Premixed flame instability in a Hele Shaw burner

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PREMIXED FLAME INSTABILITY IN A HELE-SHAW BURNER

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Summary: Experiments were performed with propane- and methane-air mixtures in a 2D-Hele-Shaw burner to determine the characteristic scales of the premixed flame instability that can be used to define an evolution equation for the front. It is found that the most unstable wavelength, depending on the Lewis number of the mixture, and the linear rate of growth of perturbations, directly measured in the present experiments, have the same order of magnitude than those previously measured on planar flames propagating freely downwards in wide tubes.

INTRODUCTION

Combustion instabilities are of primary importance for turbulent burning in actual burners and there are some hopes so that they can be simulated using a model equation such as the Sivashinsky nonlinear equation first proposed in 1977 for the flame front propagation [1]. Large-scale flame front in a number of configurations were studied theoretically and numerically [2,3] in good qualitative agreement with the experiments [4]. However a quantitative comparison is hardly expected unless a 2D-flame can be observed.

To this end, we study a flame propagating in a Hele-Shaw burner where the flame dynamics is more easily recorded than in a cylindrical burner. The only parameters of the model are a cut-off wavelength λ_c and a characteristic growth rate σ of the most unstable perturbation with wavelength $\lambda_{max}\sim 2\lambda_c$. These parameters can be estimated knowing the unstable wavelength at the onset of instability for a planar flame propagating downwards [5], and some direct measurements of the rate of growth σ were performed as a function of the wavenumber of the flame perturbation [4,6]. But these values are not directly to be carried forward on the present configuration, since a point is to know whether the mechanism of instability can be described in the same way in a 2D configuration and for a 3D planar flame [7].

The burner consists of two glass plates 0.50 m wide and 1.5 m high, separated by a gap width of 5 or 10 mm. An acoustic damper, situated at the bottom, prevents the thermo-acoustic instabilities by damping the reflection of acoustic waves. After each run, the airflow is opened and maintained until the tube walls have cooled to ambient temperature. The flow of combustible, methane or propane, is then adjusted to the desired equivalence ratio and a 2D inverted V-flame is ignited at the top of the burner with a lighter. Closing the valve at the bottom of the burner then stops the flow and the downward flame propagation is recorded thanks to a high-speed camera (Fig. 1-2).

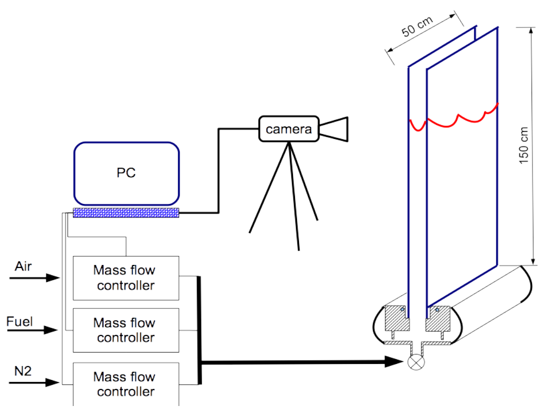

Figure 1: Experimental set-up

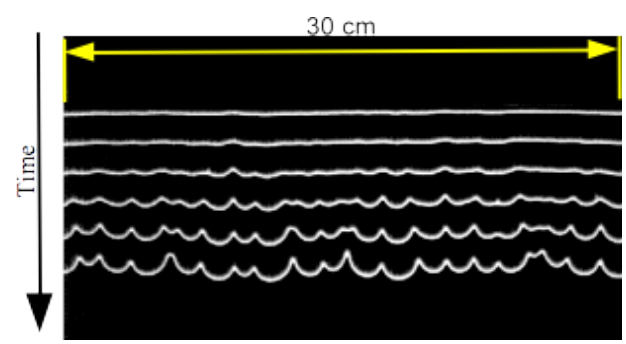

Figure 2: Flame front at successive moments separated from 16 ms (vertical scale expanded)

