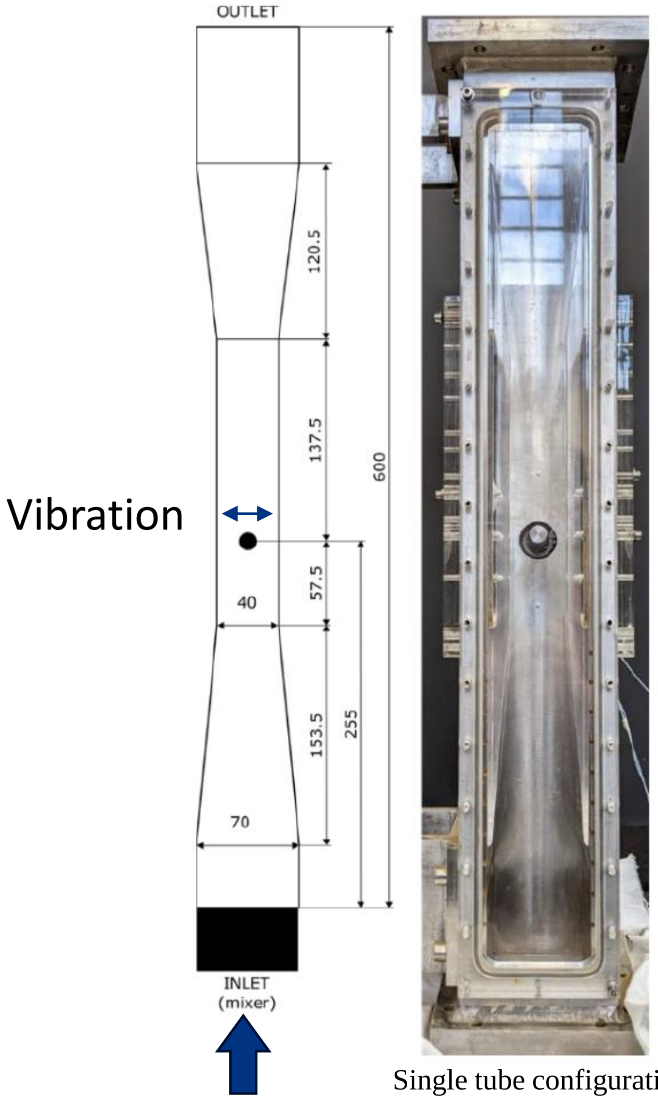
- Small hydraulic loop built at CEA (France)
- Study of FIV in a square tube bundle at low Reynolds numbers
- Test section dimensions: 70 x 100 x 600 (width x depth x height) mm3.
- Bundle parameters:
  - 3x5 tubes
  - 12.15 mm tube diameter
  - 100 mm tube length
  - P/D of 1.44
- Fluid flow characteristics are measured using a PIV setup. A high-speed camera is used to capture the flow around tubes in a 2D central plane within the test section.



View of the AMOVI test section (full bundle configuration) [1]

Single flexible tube configuration of the AMOVI test bench

- The displacement at the tip of the tube is deduced from a strain gauge instrumenting the root of the flexible blade, assuming that the first vibration mode is predominant.

