POLITECNICO DI BARI
I FACOLTA' DI INGEGNERIA
DIPARTIMENTO DI INGEGNERIA MECCANICA E GESTIONALE
SEZIONE MACCHINE ED ENERGETICA

A NOVEL FEM METHOD FOR PREDICTING THERMOACOUSTIC COMBUSTION INSTABILITY

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Combustion Instability

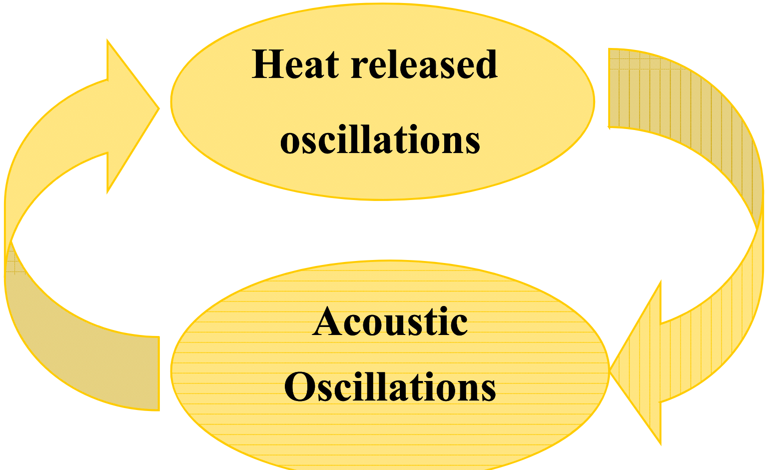
Improvement of gas turbine performance

Efficiency → annular combustors

Emissions → fuel premix

Larger tendency to the creation of thermoacoustic instability

- excessive noise
- mechanical failures
- flame detaching and misfiring
- production of emissions



Objectives

- Introduction of a mathematical model able to study acoustics and heat released oscillations;
- Resolution of this mathematical model through FEM technique in order to identify the instability conditions of the system examined;
- Demonstrate the capability of COMSOL Multiphysics to accurately solve eigenvalue problems in the analysis of combustion instability applied to complex geometries.

Mathematical Model

With regards to a compressible and viscous fluid, the conservation equations of mass, momentum and energy can be written as follows:

$$\frac{D\rho}{Dt} + \rho\nabla\mathbf{u} = 0 \qquad \rho\frac{D\mathbf{u}}{Dt} = -\nabla p + \frac{\partial\sigma_{i,j}}{\partial x_j}\mathbf{e}_i$$

$$\rho\frac{D}{Dt}\left(e + \frac{1}{2}u^2\right) = -\nabla\cdot(p\mathbf{u}) + q + \nabla\cdot(k\nabla T) + \frac{\partial}{\partial x_j}\left(\sigma_{i,j}u_i\right)$$

