Research Abstract

Role of flame-front instability in expanding turbulent flames

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Introduction

Since most of the practical combustion devices operate in turbulent environments, study of turbulent combustion is fundamentally appealing and practically important. Turbulence enhances the flame propagation by wrinkling an otherwise laminar smooth flame, leading to an increase in the flame surface area and hence the total burning rate. There have been number of studies performed to achieve a scale of the turbulent flame speed theoretically [1-3], experimentally [4-6] and numerically [7-9].

Another mechanism through which a laminar flame surface can be wrinkled is the flame-front cellular instability, which contains two major modes: Darrieus-Landau (DL) instability and diffusional-thermal (DT) instability. Darrieus-Landau instability is caused by the sharp temperature gradient across flame front causing a divergence or convergence of the flow, and diffusional-thermal instability is triggered by a mismatch in the species and thermal diffusion, i.e. preferential diffusion [10]. A large number of theoretical analyses [11][12], experiments [13][14] and simulations [15][16] have been reported about the dynamics of cellularly unstable flames.

Since the operating conditions of practical turbulent flames often include high pressure and off-stoichiometric mixtures with non-unity Lewis number, it is essential to study the interaction between turbulence and the cellular instability on flame propagation. Matalon [12] derived an analytic solution for the cellular instability in premixed expanding flames, which is

$$\frac{1}{A}\frac{dA}{dt} = \frac{\dot{R}}{R}\left(\widetilde{\omega_{DL}} - \frac{l_f}{R}\left[\widetilde{B_1} + \beta\left(Le_{eff} - 1\right)\widetilde{B_2} + Pr\widetilde{B_3}\right]\right) \qquad (1)$$

where A is the amplitude of disturbance, $\widetilde{\omega_{DL}}$ stands for the Darrieus-Landau instability and it is only a function of the thermal expansion ratio σ, while $-\frac{l_f}{R}\left[\widetilde{B_1} + \beta\left(Le_{eff} - 1\right)\widetilde{B_2} + Pr\widetilde{B_3}\right]$ represents the diffusional-thermal instability. From equation (1), we note that the two important parameters of the cellular instability are the growth rate of the Darrieus-Landau instability and the Lewis number of the mixture. Recognizing their role in flame propagation, the candidate has studied their effect in turbulent flames at conditions for which the laminar flames are cellularly unstable.

Current Work

First, we have conducted experiments at a wide range of pressures where the laminar flames exhibit the DL instability, and subsequently we performed turbulent experiments to evaluate the interaction. The Lewis numbers of the mixtures used in these experiments are maintained to be unity to eliminate the DT instabilities. We compared the turbulent flame speed with and without the Darrieus-Landau instability in different regimes of the turbulent combustion regime diagram. Then, we redefined the regimes to reflect the role of DL instability on turbulent flame propagation.

Next, we conducted experiments to evaluate the role of the Lewis number on the turbulent flame propagation. Here, by maintaining low adiabatic flame temperature, and by operating at relatively low pressures (1 to 2 atm), the DL instability is weak and hence suppressed. Again, turbulent flames in different regimes with a large range of sub-unity *Le* are studied.

Results from the above investigations will be presented at the committee meeting.

Future work

In the future, we plan to measure the local cell size distribution under laminar (DL and DT instability), turbulent stable (no instability) and turbulent unstable (DL or DT instability) conditions. Recognizing that in previous studies we focused on flame speed which a global ensemble averaged quantity of local flame front wrinkling, cell size distribution would provide a more fundamental level of interaction. Moreover, the suitability of using fractal and multifractal descriptions to model cellularly unstable and turbulent flame fronts will be explored.

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