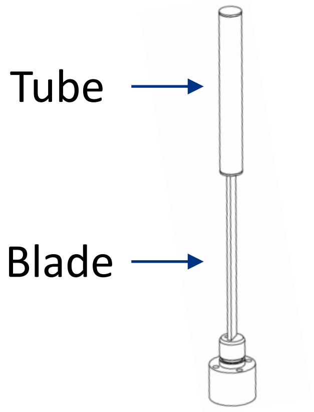


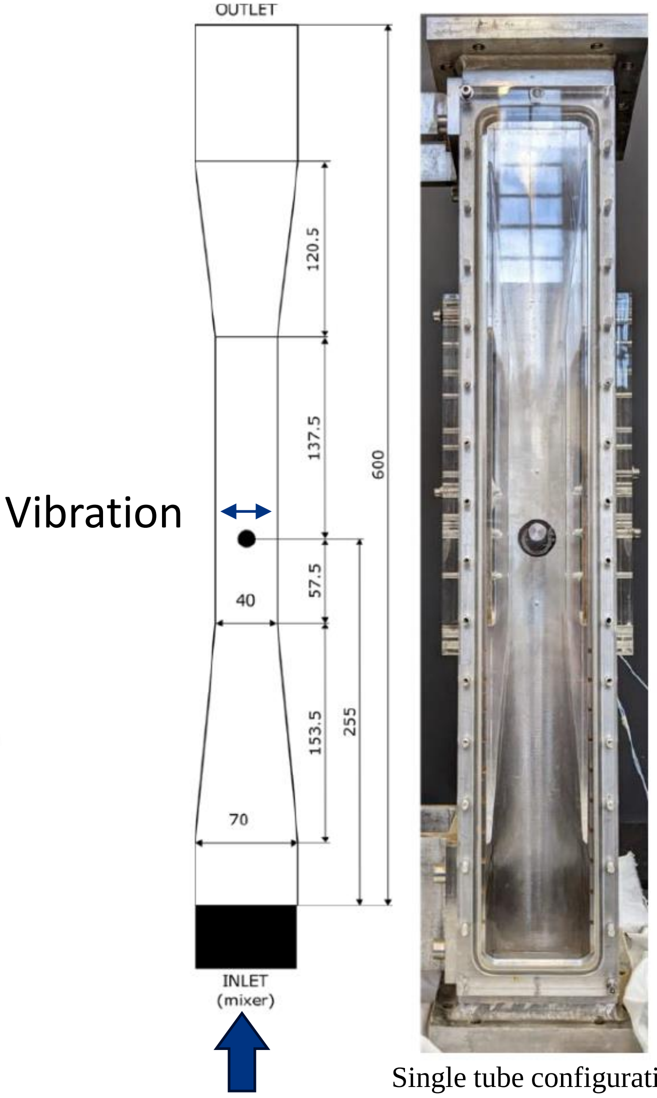
Single tube configuration [1]

Single flexible tube configuration of the AMOVI test bench

- The displacement at the tip of the tube is deduced from a strain gauge instrumenting the root of the flexible blade, assuming that the first vibration mode is predominant.
- The flexible tube is supported by a flexible blade allowing it to vibrate in only one direction, either the drag or the lift direction, with a frequency f_n=27.5 Hz and a damping ratio ξ_n=0.064% in air [1].

	Q (L/s)	p (bar)	T (°C)	Sample rate (Hz)	Time (s)
Single flexible tube (lift direction)	0.50	2.19	18	1000	409.6
	1.70	3.33	21	1000	409.6
	2.90	3.20	25	1000	409.6
	4.00	3.53	26	1000	409.6





Single tube configuration [1]

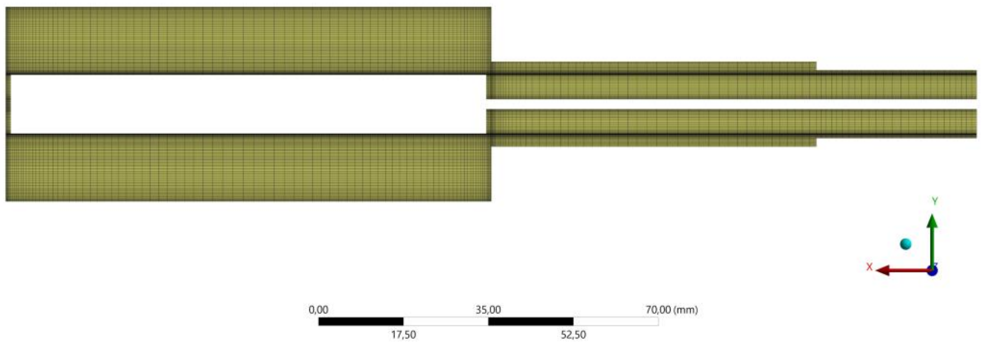
CAD modelling and mesh generation

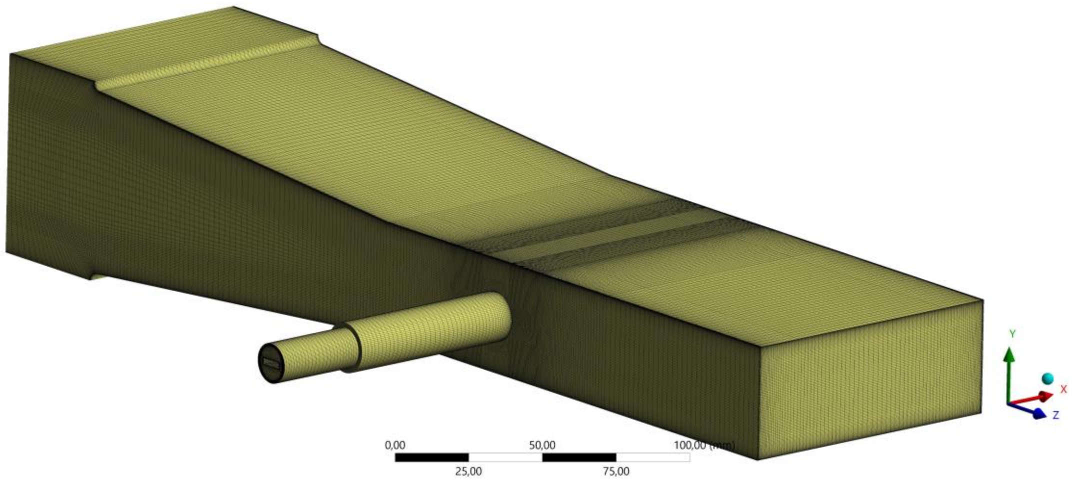
Geometry development:

- 3D CAD model has been generated from sketches and sliced in several domains.