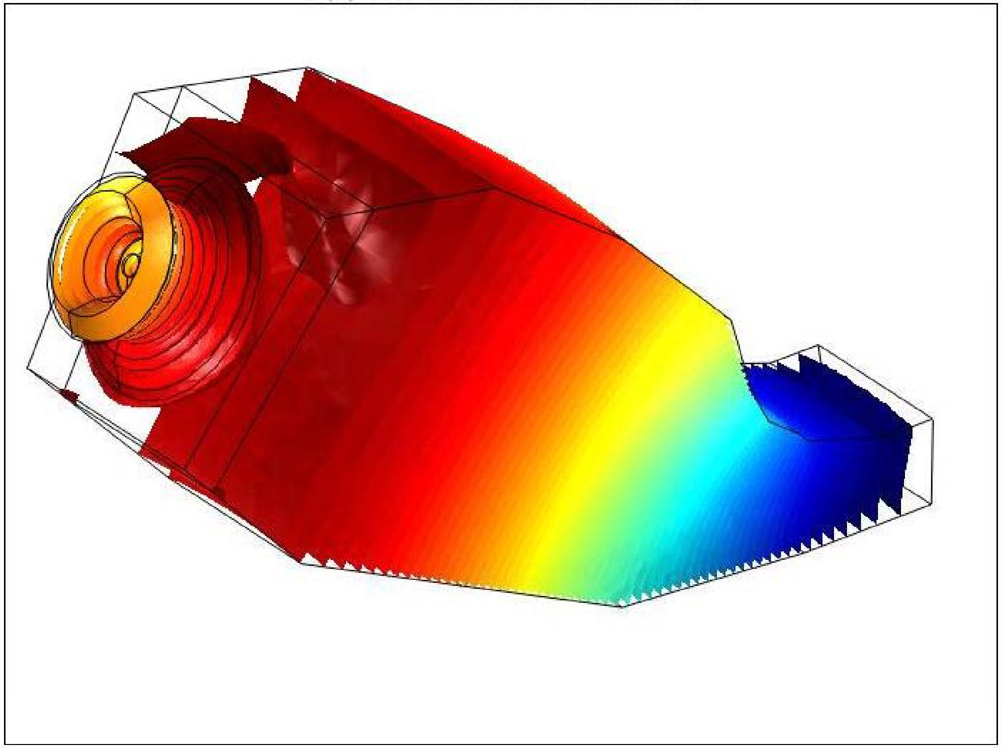
When a fluid is considered non viscous, a gas perfect and mean flow negligible, the linear forms of the previous equation brings to the inhomogeneous wave equation:

$$\frac{1}{\bar{c}^2}\frac{\partial^2 p'}{\partial t^2} - \bar{\rho}\nabla\cdot\left(\frac{1}{\bar{\rho}}\nabla p'\right) = \frac{\gamma - 1}{\bar{c}^2}\frac{\partial q'}{\partial t}$$

Heat release rate per volume unit [W/m^3].

COMSOL Multiphysics

In COMSOL Multiphysics the *Acoustics Module* is the module adopted in the present analysis.



The application mode used, *Pressure Acoustics*, is able to find the complex eigenfrequencies of the system.

Subdomain Settings

Air has been described introducing:

- *Fluid density*;
- *Speed of sound*.

Heat release has been described introducing:

- *Monopole source*

in agreement with the heat release law imposed.

Boundary Settings

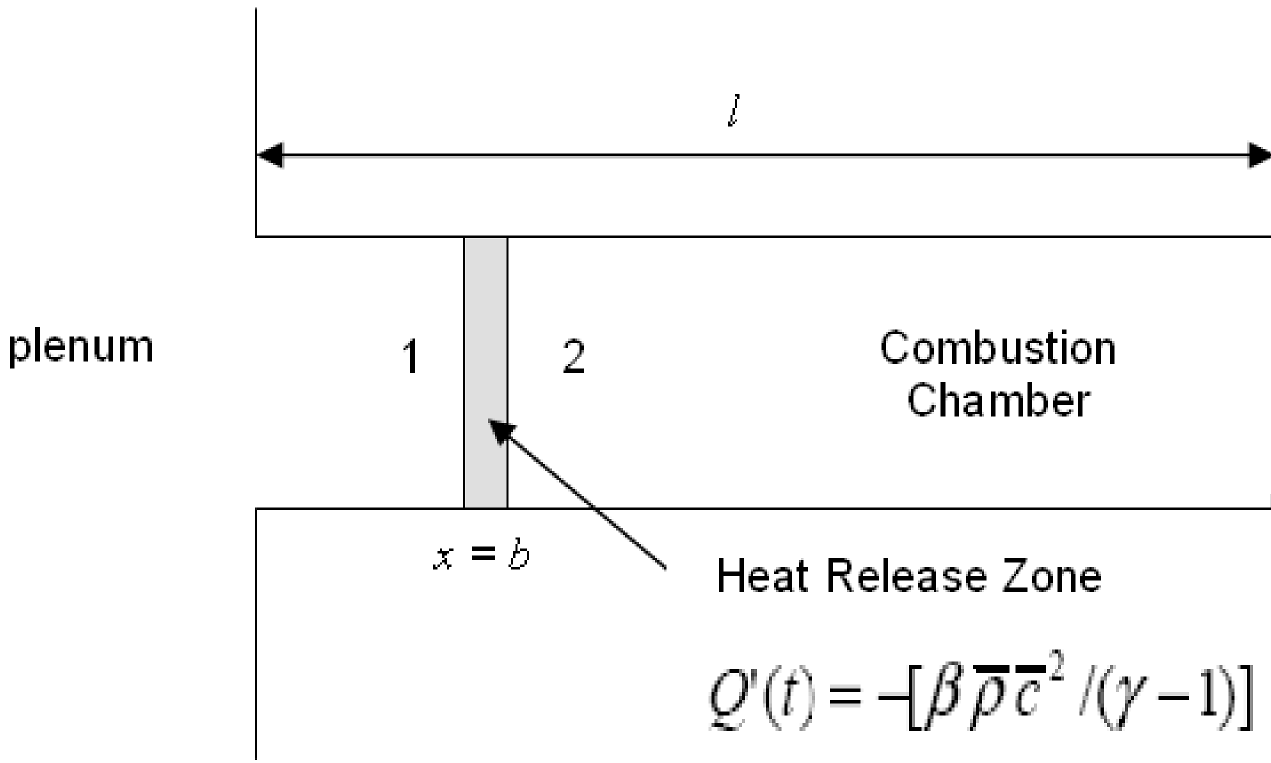
Solid walls are modelled with *Sound Hard Boundary*.

