Determination of Flame Dynamics for Unsteady Combustion Systems using Tunable Diode Laser Absorption Spectroscopy

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Abstract

Lean, premixed combustion has enjoyed increased application due to the need to reduce pollutant emissions. Unfortunately, operating the flame at lean conditions increases susceptibility to thermoacoustic (TA) instability. Self-excited TA instabilities are a result of the coupling of the unsteady heat release rate of the flame with the acoustics of the combustion chamber. The result is large pressure oscillations that degrade performance and durability of combustion systems.

Industry currently has no reliable tool to predict instabilities a priori. CFD simulations of full-scale, turbulent, reacting flows remain unrealizable. The work in this paper is part of a study that focuses on developing compact models of TA instabilities, i.e. acoustics and flame dynamics. Flame dynamics are defined as the response in heat release to acoustic perturbations. Models of flame dynamics can be coupled with models of combustor enclosure acoustics to predict TA instabilities. In addition, algorithms to actively control instabilities can be based on these compact models of flame dynamics and acoustics.

The work outlined in this thesis aims at determining the flame dynamics model experimentally. Velocity perturbations are imparted on laminar and turbulent flames via a loudspeaker upstream of the flame. The response of the flame is observed through two measurements. Hydroxyl radical (OH*) chemiluminescence indicates the response in chemical reaction rate. Tunable Diode Laser Absorption Spectroscopy (TDLAS), centered over two water absorption features, allows a dynamic measurement of the product gas temperature. The response in product gas temperature directly relates to the enthalpy fluctuations that couple to the acoustics. Experimental frequency response functions of a laminar, flat-flame burner and a turbulent, swirl-stabilized combustor will be presented as well as empirical low-order models of flame dynamics.

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