Mesh generation:

- Using multizone meshing method, several hexahedral meshes were generated.
- Mesh with 4 million elements is selected for the investigations.
  - aspect ratio: 115
  - min. orthogonality angle: 38°
  - expansion factor: 21





Rigid body motion using ANSYS CFX

- To reduce the effort of solving the full mechanical model, the response of the mechanical body motion can be solved using a rigid body solution method [2].
- A rigid body is a solid object that moves through a fluid without deforming. Its motion is derived by the fluid forces and torques acting upon it. Mesh motion is used to move the mesh by solving the rigid body equations of motion.

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- Rigid body solution algorithm (mesh motion technique):
  - Linear momentum solver
    - Newmark integration scheme (2nd order)
  - Angular momentum solver
    - First Order Backward Euler
    - Simo Wong algorithm
    (2nd order accurate, based on modified Newmark integration)

$$F = m\ddot{x}$$

$$F = F_{Aero} + mg - k_{Spring}\,(x - x_{so}) - F_{External}$$

$$M = \dot{\theta} * I\dot{\theta} + I\ddot{\theta}$$

$$M = M_{Aero} - k_{Spring\,(Rotate)}\,(\theta - \theta_0) - M_{External}$$

Rigid body motion using ANSYS CFX

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Rigid body solver requires following input:

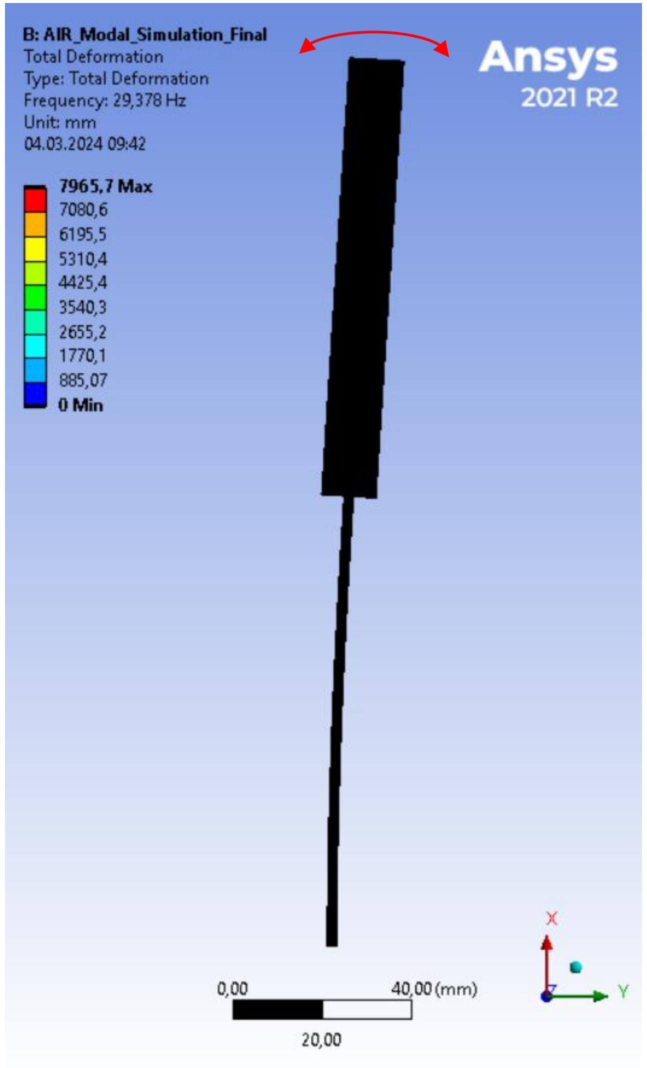
- Rigid body geometry
- Mass moment of inertia
- Body mass
- Stiffness /- Torque (as external forces), Gravity
- Motion constraint or degree of freedom

Modal simulation with ANSYS Mechanical

- CAD model from the CEA’s drawings was generated for the flexible AMOVI tube with blade.
- Unstructured mesh with 1 million of elements is generated.
- Bottom face set specified as a fixed support.
- Density of stainless tube is 8300 kg/m3, elasticity is 200 GPa and Poisson ratio is 0.3.
- Weight of tube+blade is 45.3 g.

Simulation results:

- The calculated first eigenfrequency of fn 29.3 Hz agrees well with the experimental result of 27.5 Hz, reported by CEA.