Inlet & Outlet wall are modelled with one of the following conditions:

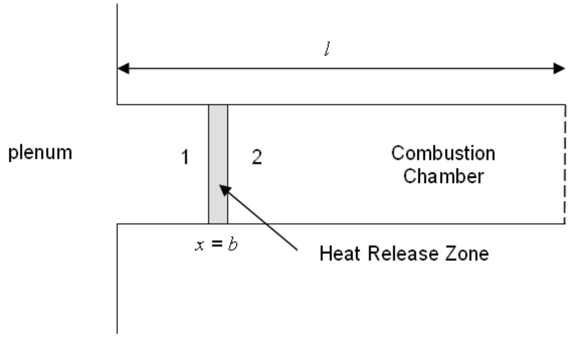
- *Sound Hard Boundary;*
- *Sound Soft Boundary;*
- *Normal Acceleration.*

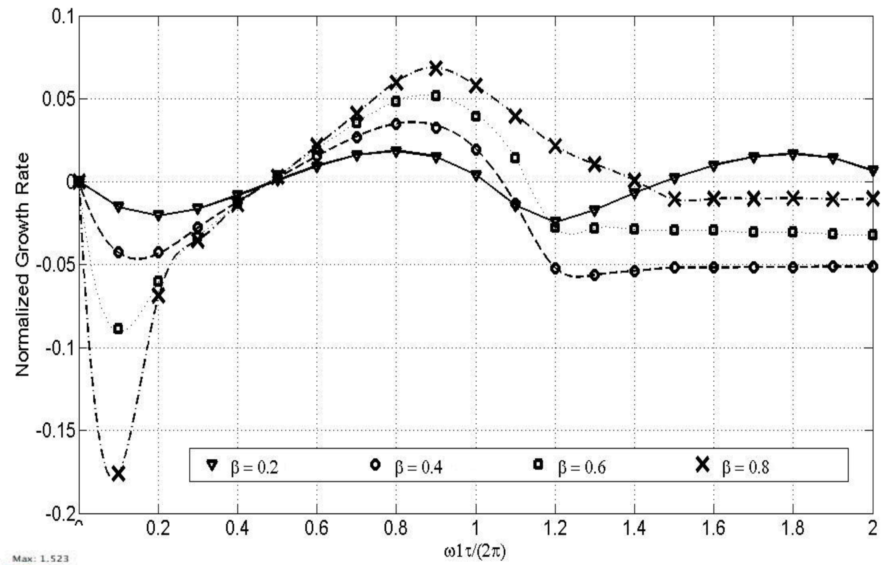
The right condition is defined in agreement with the examined test.

