Investigation of Mean-Flow Effects on Tubular Combustion Chamber Thermoacoustics Using a Burner Transfer Matrix Approach

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Introduction: typical thermo-acoustic calculations generally performed under the zero-Mach number assumption. A methodology to account for local mean-flow effects on thermo-acoustic instabilities computations is presented. A 3D FEM model of a simplified combustor is solved in COMSOL Multiphysics® with the *Pressure Acoustics* interface replacing the burner with its transfer matrix (BTM), computed through the *Aeroacoustics* interface considering an imposed mean-flow. The BTM ability to represent local mean-flow effects and the impact on the resonant frequencies and their growth rate is then evaluated .

Computational Model:

The simplified tubular combustor, studied by Dowling and Stow [1], is investigated.

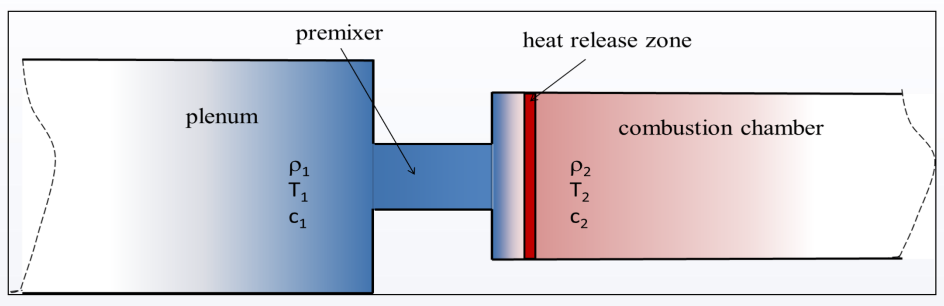


Figure 1 Simplified scheme of the investigated combustor.

Solution of thermoacoustic problem: determining the resonant frequencies of the combustor and their stability properties.

- Frequency domain analysis **:** inhomogeneous wave equation

$$\phi'(t) = Re\left(\hat{\phi}\, exp(i\omega t)\right) \quad \rightarrow \quad \frac{\lambda^2}{c^2}\hat{p} - \nabla^2\hat{p} = -\frac{\gamma-1}{c^2}\lambda\hat{q}$$

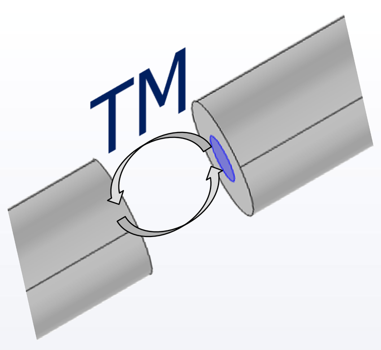
RHS term, representing heat release fluctuations, is modelled by means of a Flame Transfer Function (FTF)

$$\frac{\hat{q}}{\bar{q}} = -k\frac{\hat{u}_i}{\bar{u}_i}exp(-i\omega\tau_{conv})$$

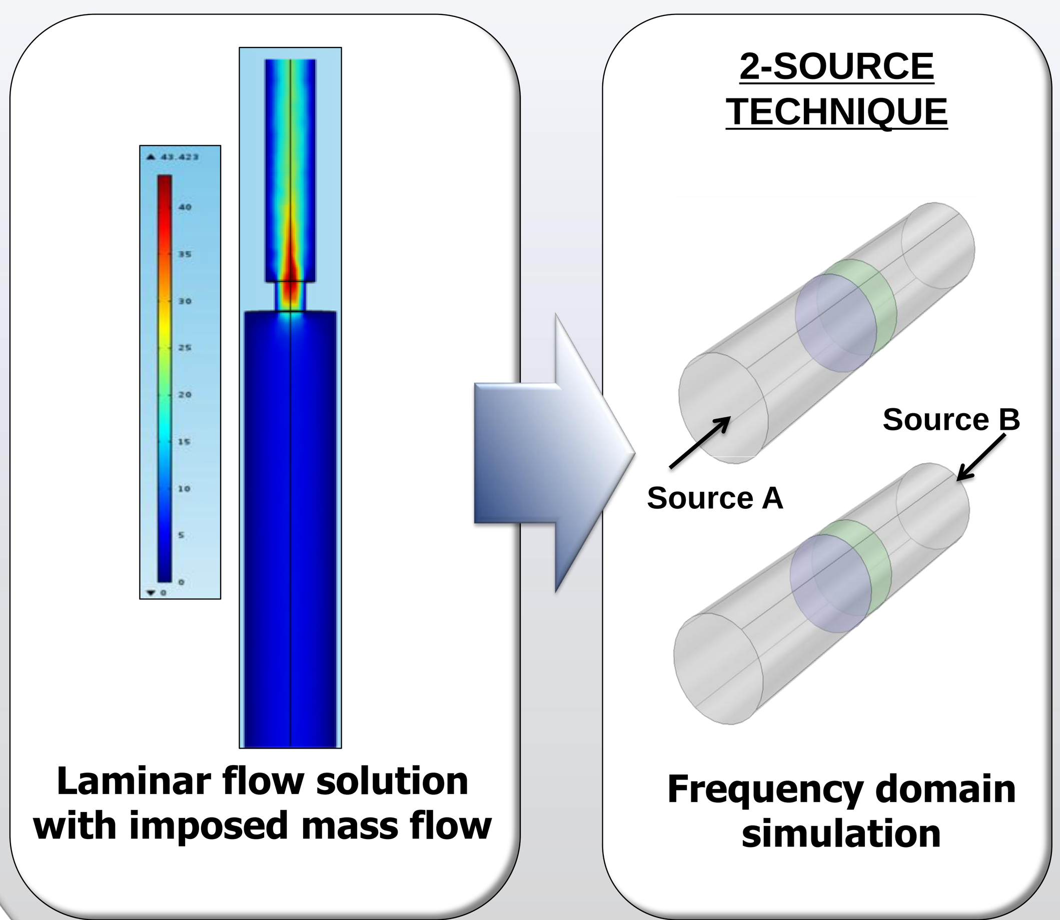
- Solver: *Pressure Acoustics* interface of COMSOL Multiphysics®
- Main assumptions: Linearity & Negligible mean flow.
- The premixer, where mean flow is not negligible, is replaced with its transfer matrix.
- **Local mean-flow effects are taken into account at the burner section.**

