IMPLICIT LARGE EDDY SIMULATIONS OF 2D FLOW AND HEAT TRANSFER IN THERMOACOUSTIC RESONATORS

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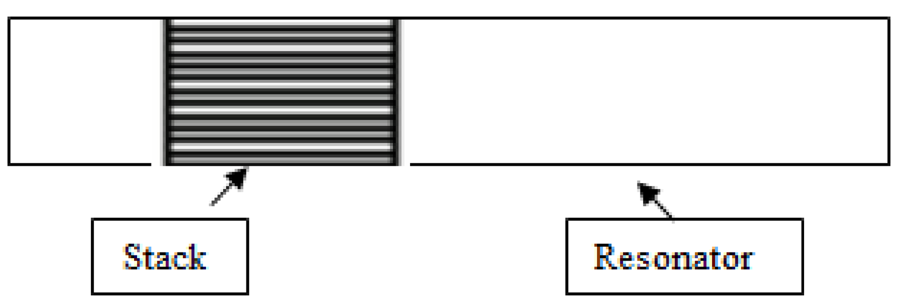
Introduction:

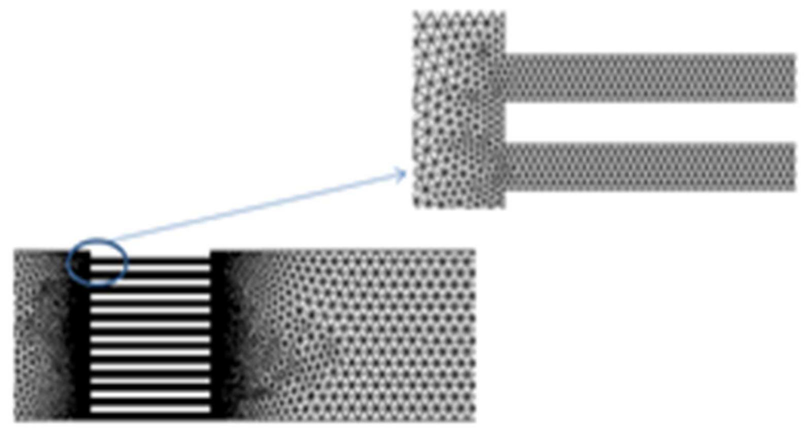
In this study, we have devised a numerical 2D model (plane symmetry) of a linear thermoacoustic machine composed of two heat exchangers, stack and a resonator. It solves the coupled compressible Navier-Stokes and heat transfer equations using COMSOL Multiphysics software, using an ideal gas model for air, and P2-P1 finite elements.

Implicit Large Eddy Simulation (iLES) has been used to simulate the transitional flow and thermoacoustic dynamics in this device.

These techniques are numerically efficient, since they require only a moderate refinement of the spatial mesh and time-stepping sequence, without any additional terms or equations [4].



Schematic of 2D linear thermoacoustic wave generator



Mesh used in the stack

Mathematical Model:

The evolution of the physical parameters is governed by the Navier-Stokes equations applied to the gas circulating in the resonator and in the stack, using the ideal gas model for air.

$$\frac{\partial \rho}{\partial t} + \nabla\cdot(\rho u) = 0$$

$$\rho\frac{\partial u}{\partial t} + \rho(u\cdot\nabla)u = \nabla\cdot\left[-pI + \mu(\nabla u + (\nabla u)^T) - \frac{2}{3}\mu(\nabla\cdot u)I\right] + F$$

$$\rho C_p\frac{\partial T}{\partial t} + \rho C_p u\cdot\nabla T = \nabla\cdot(k\nabla T) + Q + Q_{vh} + W_p$$

With :

$$W_p = \alpha_p T\left(\frac{\partial p_A}{\partial t}\right)$$

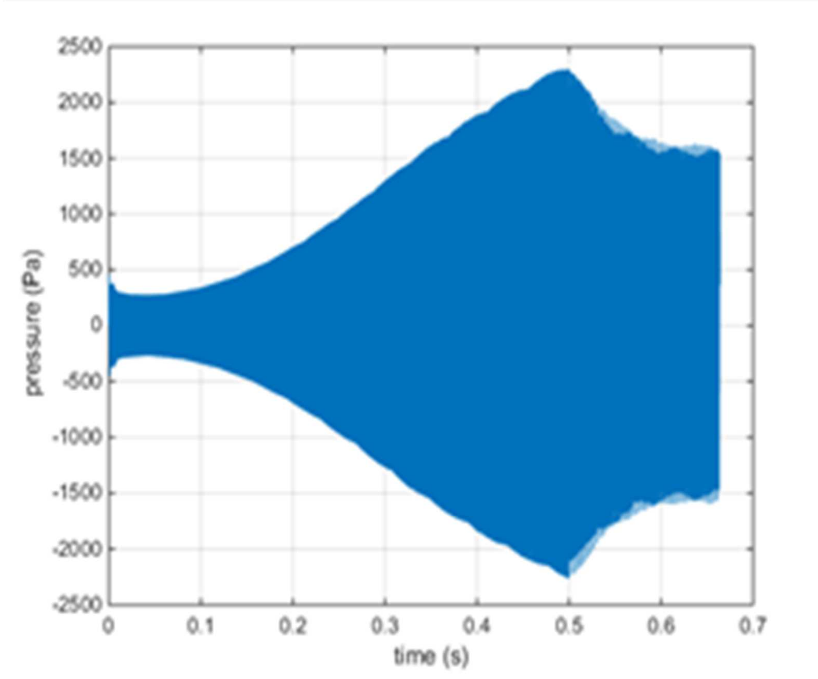
$$\alpha_p = -\frac{1}{\rho}\left(\frac{\partial \rho}{\partial T}\right)\bigg|_p$$