Preliminary Tests on Linear Combustion Chamber



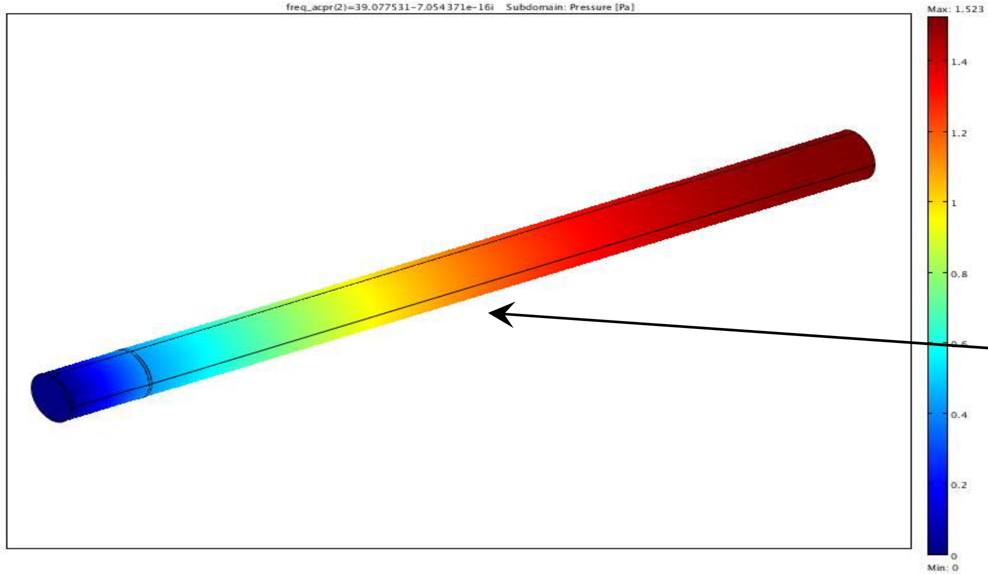
$$Q'(t) = -[\beta \overline{\rho}\,\overline{c}^2 / (\gamma - 1)]\; u'_1(t - \tau)$$





Analytical solution is available:

