Simulation of fluidic oscillators with *Code_Saturne*

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Fluidic oscillators have been the subject of many experimental and numerical studies, however, to our knowledge, all the numerical simulations of fluidic oscillators are based on RANS turbulence models. The aim of the present work -still in progress- is to carry out a high resolution numerical simulation (LES or DNS) in order to provide better insight of fluid dynamic behaviour of the oscillators, as well as benchmark results that can be used as a reference.

Fluidic oscillators are devices with no moving parts that pulsate at uniform and predictable frequencies that depend on the Reynolds number of the flow inlet and their geometric configuration. They are well known since at least 1970 [3]. Among their applications we can mention combustion control [2][4], modifying flow separation in airfoils [5], or drag reduction [6].

In all cases, the oscillators are based on a feedback mechanism. Two popular configurations are described in [7]: Warren's circuit with two feedback loop channels, and Spyropoulos' with a single feedback loop channel. In the present work, our attention is focused in a Warren circuit, as in [1][2][4].

Numerical experiments

The geometry considered in our work, similar to the oscillator considered in [1] is shown in Fig. 1.

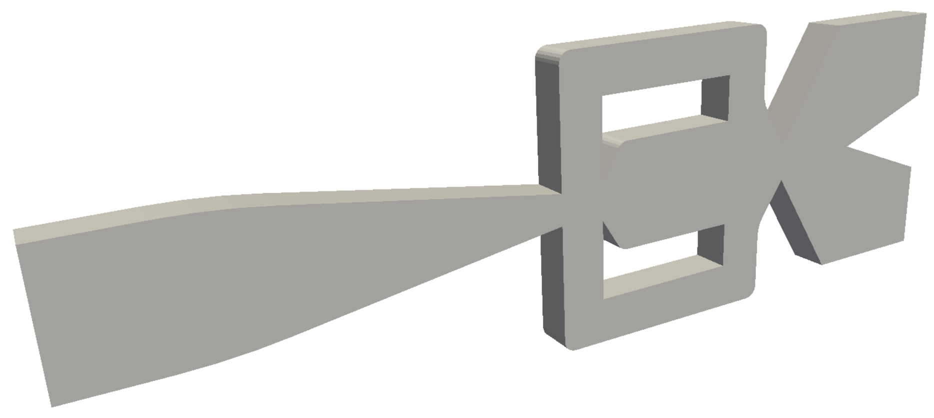

Figure 1: Oscillator geometry.

The jet created by the nozzle tends to attach to one of both sides of the wall due to the Coanda effect. For instance, assuming that in a particular instant the jet is attached to the bottom wall (Fig. 7) , most of it is going to leave the oscillator through the bottom outlet. However, a part of it is going to recirculate through the top feedback loop, causing the jet to attach to the top wall and eventually switching the device to the opposite state (Fig. 11). Then the jet attaches to the top wall and exits the device through the top port (Fig. 15).

The Reynolds number (based on inlet width) used for our simulations is 10^4. As a reference, in the experimental work [1] with a similar geometric configuration and an equivalent Reynolds number, the oscillation frequency was 15.4 Hz.

From a numerical simulation point of view, it is important to include a part of the discharge zone in the domain considered, since a fraction of the discharged flow tends to recirculate back to the oscillator using the opposite port.

The following meshes and domains are considered for the simulations:

MESH	# cells	# interior faces	# boundary faces	# 3D planes
A	33 355	49 390	67 995	1
A1	32 425	48 050	66 025	1
B	333 550	794 095	79 560	10
B1	324 250	772 325	76 600	10

Table 1: Considered meshes.

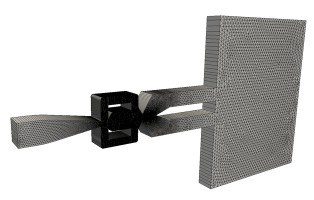

Figure 2: Mesh A.

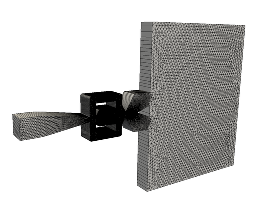

Figure 3: Mesh A1.

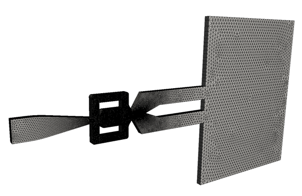

Figure 4: Mesh B.

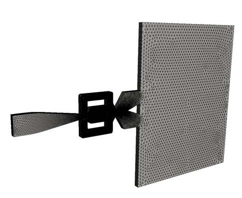

Figure 5: Mesh B1.