$$\rho = \frac{P_A}{R_S T}$$

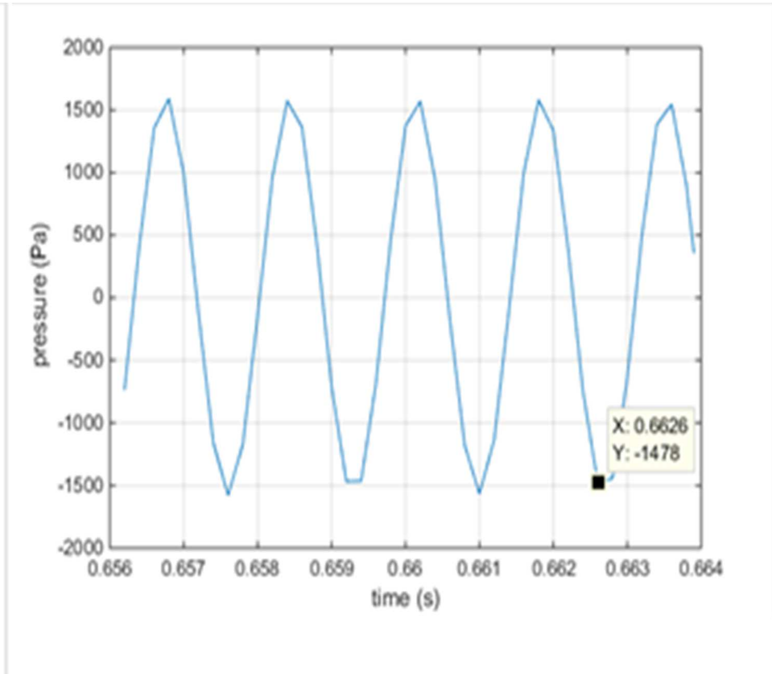
Initial and boundary conditions for air (ideal gas model) :

Paramètres	Valeurs
Initial temperature (K)	300
Ambient pressure (Pa)	101325
Inlet pressure to the engine (Pa)	10
Heat transfer coefficient in the stack (W/m^2/K)	50
Initial velocity (m/s)	0
Time step (s) : maximum 10^{-5}	initial: 10^{-7}

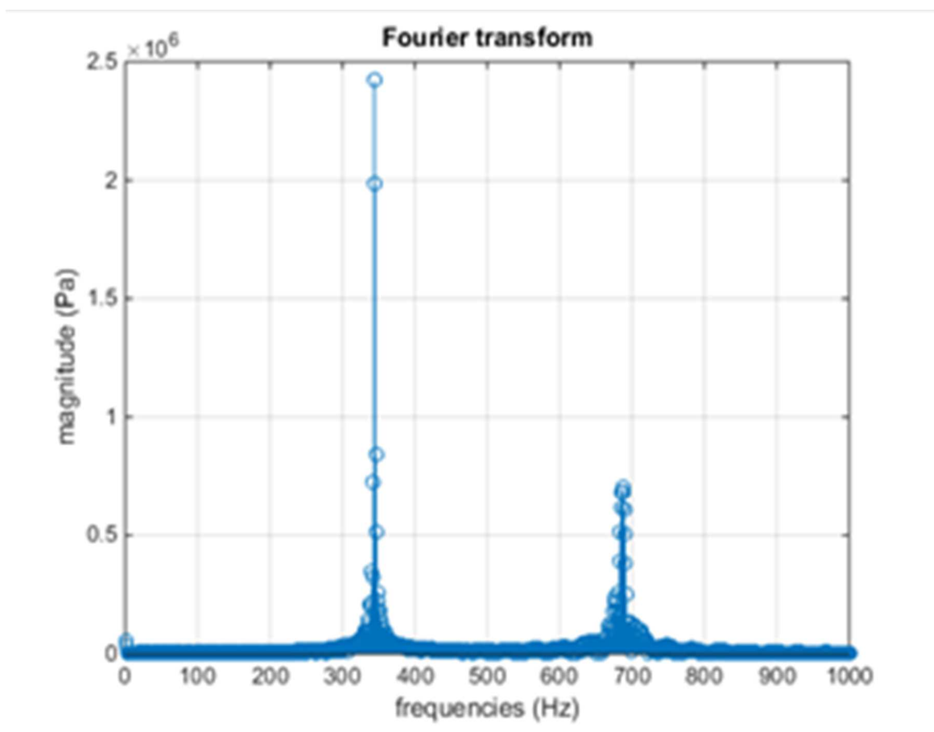
Results: The calculation is done using a triangular mesh with a total cell number of 25523 (~ 180 000 dofs)



Evolution of the acoustic pressure in the stack



Evolution of pressure in steady sate



Fourier transformation

Conclusion:

This confirms that the results of the COMSOL numerical model of this thermoacoustic device match a linear thermoacoustic machine [1-2], in which the same frequency is obtained.

The simulation was carried out by solving the mass conservation equation, momentum and energy equations, for compressible flows.

References:

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4. Margolin, W.J. Rider, «Implicit Large Eddy Simulation», F.F. Grinstein, L.G. ,Cambridge University Press, 2007.