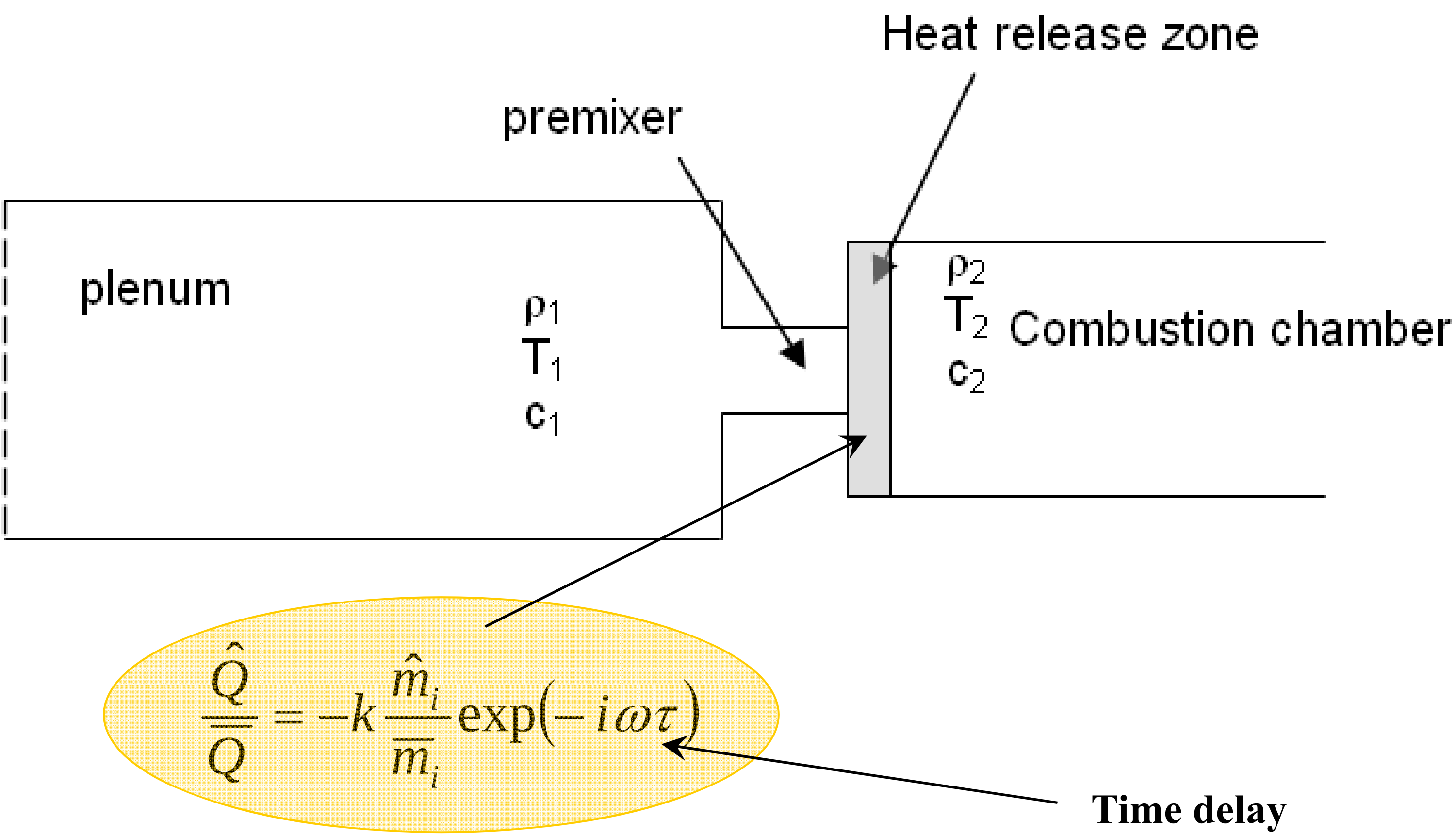
$$\tan(\frac{\omega}{c}b)\tan[\frac{\omega}{c}(l-b)]=1-\beta\exp(-i\omega\tau)$$



First Axial Mode

Pressure Wave

Tests on Linear Combustor with variation of section



$$\frac{\hat{Q}}{\overline{Q}} = -k\frac{\hat{m}_i}{\overline{m}_i}\exp(-i\omega\tau)$$