Stiffness derivation with ANSYS Mechanical

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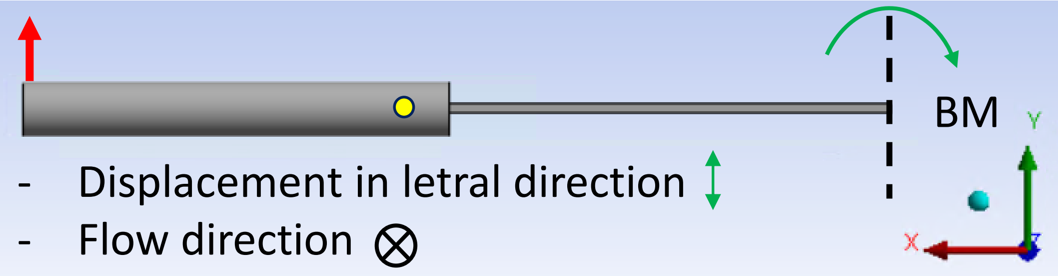
- The fluid flow is in Z direction and the body vibrates in Y (lift) direction.

- An external load (1 N, 2 N and 3 N, respectively) has been applied in Y-direction (Lift) and the corresponding displacements and resulting torques on the fixed support were calculated.

- Stiffness of 21.13 N/m.rad has been derived from data.



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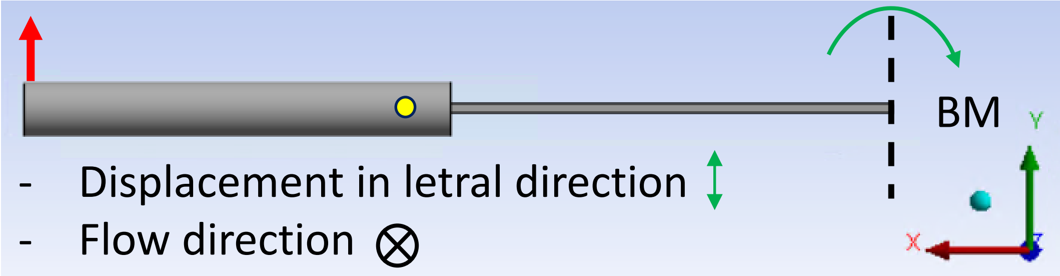
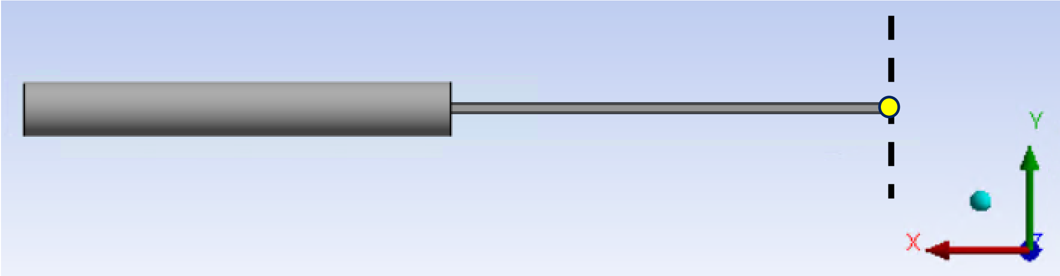


- Stiffness of 21.13 N/m.rad has been derived from data.

- The mass moment of inertia (7.6e-4 kg.m2) was derived based on the rigid body coordinate system using the parallel axis theorem.



