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Simulation of combustion – Acoustic interactions using a conjugate method

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A B S T R A C T

A modern approach of conjugate problem formulation currently widely used in heat transfer theory and applications is applied to simulate combustion–acoustic interaction process. The term conjugate corresponds to problems when solution domain consists of two or more subdomains with different properties and/or with phenomena described by different type of differential equations. In heat transfer, such subdomains are usually a fluid and a body or two fluids separated by solid. Similarly in combustion, such subdomains are fresh and burnt gases divided by a flame. As an example, the effect of flame location and burnt/fresh gases temperature ratio on combustion stability is investigated. It is assumed that forced oscillations are imposed on an existing in a tube flow, and stability of final oscillations at different flame locations and temperature ratios is studied. The well-known simple one-dimensional approach is improved using a physically founded, more reliable combustion model and an alternative method of solution based on strict mathematical formulation as a boundary-value problem similar to that applied in conjugate heat transfer theory. The mathematical development leads to a system of two integro-differential equations determining final velocity and pressure amplitudes at the flame. Analysis of an exact solution of this system gives the domains of similarity parameter defining time lags of the imposed forced oscillations that theoretically provide stability of the final oscillations. The stability pattern shows that the value of time lag decreases with increasing both parameters flame distance from the tube entrance and burnt/fresh temperature ratio.

1. Introduction

There are two problems analyzing the interaction processes between the heat and the acoustic waves. The old one studying heat-driving acoustic oscillations in simple devices, like Rijeke tube, and the other problem which appeared much later after the modern active control technique came to practical use. The huge literature enriched by sixty-years studying of the first problem is presented in many reviews of different models and results of investigations from early elementary understanding [1–3] to current more deeper and practical conceptions [4–12].

The situation with the other problem consisting of understanding and simulation heat–acoustic interaction in active control processes is different. The modern active control techniques include the open-loop and closed-loop control systems. Although these control techniques significantly differ from each other, the physical processes inside the combustion systems in both cases are determined by the interaction between existing in the combustor and incoming flows resulting in output during every control action. This interaction of two different flows with unsteady heat release is the basic physical mechanisms in both types of active control. The problem describing such input–output process of two oscillations–heat release interaction is quite different from simpler one of analyzing and simulating single oscillation–heat release interaction in Rijeke tube and similar devices.

Many various models are used for analyzing control strategies and design different types of the controller. Several reviews [13–19] describe and discuss these approaches giving the understanding of the principles of practical implementing of the active control systems.

At the same time, there are few studies of the input–output interaction mechanism. Dowling and Morgans [19] considered two main approaches for creating acoustic models two study active control mechanism. One is based on Galerkin method expansion and another that uses the wave equation solution. Because the Galerkin expansion method associated with truncating errors, the alternative approach based on wave equation enables more accurate modeling. Well-known examples of models of this type used for active control simulation are discussed below.

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