Non-linear numerical models applied to the study of LP combustor instabilities

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1 Introduction

The increasing adoption of lean premixed (LP) combustion technologies is rising the need to study the dynamic behavior of flames in combustors [1]. Indeed combustion in lean conditions is much more prone to "instabilities" that manifest as oscillations of the flame able to drive detrimental pressure oscillations (thermo-acoustic instabilities). The proper characterization of these instabilities is the loss, after the change or perturbation of some system parameters, of a stable and steady regime to acquire a new stable but oscillating regime.

Even though some of the most fundamental results date back more than 100 years ago [2], a full clear understanding of the mechanisms leading to the appearance of a dynamic combustion behavior is still not achieved.

The full characterization of these instabilities is a difficult process. Most of the approaches adopted up to now belongs to the class of linear stability analysis. However the informations that can be obtained in the framework of linear stability analysis are limited. For instance, no information can be obtained on the saturation of the instability amplitude. Therefore, the adoption of non-linear modeling approaches appears advisable.

In this paper some results obtained with non-linear numerical models are illustrated. Two kind of non-linear models have been considered.

The first ones are very simple and built by considering the combustor as a network of Perfectly Stirred Reactors. While this level of description is inadequate to fully take into account the complex coupling between all feedback mechanisms acting in a real device, they possess the great advantage that the study of their stability can be afforded in the well established theoretical framework of bifurcation theory [3]. Furthermore it is possible to employ the computational techniques of continuation analysis [4] to obtain the complete stability map, including steady as well unsteady and stable as well unstable solutions, of the systems described by these models, i.e. to predict all the possible behaviors of these models with respect to changes of the model's parameters.

This approach allowed to identify the possibility of the occurrence of oscillating behavior induced by a feedback mechanism between the chemical heat release rate and the heat transfer at the walls [5], or to investigate some possible effects of changes in the chemical reaction rates due to changes in fuel composition as it occurs for instance with the addition of small quantities of hydrogen to methane-air mixtures [6], or to identify the possible effects of increase of recirculation of hot gases in the combustion chamber [7].

The possibility to include in these simple models the effect of the important mechanism of proper time lag distribution [8] is currently under investigation.

The second kind of non-linear models are the models adopted in the Computational Fluid Dynamic (CFD) approach. This approach, in principle, allows for the full inclusion of all mechanisms acting in a real device, even if the resulting model can be extremely complex and prohibitively to solve even for a single set of all the involved parameters. Several examples of application of this approach are given in the literature [9, 10]. It aims at the simulation of the real response of the combustor to a disturbance, providing the most complete description of the phenomena occurring in the combustor nowadays available, including an estimate of the saturation of the instability amplitude. However the interactions among all the mechanisms involved are so complex that is very difficult from the analysis of the numerical results to identify the driving instability mechanism. Furthermore the automated bifurcation analysis of CFD-like models is really a formidable task [11], at present not affordable with application of reactive flow models.

Here a different use of the CFD approach is proposed in conjunction with the results given by the simplified models previously illustrated. CFD simulations have been set up in such a way that only few mechanisms are allowed to occur so that their role in driving the combustion instability can be more easily understood. The aim of these simulations is to verify if the instability mechanisms, that have been predicted to play a role with the simplified models, can effectively occur in real combustor configurations and if they becomes relevant for values of the operating parameters significant during the real running of a combustor.

Guidance for the proper choice of few sets of parameters values to adopt for the CFD simulations is given by results of the bifurcation analysis of the simpler models. Following this approach it has been possible to perform a limited number of CFD simulations but corresponding to stable oscillating regimes with well distinguished properties.

Situations for which the interpretation of the Rayleigh criterion in terms of time lag distribution is not allowed, have been identified [12].

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