Thermoacoustic Analysis of Combustion Instability Importing RANS Data

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Abstract

Modern gas turbines equipped with lean premixed dry low emission combustion systems suffer the problem of thermoacoustic combustion instability. The acoustic characteristics of combustion chamber and of the burners, as well as the response of the flame to the fluctuations of pressure and equivalence ratio, play a fundamental role on the conditions at which the instability may occur. COMSOL Multiphysics is used to solve the Helmholtz equation with a source term that models the heat release fluctuations. The frequencies at which thermoacoustic instabilities are expected and the growth rate of the pressure oscillations at the onset of instability are identified. COMSOL Multiphysics is able to treat complex geometries such as annular combustion chamber equipped with more burners. The problem is solved in the frequency domain using the eigenfrequency "Pressure Acoustics" interface. The adopted acoustic model is based upon the definition of the Flame Response Function (FRF) to acoustic pressure and velocity fluctuations in the burners [1]. The boundary conditions are considered basically as three types: sound hard (wall), sound soft and normal acceleration. The geometry chosen to represent the combustor by Ansaldo Energia is modeled in COMSOL Multiphysics as only a quarter of the whole combustor, applying symmetry conditions on periodic faces (Figure 1). Transfer matrix is applied removing every burner, so that the upstream port of each matrix is the exit from the plenum and the downstream is the inlet of the combustion chamber, following the criteria discussed in [2]. Operating conditions are taken from experimental data and from RANS simulations of Ansaldo combustor. Data from RANS simulations are used to obtain a distribution of FRF of the k-tau type as a function of the position within the chamber. RANS data are properly modified in the grid format to be accepted by COMSOL and to match the two different computational grids (the RANS one with the COMSOL one). The temperature field inside the combustion chamber is obtained from the RANS data (Figure 2). The intensity coefficient k is assumed to be proportional to the reaction rate of methane in a two step mechanism (Figure 3). The time delay tau is estimated on the basis of the trajectories of the fuel particles from the injection point in the burner to the flame front. The paper shows the results coming from the application of FRF with spatial distributions of both k and tau, which result to have a significant influence, both to the eigenfrequency values and to the growth rates, in several of the examined modes (Figure 4). The proposed method is therefore able to establish a theoretical relation of the characteristics of the flame to the onset of the thermoacoustic instability. The introduction of a spatial distribution of heat release and time delay determines a more detailed analysis when a complex configuration is examined. Through an actual flame shape it is possible to take into account the effects of the 3D distribution of the flame inside the combustor and the effects

of the non linearity of the heat release can be investigated.

Reference

[1] G. Campa, S. Camporeale, “A Novel FEM Method for Predicting Thermoacoustic Combustion Instability”, European COMSOL Conference 2009, Milan, Italy.
[2] G. Campa, S. Camporeale, “Application of Transfer Matrix Method in Acoustics”, European COMSOL Conference 2010, Paris, France.

Figures used in the abstract

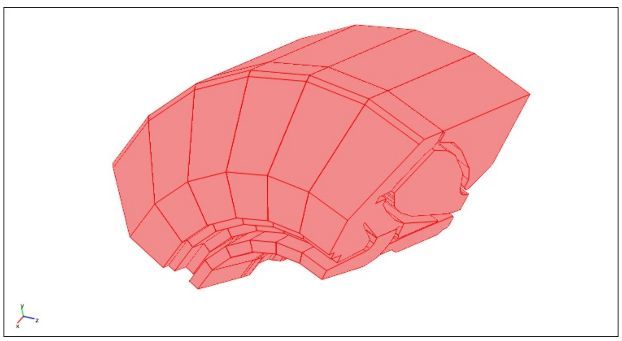

Figure 1: Geometry of the Ansaldo annular aombustion chamber.

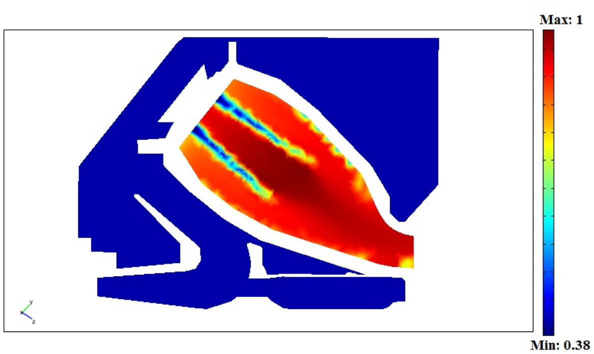

Figure 2: Temperature field in COMSOL (imported from RANS simulations).

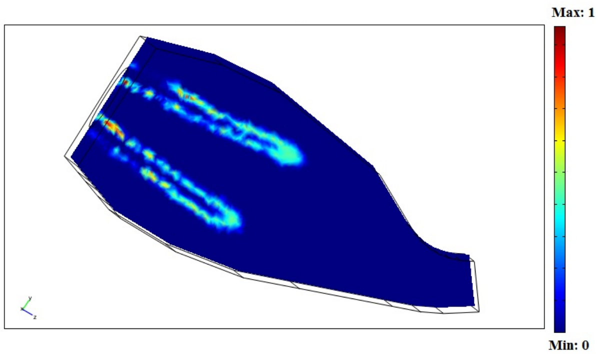

Figure 3: Rate of reaction distribution in COMSOL (imported from RANS simulations).

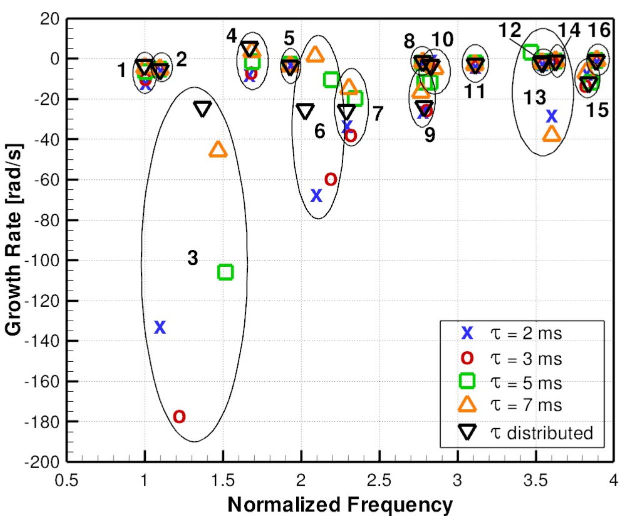

Figure 4: Combustion chamber modes for different values of tau with the spatially distributed flame.