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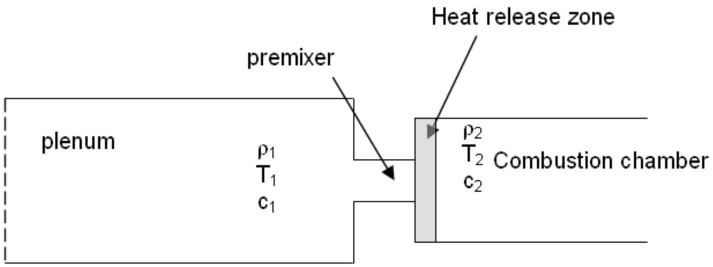
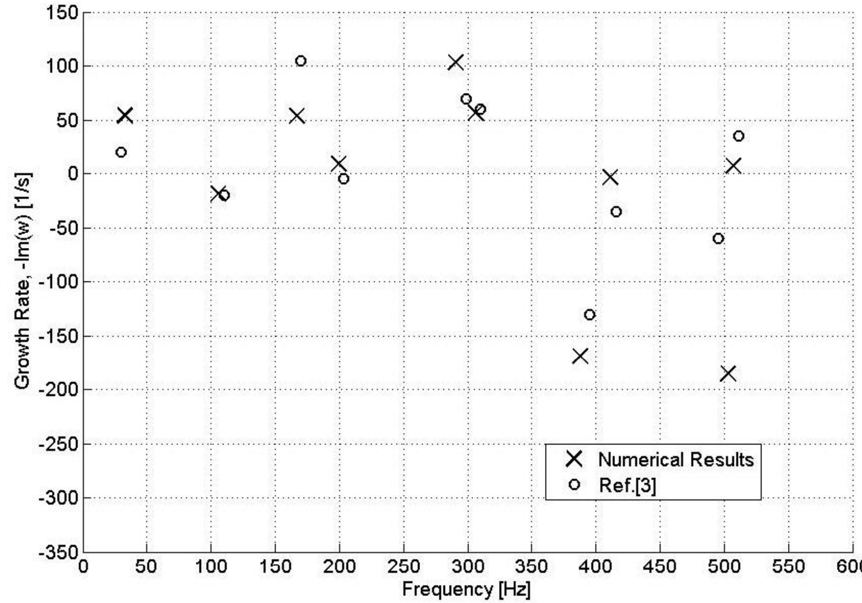
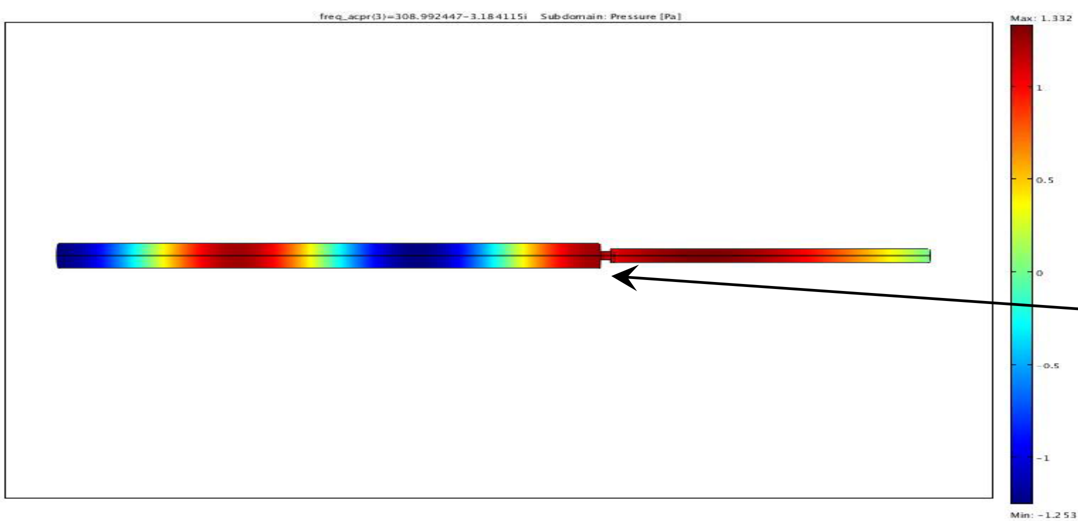