EXPERIMENTAL RESULTS

Experiments were performed with propane and methane-air mixtures whose dynamic properties are a priori known [5]. Near stoichiometric mixtures were diluted with nitrogen in order to reduce the growth rate of the perturbations and to improve the accuracy of the measurements. The initial flame contour appears relatively flat (Fig. 2), so Fourier analysis of the successive records of the flame contour can give access to the linear growth rate of the spontaneously excited

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perturbations of the flame (Fig. 3). Using this procedure, we only access to the growth rate of large wavelengths of perturbations (Fig. 4, colored symbols) as the information on the domain of large wavenumbers is quickly hidden by the most unstable response of the flame. Introducing a plate with periodic bights a few centimeters above the burner exit, it is possible to force the flame response at the desired wavelength, so extending the measurements of the dispersion relation to larger wavenumbers k=2π/λ (Fig. 4, black symbols). A best parabolic fit through these data (blue line) compares favorably with previous measurements (large red symbol) and with the classical relation [5-7]: the slope dσ/dk at small wavenumber is close to the one calculated by considering only the Darrieus-Landau instability, and the general trends of this curve resemble the hypotheses used in Sivashinsky's simulations. In particular, the large-scale cut-off wavelength is close to the one calculated with gravity effects, the small-scale cut-off wavelength is about half the most unstable wavelength, and its value varies with the equivalence ratio of the combustible mixture (not shown here) in relation with Lewis number effects [8].

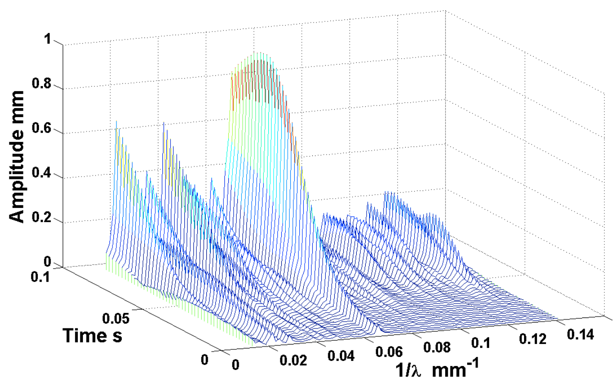

Figure 3: Spectrogram of successive flame contours with forcing at λ=15mm; propane-air, ϕ=0.7, δ= 0.21

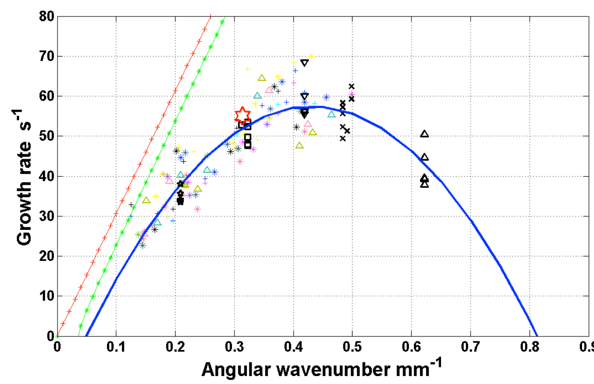

Figure 4: Measured growth rate of propane-air flame (ϕ=0.7, δ= 0.21) compared to the dispersion relation of Darrieus-Landau instability with (---) or without (---) gravity effects. See text for the meaning of the symbols.

However, these wavelengths are slightly larger than those measured at the onset of instability of planar flames propagating downwards, probably because of 3D-effects that modify the 2D flame speed and the transverse flux, inducing changes in the expansion ratio that controls the rate of growth.

CONCLUDING REMARKS

These experiments confirm that the dynamics of 2D-flame that can be observed in a Hele-Shaw burner is analogous to the dynamics of planar flames previously described, with only small changes needed to correct the cut-off wavelength and the growth rate for 3D effects. It is thus probable that these flames could be relevantly simulated using a model equation such as the Sivashinsky's equation.

Acknowledgements: This work was supported by the French National Research Agency under agreement ANR-14-CE05-0006 and it has been carried out in the framework of the Labex MEC (ANR-10-LABX-0092) and of the A*MIDEX project (ANR-11-IDEX-0001-02).

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