Turbulence generation by planar detonations in heterogeneous mixtures

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A detonation wave is a supersonic combustion wave across which the thermodynamic variables (e.g., pressure and temperature) increase sharply. It can be considered as a reacting shock wave where reactants transform into products, accompanied by an energy release across it [1].

Detonation waves have been explored extensively for propulsion applications (e.g., pulsed detonation engines) because of their theoretical advantage over deflagrative combustion. One of the major problems is the lack of understanding of the heat transfer characteristics and the noise generation mechanism of the system [2]. In this work we will analyse the effect of local perturbations in the fuel mass fraction mimicking the effect of mixture heterogeneities on detonation dynamics.

Unlike detonations moving in low-vapor pressure liquid fuel-air mists or sprays, the characteristics of detonations in high-vapor-pressure liquid fuels are similar to those of gaseous detonations. The multidimensional structure of the detonation front may play a pivotal role in the detonation dynamics and the burnt-gas properties [3]. It has been reported that, when moving through fuel-air sprays with large droplets, detonations exhibit a deficit in the propagation velocity compared to the gas-phase velocity [4]. Similar studies have investigated the effect of water droplets immersed in gaseous reactive media [5].

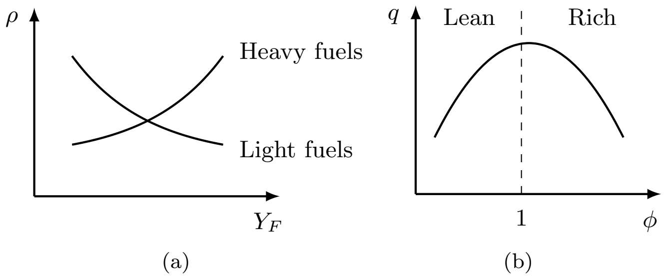

FIG. 1: Variation of mixture density (a) and heat release (b) with the fuel mass fraction and the equivalence ratio.

A linear stability analysis is proposed to investigate the effect of local perturbations in the fuel mass fraction emulating the mixture heterogeneity. The probability density distribution of the fuel concentration, assuming small deviations with respect to the average properties, is taken to be isotropic, with the characteristic size being much larger than the detonation thickness in the fast-reaction limit considered in the analysis.

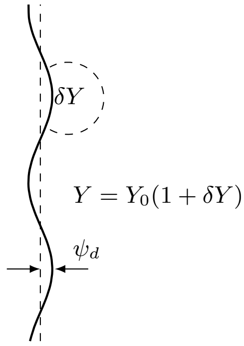

FIG. 2: Sketch of the corrugated detonation front, where ψ_d is the amplitude of the detonation shape deviations respect to the planar shape.

Two main parameters are identified. The variation of density (ρ) with the fuel mass fraction (Y_F), which distinguishes light and heavy fuels, and the variation of heat release (q) with the equivalence ratio (ϕ), which roughly distinguishes lean and rich mixtures (see Fig. 1). Constructive and destructive interferences of both effects are expected (see Fig. 2), the former corresponding to light/lean and heavy/rich configurations and the latter for the two other cases. This may lead to qualitatively different results in the non-homogenous flow downstream. Akin to non-reactive shocks [6], the generation of turbulence and noise induced by detonation vibrations will be also addressed, and the impact on the average propagation velocity will be quantified.

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