Double Cellular Detonations in H_2-NO_2/N_2O_4 Mixtures: 2D Numerical Study

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Detonation waves in hydrogen–nitrogen oxide mixtures (i.e. H_2NO_2/N_2O_4) can exhibit a double cellular structure under certain conditions, believed to be attributed to a two-stage heat release process with different amplitudes and timescales. This study presents new insights into the behavior of these detonations through two-dimensional (2D) numerical simulations with detailed chemistry, and where momentum losses have been taken into account using a simple flow-divergence model. Although previous experiments on H_2-NO_2/N_2O_4 detonations have confirmed the existence of this double structure at high pressures, its disappearance at lower pressures has remained an open question. Our simulations confirm that at ambient pressures, at 100 kPa, a well-defined double cellular detonation structure persists. However, at lower pressures, 25 kPa, a significant velocity deficit occurs when momentum losses are present, and a transition to a single, irregular cellular structure is observed. When losses due to flow divergence are omitted at low pressures, the double cellular structure is restored. This finding highlights the sensitivity of detonation structure to hydrodynamic losses. The results suggest that the transition from double to single cellular structures is not solely a function of pressure but also depends on the hydrodynamic losses. In this sense, it is likely that losses cause elongation of the cellular structure in such a way that only the fine structures are captured by simulation at low pressures with losses, while the large structures extend beyond the physical domain simulated. The relevance of these findings extends beyond hydrogen detonation physics, offering valuable analogies to thermonuclear detonations in Type Ia supernovae. In particular, the multiscale detonation structures observed in C+O mixtures (Gamezo et al., 1999; Khokhlov, 1989) show similar sensitivities to reaction kinetics, shock dynamics, and energy release variations. The transition from double to single structures at low pressures in H_2-NO_2/N_2O_4 mixtures may provide insights into how thermonuclear reactions evolve in white dwarf explosions, particularly in regimes where reaction-zone structures influence large-scale supernova dynamics. Future work will focus on increasing numerical resolution better to capture the coupling between chemical kinetics and hydrodynamics, further refining the connection between terrestrial detonations and supernova explosion models.
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