



Theoretical and numerical study of the variation of flame speed with oscillating stretch

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The use of lean hydrogen technologies requires accurate combustion models for CFD, which is a challenge. First because these flames present negative Markstein numbers ($Ma < 0$) leading to a high sensitivity of the laminar flame speed to turbulent stretch [1]. Secondly because the low laminar flame speed of such mixtures induces a large range of Karlovitz numbers from unity to hundreds, meaning that turbulent time-scales can be both much larger or smaller than the flame time [2].

To contribute to this task, this study aims at elucidating the sensitivity of consumption and displacement speeds of laminar flames submitted to unsteady strain and curvature oscillations for both negative and positive Markstein number flames. For this purpose Joulin's theory [3], based on constant density and diffusivity hypothesis, is extended to cover different definitions of the consumption speed and displacement speed.

The theory is then validated against a set of detailed numerical simulations for oscillating counter-flow flames of lean hydrogen/air ($Ma < 0$) and stoichiometric iso-octane/air ($Ma > 0$) mixtures. An original procedure is proposed to deduce the Markstein lengths from two sets of DNS: one considering only strain oscillations, the other one both strain and curvature.

For both flames, results reveal a good agreement between theory and simulations in terms of high frequency asymptotic Markstein numbers. It is first verified that for all definitions of the flame speed considered, the sensitivity to strain rate vanishes at high oscillation frequencies, as found in previous studies. In contrast, sensitivity to curvature remains finite and proportional to the fuel diffusivity at high frequencies for all flame speeds considered, except for the consumption speed defined as the line integral of the reaction rate in the direction normal to the flame. Two other definitions, valid for all chemistries and curvatures, show an extra sensitivity of the consumption speed at high oscillation frequencies which is purely a geometrical effect due to the choice of the reference surface. This effect leads to different curvature Markstein numbers at all frequencies.

The rate of relaxation of Markstein numbers towards their asymptotic values is qualitatively well reproduced by theory for the hydrogen flame, less so for the iso-octane flame, probably because it doesn't satisfy correctly the deficient species assumption used in the theory.

References

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