Burner Transfer Matrix (BTM) Computation:

Numerical computation of BTM with *Aeroacoustics* interface in COMSOL Multiphysics®.



Implementation of the two-source technique.



$$\begin{bmatrix} p'/\rho c \\ u' \end{bmatrix}_{d,A} = \mathbf{T}(f)\begin{bmatrix} p'/\rho c \\ u' \end{bmatrix}_{u,A}$$

$$\begin{bmatrix} p'/\rho c \\ u' \end{bmatrix}_{d,B} = \mathbf{T}(f)\begin{bmatrix} p'/\rho c \\ u' \end{bmatrix}_{u,B}$$

Postprocess in MATLAB®

$T_{11}(f)\quad T_{12}(f)\quad T_{21}(f)\quad T_{22}(f)$

Figure 2 Scheme of the BTM computation procedure

Results:

- Tested three cases varying the flow rate (0.05-0.075-0.1 Kg/s)
- Comparison with analytical solution [1], theoretical BTM formulation (Th. TM) [2, 3], 1D in-house code.
- Without heat release:
  - The stabilizing effect of the mean flow is properly predicted.
  - The effects of turbulence on the dissipation are neglected.
    - Higher growth rate

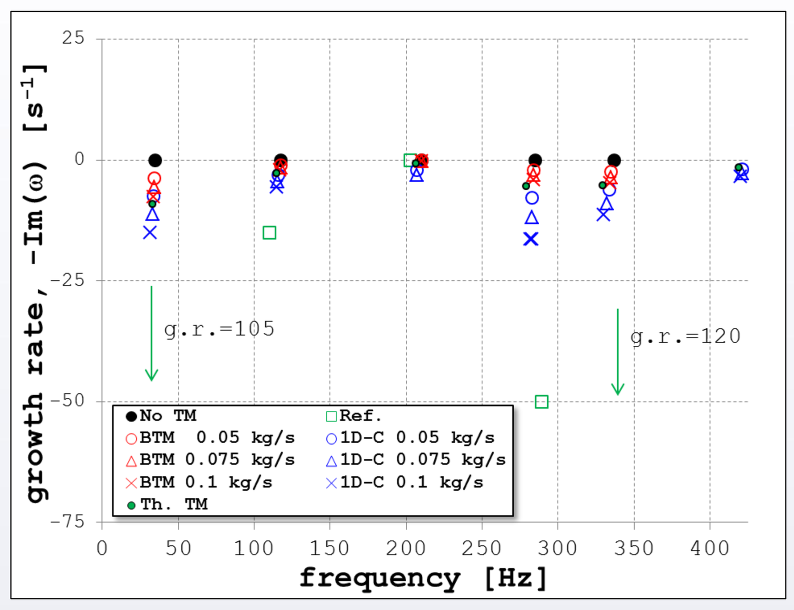


Figure 3 Resonant modes of the combustor for no unsteady heat release

- With unsteady heat release:
  - The principal modes are well represented in COMSOL.
  - The effect of the mean flow is to decouple the connected part of the plenum and combustion chamber.
- Good agreement with the reference 1D in-house code solving linearized NS equations.