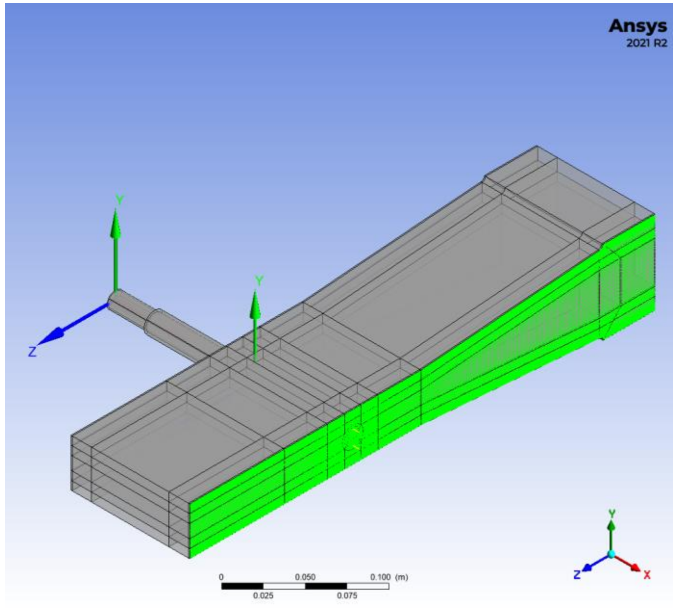
Simulation Setup

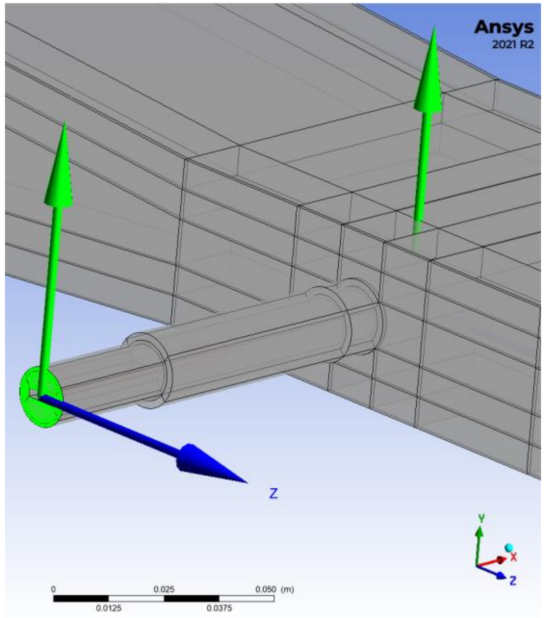
Numerical setup:

- Transient, SST turbulence model (Intensity at inlet = 5%)
- Buoyancy with production and dissipation
- High resolution advection scheme
- Automatic wall functions
- Mass flow rate is 2.89 kg/s.
- Residuals control: <1e-5 RMS,
- Inner loop = 1 ~20 and max. CFL < 5

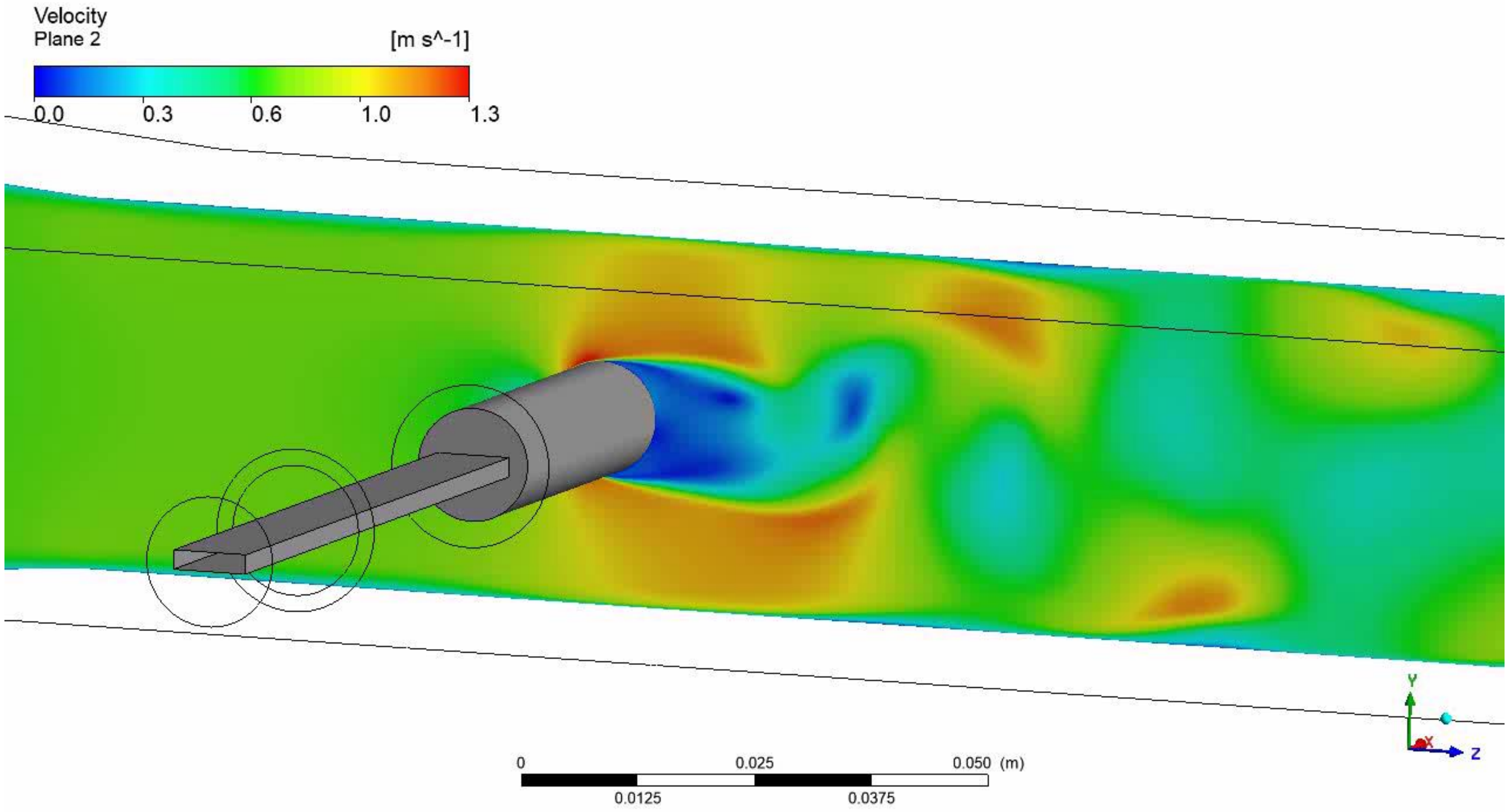
Rigid body setup:

