Gallery of Fluid Motion

Premixed-flame oscillations in narrow channels

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Propagation of premixed flames in confined vessels typically undergoes oscillatory motions due to the coupling of the reaction front, the induced flow dynamics, and acoustics. The first scientific report regarding thermoacoustics [1] appeared over two centuries ago and, because of its practical importance, great effort has been done since then to understand the phenomenon [2]. However, most of the experimental research has been performed in vertical tubes [3] under strong buoyancy effects. Here, the first thermoacoustic study reported in a horizontal narrow-channel (Hele-Shaw) vessel, as described in [4], has proved instrumental to further understand the dynamics of the instability.

First, a top-view composition of a lean flame with equivalence ratio $\phi = 0.8 < \phi_{cr}$ and a rich one with $\phi = 1.2 > \phi_{cr}$ is shown in Fig. 1. The parameter ϕ_{cr} indicates the critical equivalence ratio at which the flame transitions from the primary acoustic regime, experiencing small-amplitude oscillations and acoustic waves of the order of hundreds of Pascals, to the secondary acoustic instability, encountering large-amplitude oscillations with a characteristic finger-shaped front and pressure waves one order of magnitude higher.

In addition, a detail of the evolution from primary oscillations to the secondary regime is shown in Fig. 2, offering unprecedented lateral perspectives of the flame front during successive cycles of the aforementioned process. In column (a), shortly after ignition, the flame propagates experiencing smooth oscillations and maintaining a parabolic front, before evolving to a nearly planar flame (b). Next, the flame develops a rippled front, with a cell wavelength smaller than the separation between plates $h = 10$ mm (c). These new cells progressively wrinkle the front and the flame quickly increases its oscillation amplitude (d) that finally undergoes a violent beat (e)

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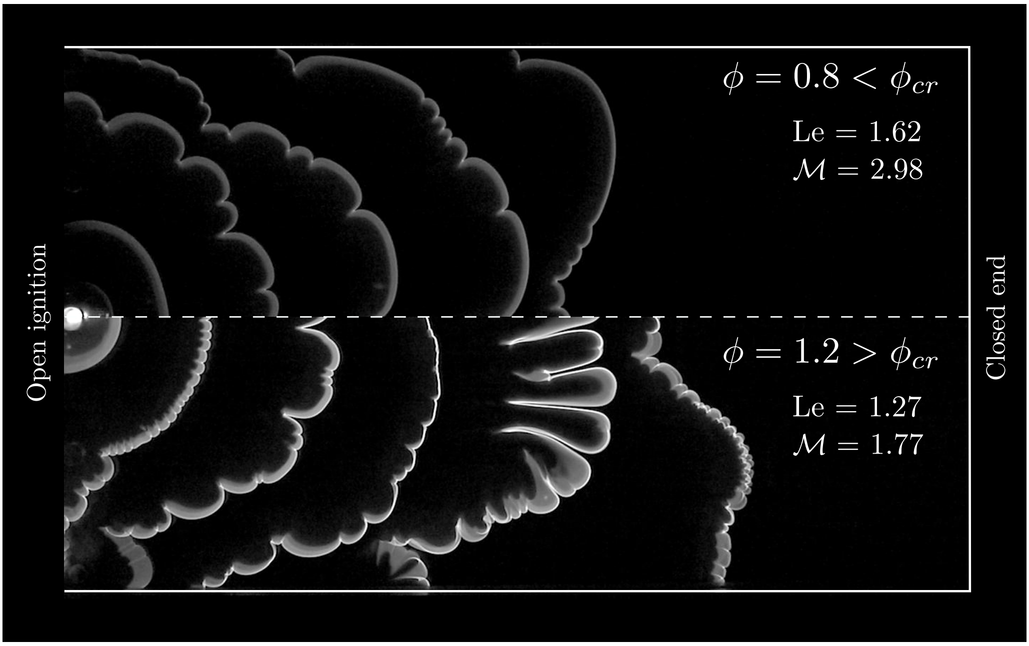

FIG. 1. Top view of premixed propane-air flames propagating in a 900-mm-long, 500-mm-wide, and 10-mm-thick vessel open at the ignition end. https://doi.org/10.1103/APS.DFD.2018.GFM.V0018

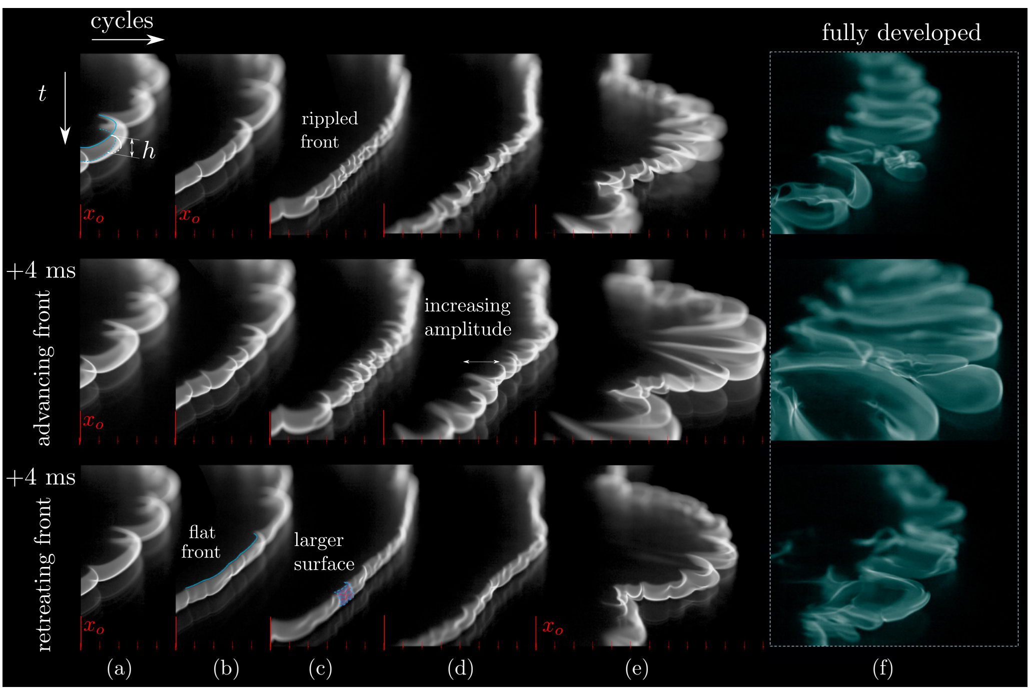

FIG. 2. Side-view detail of the instability transition. Columns (a)–(e) show the reactive front at the beginning, peak, and trough of each cycle. Red vertical lines determine the origin of the picture x_o (long) and spatial references (short). Column (f) shows fully developed secondary oscillations at a different location. https://doi.org/10.1103/APS.DFD.2018.GFM.V0018

at a frequency near 100 Hz and velocities of around 10 m/s. Fully developed instabilities display complex dynamics during the late stages of the propagation (f). Although elaborate discussions on thermodiffusive parameters (effective Lewis number Le), front curvature and strain (Markstein number $\mathcal{M}$), equivalence ratio (ϕ), and acoustic effects have been previously offered in the literature, the exact physical mechanism responsible for the transition remains unsolved.

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