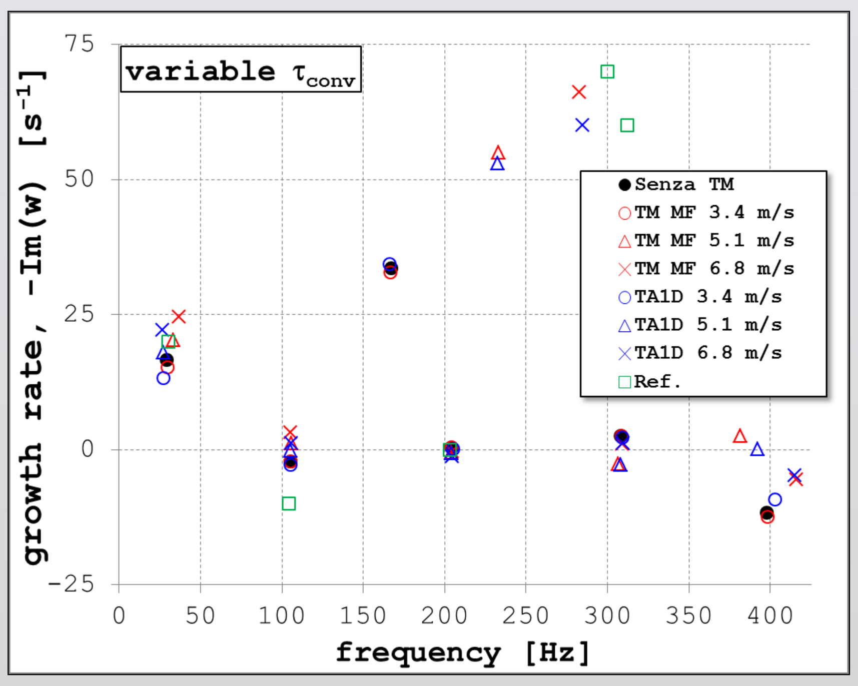


Figure 4 Resonant modes for the combustor varying the time delay with the mean flow

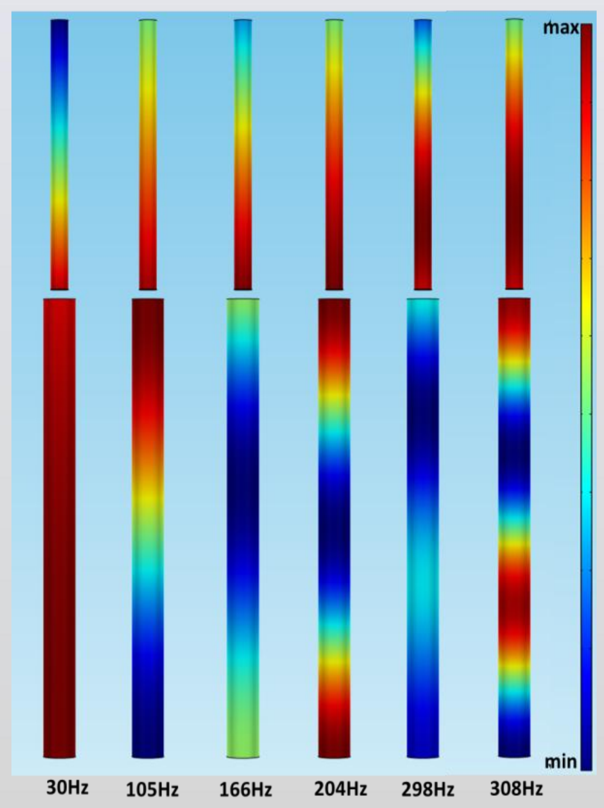


Figure 5 Mode shapes for the 0.05 kg/s case

Conclusions:

The effects of a mean flow have been introduced in the acoustic computation of a tubular combustor by BTM. Comparisons with a 1D in-house code, theoretical BTM formulation and analytical solutions available in literature showed a good prediction of the trends but an underestimation of the dissipative effect. Improvement in the BTM computation should be led by the introduction of turbulence effects, neglected in the actual BTM computation.

References:

[1] A. P. Dowling e S. R. Stow, «Acoustic analysis of gas turbine combustors,» *Journal of propulsion and power,* vol. 5, n. 19, pp. 751-765, 2003.
[2] D. Fanaca, P. Alemela, F. Ettner, C. Hirsch, T. Sattelmayer e B. Schuermans, «Determination and comparison of the dynamic characteristics of a perfectly premixed flame in both single and annular combustion chamber,» *ASME paper, GT2008-50781.*
[3] P. Alemela, D. Fanaca, F. Ettner, C. Hirsch, T. Sattelmayer e B. Schuermans, «Flame transfer matrices of a premixed flame and a global check with modeling and experiments,» *ASME paper, GT2008-50111.*