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Numerical investigation on the influence of Aluminum particles on hybrid H_2–Air Detonations

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The influence of reactive particles on gaseous detonations needs to be investigated to enhance explosion safety and leverage their potential in propulsion and energy applications. Based on particle characteristics, detonations are classified as heterogeneous (reactive particle + oxidizer), hybrid (reactive particle + reactive gas + oxidizer), or dusty (inert particles + reactive gas + oxidizer) [1]. This study focuses on hybrid detonations with metal particles. We use an in-house Eulerian–Eulerian solver, HyBurn [2], to simulate gas–particle dynamics. Turbulence is modeled using implicit LES with a low-Mach correction to the Riemann solver [3]. Simulations are conducted for Al–H_2–air detonations in a narrow 2-D channel filled with stoichiometric H_2–air and a uniform aluminum particle volume fraction ($\phi_{\mathrm{Al}} = 0.25$) with monodisperse 1 μm particles. Aluminum was selected for its high energy density and ease of production. Addition of Al particles reduced the detonation cell size and increased the reactivity. In the stoichiometric case ($\phi_{\mathrm{H_2}} = 1$), the added heat from particle combustion accelerated H_2 reactions, increasing D_{CJ} from 1950m/s [4] to 2090m/s. Mixtures with $0.1 < \phi_{\mathrm{H_2}} < 1.8$ were then examined, which showed that addition of Al-particles extended detonation limits for lean mixtures from $\phi_{\mathrm{H_2}} = 0.7$ to 0.5 by sustaining shock–flame coupling. D_{CJ} peaked at 2195 m/s for $\phi_{\mathrm{H_2}} = 1.2$ and declined with richer mixtures. In fuel-rich cases, Al particles can either promote or hinder detonation, depending on competition with H_2 for available oxygen. Ongoing work investigates the conditions favoring each reaction pathway.

References

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