Rayleigh Criterion: Theory and Experiments

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Introduction

Turbulent reacting flows are normally associated with "stable" processes, in the sense that the amplitude of fluid dynamic and thermodynamic property fluctuations is small when compared with equivalent average values (e.g. Libby and Williams, 1994). In this case, no periodic correlation exists between fluctuations at a given point in the combustion chamber and fluctuations at another point, with the exception of the turbulent structure.

On the other hand, when correlation in time or in space exists, the oscillatory motions become organised with high amplitudes, leading to unsteady flames. The presence of combustion oscillations in reactive systems has long been a subject of interest. Work in this area has focused on the mechanisms of unstable combustion in solid, liquid and gaseous propellant rocket motors, ramjets and turbojet thrust augmentors, as reviewed with different purposes by Schadow and Gutmark (1992), Candel (1992) and Zinn (1992), Raun et al., (1993) and McManus et al., (1993). In addition, combustion instabilities were also found to occur in other devices such as boilers (Benelli et al., 1984) and industrial combustion chambers (Doresteijn, 1968; Thring, 1969, Putnam, 1971; Eisinger, 1991). It is clear that much has been learnt from previous work applied to rocket motors, jet engine afterburners and ramjets (e.g., Crocco, 1965; Harije and Readon, 1972; Culick, 1988), but whether the unsteadiness is undesirable (as in aeronautic and aerospace applications) or desirable (as in pulse combustor technology), the phenomenon is similar and derives from interactions between the flow field and the combustion process itself.

In general, unsteadiness results from coupling between combustion and gas dynamic processes with oscillatory energy, higher than a critical value related to viscous dissipation, heat transfer and acoustic radiation, being supplied to sustain the oscillations – validating the so called Rayleigh Criterion. Coupling between these unsteady modes and the acoustic modes of the cavity may occur, resulting in so-called combustion-driven acoustic oscillations.

Typical Combustors and Oscillating Modes

Typical combustor geometries, as schematically shown in figure 1, can be classified as open-flames and closed-flame devices.

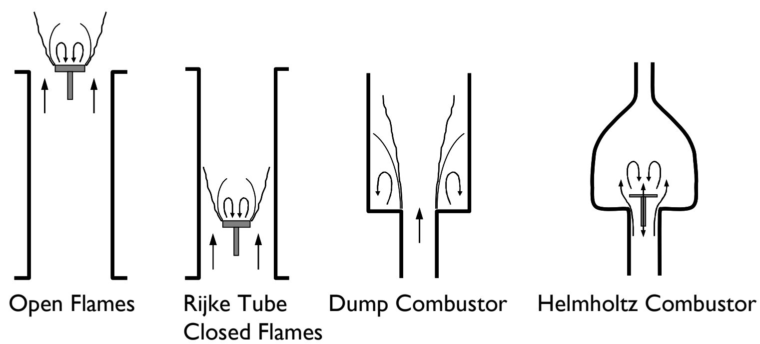

Fig 1 – Typical combustor geometries

Thermoacoustic interaction occurs spontaneously at the natural modes of oscillation of the combustion chamber, with the Rijke tube being the most important example (e.g. Mandarame, 1981; Carvalho et al., 1984; Raun et al., 1993; Carvalho et al., 1989). A further distinction can be made based on the heater type, and consequently, on the coupling mechanisms that support the oscillations. If an electrical device with constant current supply (Mandarame, 1981) or solid fuel bed with constant feed supply (Carvalho et al.,