- Angular momentum solver
- Mesh convergence < 1e-3 and loops = 1 ~ 20
- Solver coupling update at every coefficient loop
- 1 rotational degree of freedom on Z axis

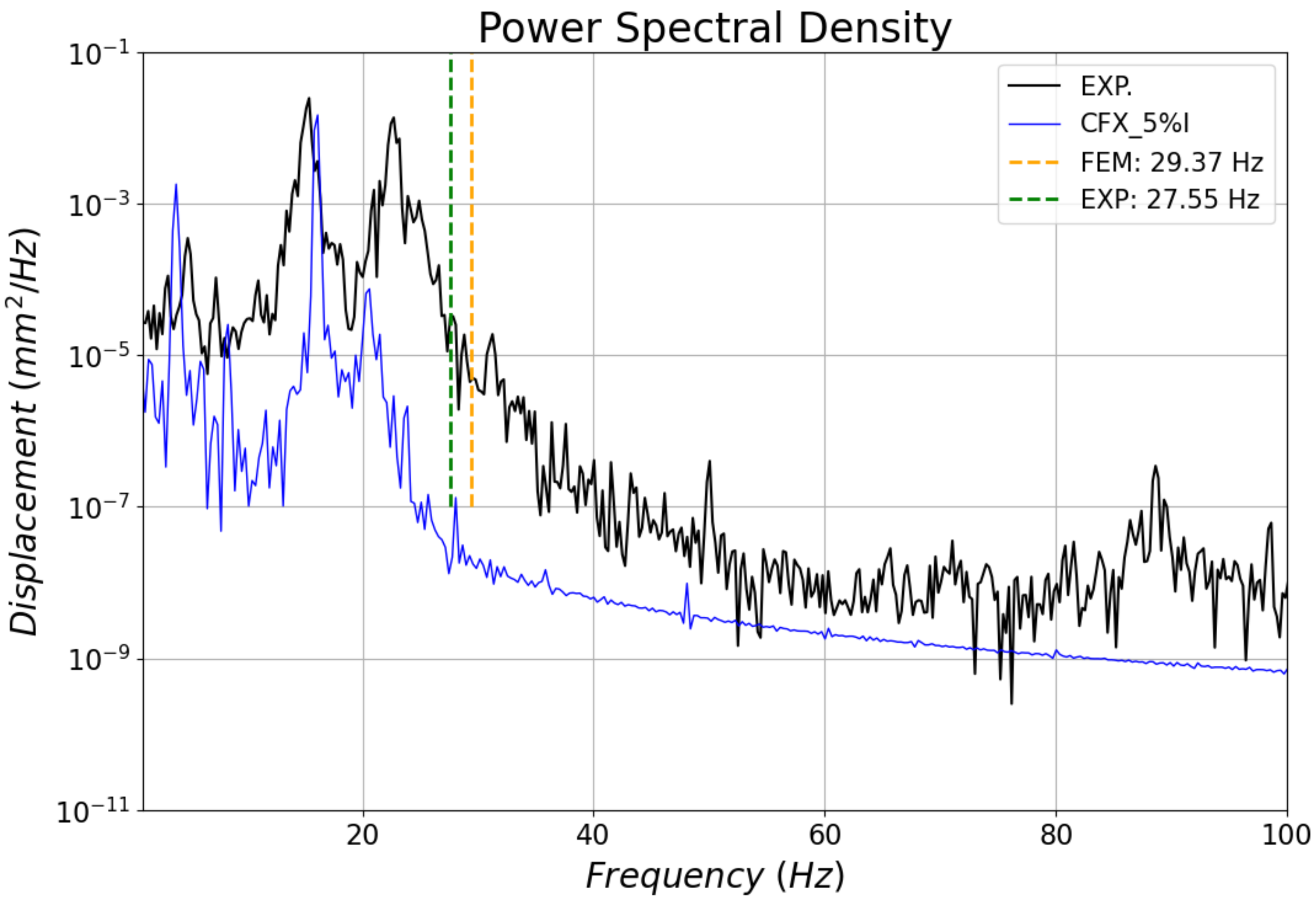




Flow induced vibration

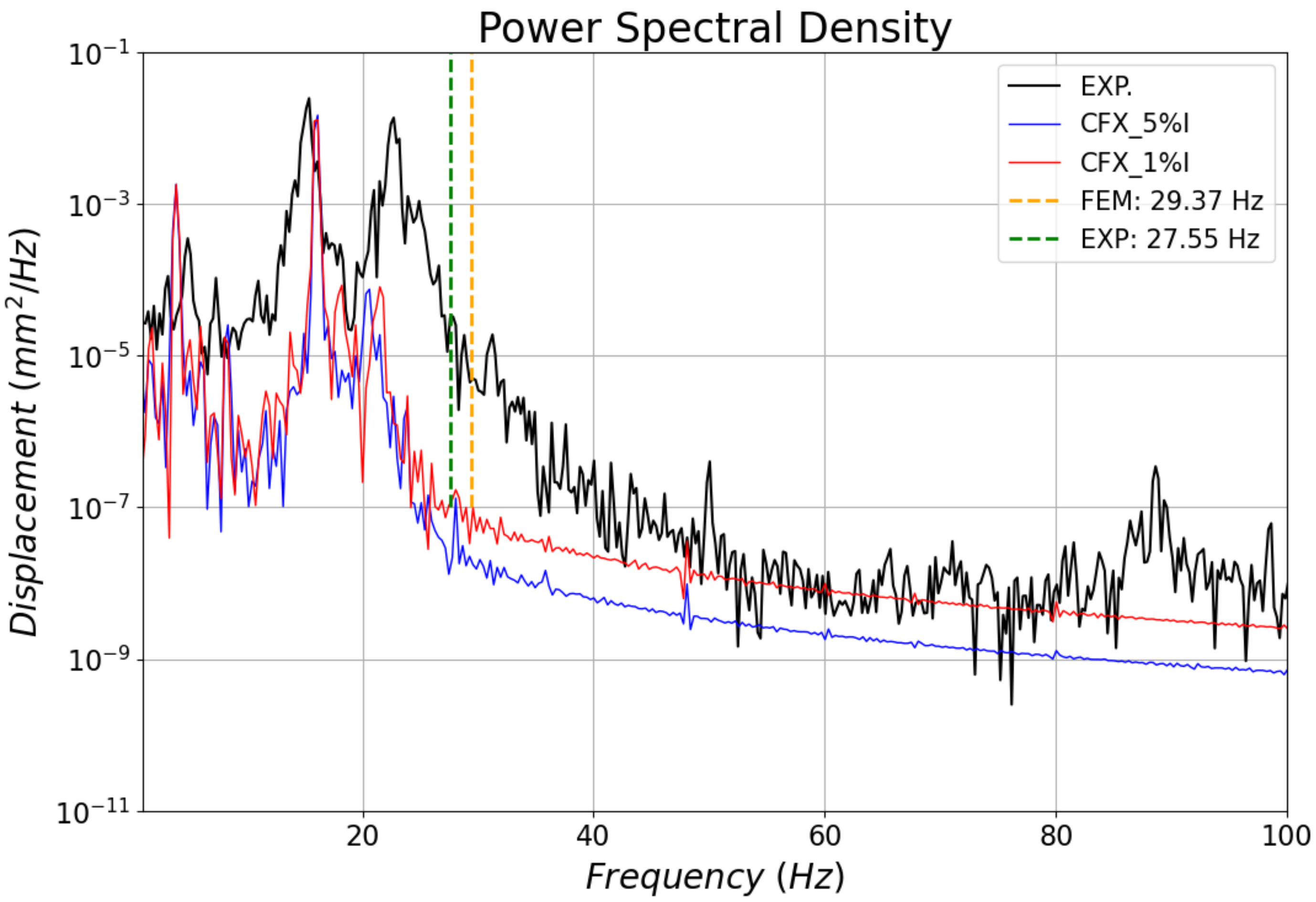


Results



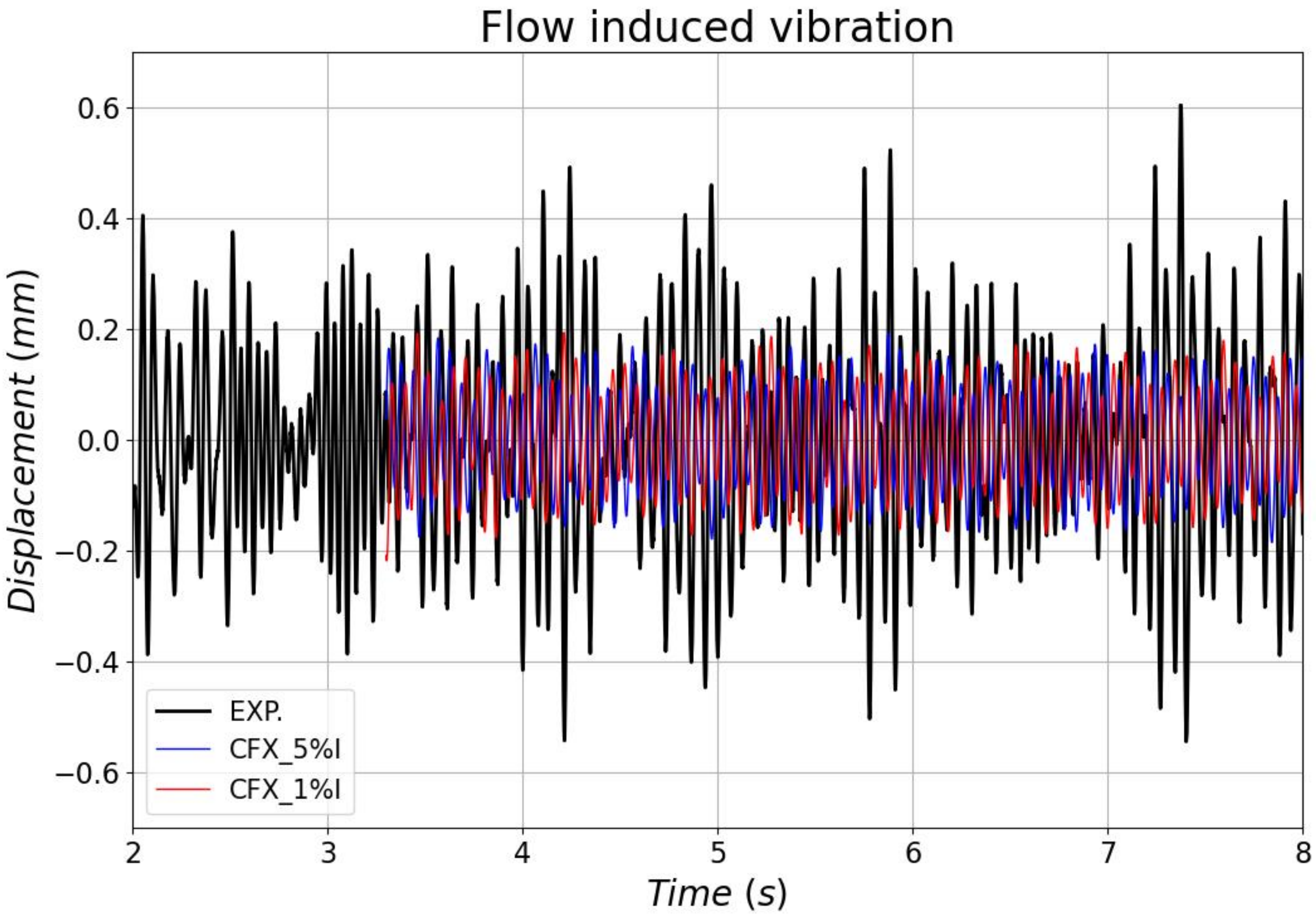
Power Spectral Density
EXP.
CFX_5%I
FEM: 29.37 Hz
EXP: 27.55 Hz
Displacement (mm²/Hz)
Frequency (Hz)
10⁻¹
10⁻³
10⁻⁵
10⁻⁷
10⁻⁹
10⁻¹¹
20
40
60
80
100

Results



Power Spectral Density
10^{-1}
10^{-3}
10^{-5}
10^{-7}
10^{-9}
10^{-11}
Displacement (mm^2/Hz)
20
40
60
80
100
Frequency (Hz)
EXP.
CFX_5%I
CFX_1%I
FEM: 29.37 Hz
EXP: 27.55 Hz

Results



Type	RMS displacement (mm)
Exp.	0.204
CFX 5% turb. Intens.	0.10
CFX 1% turb. Intens.	0.0918

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Summary and further steps

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- An FSI model was prepared using ANSYS Workbench.
- Implementation methods and boundary conditions of rigid body were analysed.
- Results were compared with experiment.

- Mesh independence of the results will be checked.
- Finer grids will be analysed and compared with System Coupling simulation (FSI).
- Other turbulence models will be investigated.

References

1) D. Panunzio, P . Piteau , R. Lagrange, C . Gauthier. AMOVI tube bundle Experiment, CEA. (15th September 2022).

2) ANSYS 2021 R2 User guide.

Partners

Associated Partners

*

*EDF R&D UK Center

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Thank you!

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