Meshes A and A1 are used for **URANS k-omega SST** turbulence model while meshes B and B1 are used for **LES** turbulence models. URANS k-omega SST is also run under mesh B1.

All the simulations are run for a total of 40 s, taking a constant time step of 0.001 s, thus making a total of 40000 time iterations. Moreover, a second order time scheme is considered (only for LES simulations) and a number of RHS reconstructions of 5 for pressure and 10 for velocity. The scheme for velocity is set to centered and the parameters of the solver are left to the default values. Finally, the gradient reconstruction is changed to iterative reconstruction with least squares initialization (`imrgra = 5`).

The boundary conditions used are:

- **Inlet**: for the entrance in the jet nozzle.
- **Outlet**: for the farthest exit in the discharge zone.
- **Wall**: for the interior walls as well as the exterior top and bottom walls of both the oscillator and the discharge zone.
- **Symmetry**: for the front and back walls.

Results and discussion

All the previous simulations describe well the basic oscillator behaviour and predict a oscillating frequency roughly similar to the experimental. Nevertheless, their results are not identical. In order to compare them, the flow rate of each outlet as a function of time is computed, as well as its FFT. A typical result is presented in Fig. 6. The frequency, maximum and minimum flow rate are presented in Table 2. As aforementioned, the flow rates are below zero due to recirculation.

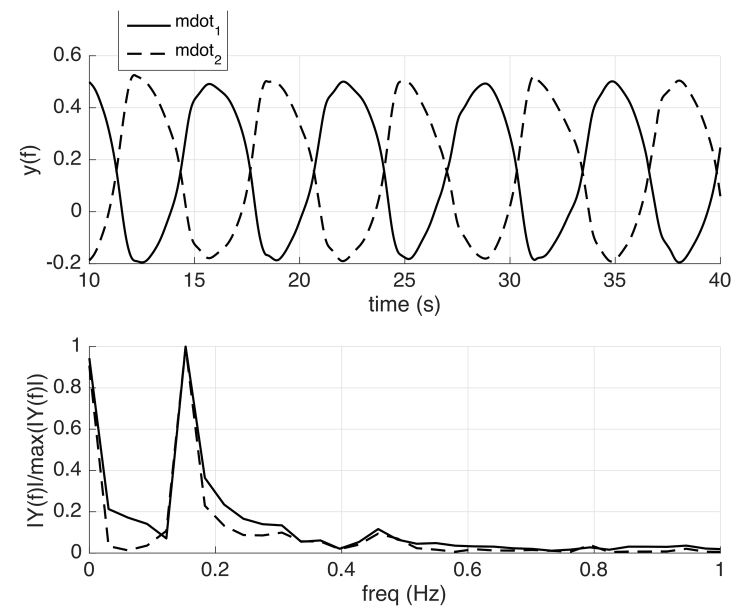

Figure 6: Mass flow at both exits and FFT.

Turbulence Model	Mesh	Freq. (Hz)	Max. value	Min. value
URANS k-omega SST	A	13.33	0.96	0.09
URANS k-omega SST	A1	14.82	1.70	-0.68
URANS k-omega SSt	B1	14.82	0.49	-0.19
no model	B	13.37	-	-
no model	B1	15.17	0.50	-0.19
LES Smagorinsky	B	17.19	-	-
LES Smagorinsky	B1	16.29	0.47	-0.17
LES WALE	B1	17.78	0.48	-0.17

Table 2: Simulations summary.

A sequence of the oscillator states is represented in Figs. 2, for LES Smagorinsky and URANS k-omega SST turbulence models. As it can be seen, the LES simulation provides a more detailed picture of the fluid dynamics.

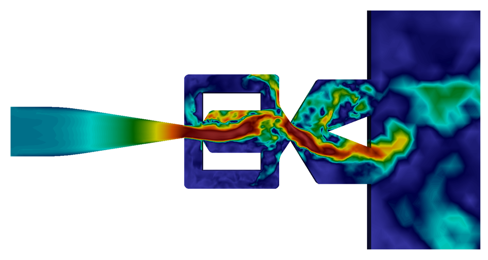

Figure 7: Phase 0 deg.

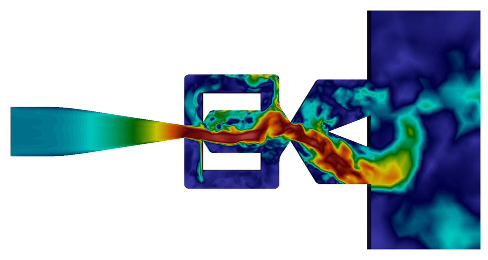

Figure 8: Phase 40 deg.

