A shock dynamics approach for analyzing two-dimensional numerical detonation cells in gases

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The reaction zone of a detonation in gases exhibits a three-dimensional, unsteady cellular structure. Thus, the leading shock of self-sustained detonations consists of Mach stems –the cells– with longitudinal shocks that cyclically decelerate from velocities greater than to lesser than the Chapman–Jouguet value D_{CJ}, with continuously decreasing total curvature. Relationships between the normal shock velocity D_{n}, the normal acceleration $\dot{D}_{\mathrm{n}}$, and the total curvature κ have been commonly used to analyze the dynamics of these shocks and the physics of the flow that sustains them.

For example, Jackson et al. [1, 2] have analyzed the cell dynamics with D_{n}-κ and D_{n}-$\dot{D}_{\mathrm{n}}$-κ relationships for the detonation in a straight channel. Based on a D_{n}-κ relationship evaluated from the shock front of a cell, they identified three features [1]: reactive Mach stem, inert blast wave, and the transition between the two. With a D_{n}-$\dot{D}_{\mathrm{n}}$-κ relationship evaluated along the normal to the detonation cell front, they observed a surface in the D_{n}-$\dot{D}_{\mathrm{n}}$-κ space during a cell cycle [2]. However, their analysis addressed the specific case of a very weakly unstable mixture with a one-step chemistry, a high specific heat ratio $\gamma \sim 1.6$, and a single cell in the channel width. By contrast, the present work considers D_{n}-$\dot{D}_{\mathrm{n}}$-κ relationships evaluated from two-dimensional simulations, with detailed chemistry and several cells in the channel width [3, 4].

In the main, for the regular hydrogen-based mixture $2\,H_2 + O_2 + 7\,Ar$, the same three features as in [1, 2] are observed. For the irregular $2\,H_2 + O_2$ mixture, forward jetting and compression waves from the delayed combustion of unburnt pockets can significantly modify κ and $\dot{D}_{\mathrm{n}}$. Further analysis then confirms the shock-ignition criterion expressing boundedness of the induction time [5–7], i.e., a rate of heat production greater than that of adiabatic cooling from volumetric expansion, that shock-flame decoupling in cells depends more on flow unsteadiness ($\sim \dot{D}_{\mathrm{n}}$) than on flow divergence ($\sim \kappa$).

References

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