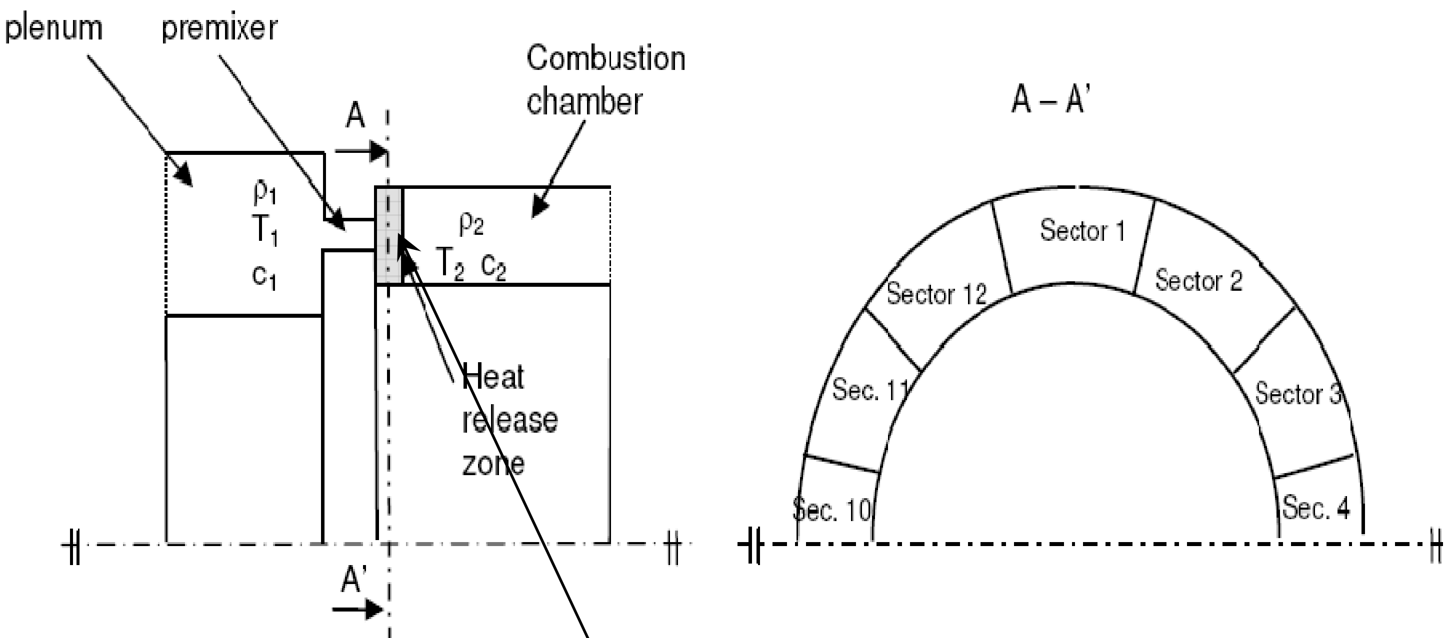




Axial Mode

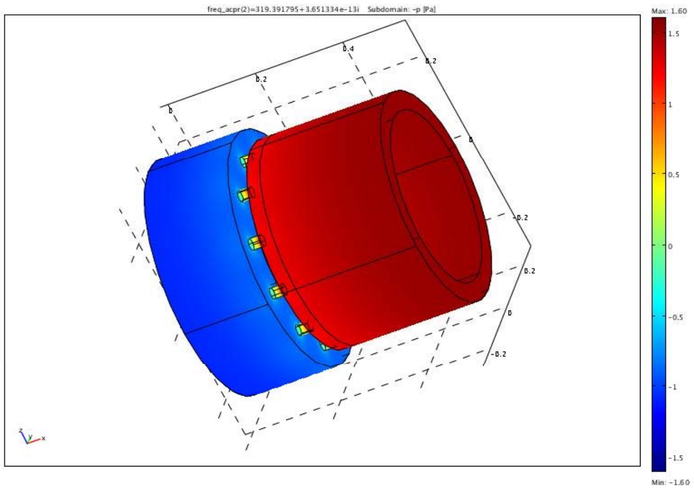
Pressure Wave

Tests on Annular Combustion Chamber



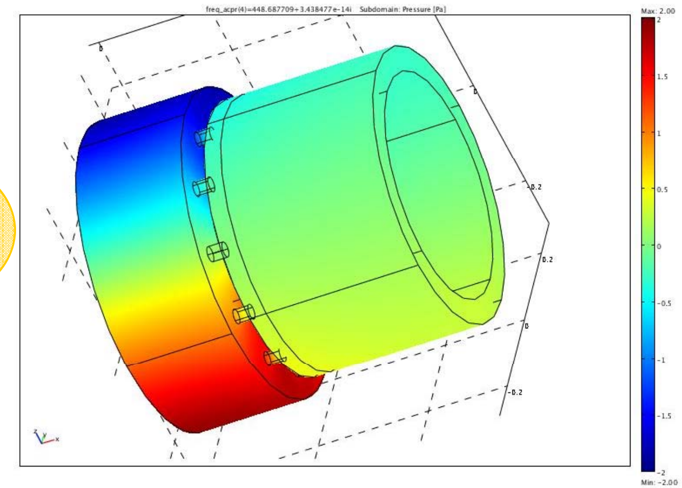
$$\frac{\hat{Q}}{\overline{Q}} = -k\,\frac{\hat{m}_i}{\overline{m}_i}\exp(-i\omega\tau)$$

(1,0,0)



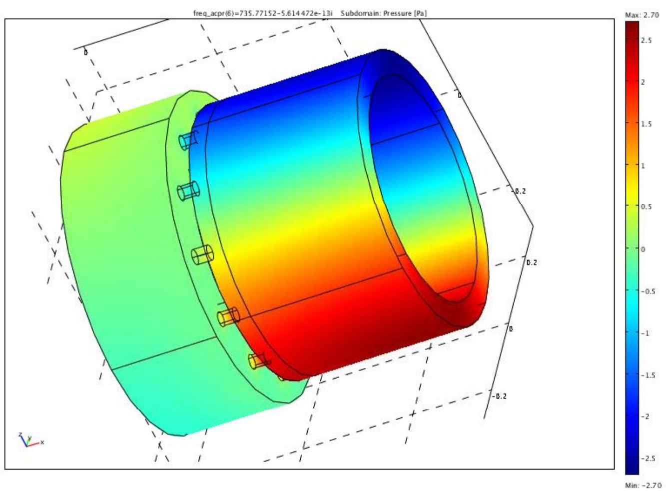
Unstable for τ > 0.002 s

(0,1,0)



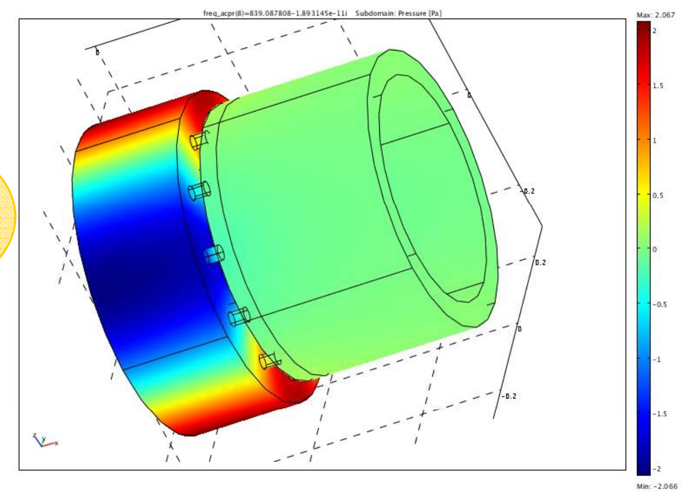
Unstable for τ = 0.001 s 0.003 s 0.005 s

(1,1,0)



Unstable for τ < 0.002 s and τ > 0.004 s

(0,2,0)



Unstable for 0.003 s < τ < 0.006 s

Conclusions

- The mathematical model introduced has been successfully solved;
- COMSOL Multiphysics provides sufficient level of accuracy in the identification of stable and unstable eigenmodes;
- The FEM analysis has been successfully applied to different kinds of heat release law and different boundary conditions;
- The present approach is appropriate to treat complex geometry;
- COMSOL Multiphysics provides a commercially available tool that can analyze combustion instability problem.

Further Applications

The method can be applied to analyze the effects of:

- Passive damping devices;
- Geometry of the system;
- Flame response functions;
- Transfer function matrices of the burners.

Thank you
for attention

Questions?