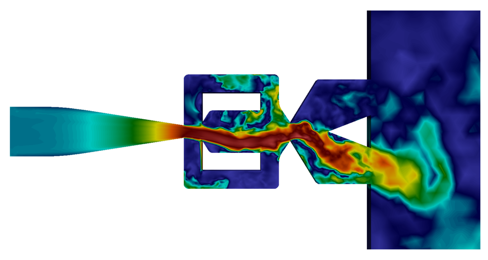

Figure 9: Phase 80 deg.

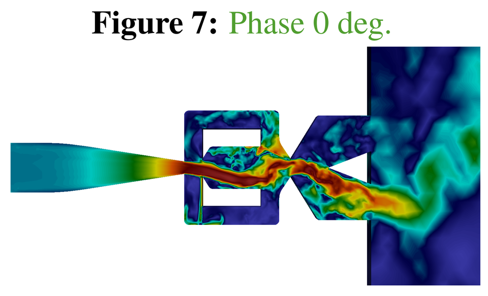

Figure 10: Phase 120 deg.

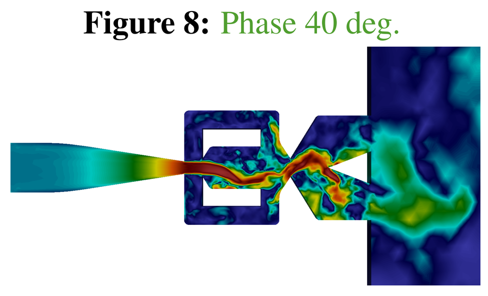

Figure 11: Phase 160 deg.

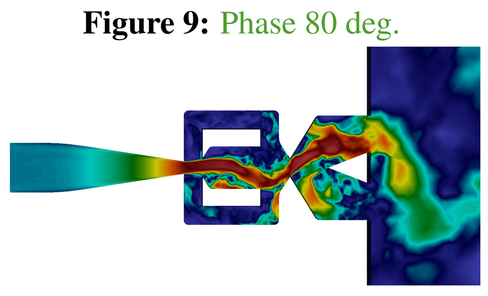

Figure 12: Phase 200 deg.

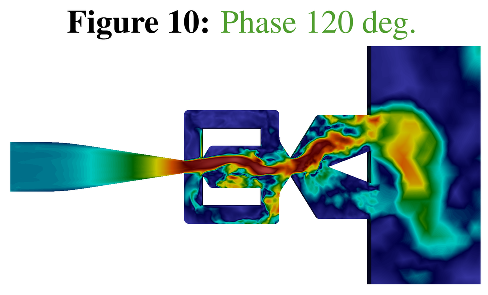

Figure 13: Phase 240 deg.

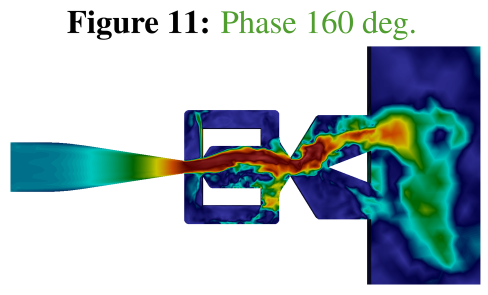

Figure 14: Phase 280 deg.

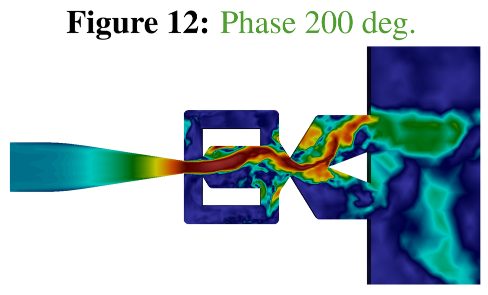

Figure 15: Phase 320 deg.

Conclusions and future work

A set first set of numerical simulations of fluidic oscillators has been carried out using *Code Saturne* and a variety of meshes and turbulence models, including an under-resolved no-model simulation. Both URANS models and LES models capture the physics of the problem, but -as expected- LES seems to provide much better detail. The simulation with no model, despite being very under-resolved are at least realistic.

In the immediate future, an estimation of the computing time needed for a resolved no model (DNS) simulation of the oscillator will be carried out. As our main interest is the flow physics, periodic boundary conditions will be used in the axis perpendicular to the main flow. If possible, mesh multiplication tools will be used to generate a suitable mesh. Better post-processing tools (phase-averaging, monitoring of the flow rates at different channel sections, etc) will be developed to analyze the results.

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