PREMIXED LAMINAR FLAME MODELING FOR THERMO-ACOUSTICS

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1 Introduction

Noise problems often arise in technical combustion systems like domestic gas boilers or gas turbines. These problems are related to the interaction of acoustic waves in the complete system with the flame. Acoustic waves could lead to fluctuations in the heat release of the flame which could amplify the acoustic wave. This may cause an increase in the acoustic energy in the system, provided the Rayleigh criterion is satisfied. If this happens near eigenmodes of the system, it gives rise to acoustic instability, observed through noise and possibly even system failure if the velocity and pressure amplitudes are very large.

The feedback mechanism between the acoustic field and the heat release fluctuations can have different origins. Sometimes, pressure waves lead to fluctuating fuel flow near the fuel injector, thereby introducing equivalence ratio variations and as a result heat release variations. There are multiple other ways to arrange this coupling. We consider premixed laminar flames to analyse the response to a fluctuating velocity field, resembling an acoustic wave. There are two different mechanisms for the acoustic field-flame interaction. First, flat flames stabilized on surface burners, heat loss fluctuations are generated by the oscillating flame front, subsequently leading to heat release fluctuations. Second, Bunsen-type flames are less sensitive to heat loss fluctuations to the burner. These flames display an oscillating flame surface area, giving rise to a fluctuating heat release in a different way. We will consider both cases due to their different physical nature.

Nowadays, lean premixed flames stabilized on surface burners or small Bunsen-type conical flames stabilized on perforated plates are mostly used in domestic central heating systems. This study discusses the modeling of premixed laminar planar and multi-dimensional flames to study the main physical phenomena expected to play a role. Knowledge of these 'generic' flame structures might give new insight in the field of turbulent flames as appearing, for instance, in gas turbines. A major part of this study focusses on the modeling of the two fundamental flame types: flat flames stabilized on surface burners and Bunsen-type flames on perforated burners with slits and holes. The broad range of burner systems used nowadays in central heating equipment and other household appliances may be considered as mixed variants of these two limiting situations.

As such burner-flame systems can be considered as low-Mach number reacting flows, the acoustic transfer matrix (or flame transfer matrix) $\mathbf{T}$, describing the response of the flame and burner to the acoustic field, is given by

$$\begin{pmatrix} p'_\mathrm{b} \\ u'_\mathrm{b} \end{pmatrix} = \mathbf{T} \begin{pmatrix} p'_\mathrm{u} \\ u'_\mathrm{u} \end{pmatrix} = \begin{pmatrix} 1 & 0 \\ 0 & T_{22} \end{pmatrix} \begin{pmatrix} p'_\mathrm{u} \\ u'_\mathrm{u} \end{pmatrix}. \tag{1.1}$$