Assessment of Accurate Laminar Flame speed Measurements

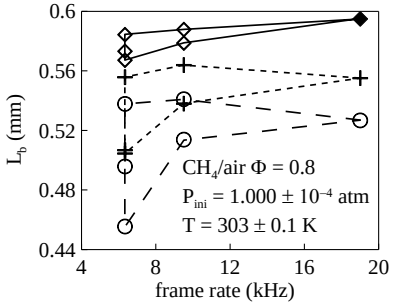
J. Goulier[1, 2], D. Nativel[1], N. Chaumeix[1], N. Meynet[2]
[1]ICARE CNRS, 1C av de la recherche scientifique 45000 Orléans, France,
[2]IRSN PSN-RES/SAG/BPhAG, 92262 Fontenay Aux Roses, France

In the framework of the safety analysis of hydrogen explosions in nuclear power plants, fundamental properties of combustion of hydrogen based mixtures are needed. Among them, laminar flame speed. Indeed its knowledge is important since (i) it is the reference value used in turbulent models used in CFD codes for the assessment of explosion hazard in addition to (ii) the validation of detailed or reduced mechanism which will be used to derive the activation energy needed in the evaluation of the tendency of a flame to accelerate strongly. As such, it is important to verify for a given configuration the impact of the methodology on the precision that one can expect on the laminar flame speed final value. During this study, the outwardly expanding spherical flame of methane/air mixtures at ambient temperature and pressure is chosen to assess (i) resolution and frame rate of the images; (ii) the image processing routine; and (iii) the theoretical model to derive the laminar flame speed. Methane was chosen as a target for comparison with the literature. The resolution and frame rate of cameras have drastically increased over the past few years, since the memory of the camera is a fixed quantity, increasing the resolution reduced the number of images and vice versa. The visualization of the flame front was obtained via a Z shape Schlieren diagnostic coupled with a high speed camera. Four quartz windows of 97 mm diameter are present on the equatorial plan of the vessel for optical diagnostics. Three different cameras ensure the acquisition of images. The resolution and frame rate used are summarized in the following table:

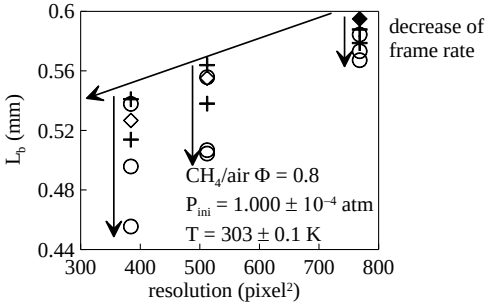
Camera	Resolution used (pixel²)	Framing rate (Hz)	Pixel size (µm)
Phantom v1210	768x768 ; 512x512 ; 384x384	19.000	28
Phantom v711	768x768 ; 512x512 ; 384x384	19.000	20
Photron APX 120K	512x512	6.000	17

For the extrapolation of the unstretched fundamental flame speed SL_0 and the Markstein length L_b both linear (Markstein and Karlovitz) and non-linear (Romney and Sivashinsky) method were used and compared. Two equivalence ratios of methane/air mixture have been studied, 0.8 and 1.1 at ambient temperature and pressure. To exclude the effect of the ignition energy, the minimum radii used to determine the flame speed is 10 mm.

Overall, the new non-linear extrapolation technics conducts to similar values of the laminar flame speed (1% variation between linear and non-linear) but has a stronger impact on the Markstein length (variation up to 30% between linear and non-linear). The standard deviation of each parameter is reduced with the non-linear extrapolation from one experiment to the other. Our results are consistent with the one found in the literature (E. Varea et al., C&F 2012 and T. Tahtouh et al., 4th ECM 2009).To highlight the impact of the resolution and frame rate, each experiment at 768 x 768 pixels and 19 kHz were duplicated into 17 different cases. Both the resolution and frame rate were reduced to 512 x 512 pixels and 384 x 384 pixels and the frame rate was divided by 2 or 3 to 9.5 kHz and 3.64 kHz. The purpose of this reduction was to eliminate all the variation between experiments (initial energy, vessel size…) and only observed the deviation due to the resolution and number of images. The effects of the variations on the Markstein length are presented on the figures below.



Markstein length as a function of the frame rate for a CH4/air at Φ = 0.8, 760 torr and 303 K. Diamond, crosses and circle match respectively for 768 pixels², 512 pixels², 384 pixels² images.



Markstein length as a function of the picture resolution for a methane/air mixture at Φ = 0.8, 760 torr and 303 K

As the frame rate increases, the number of images that can be used increases; therefore the laminar flame speed and the Markstein extrapolated are more weighted and the scattering of the result is reduced. A higher resolution increases the precision on the determination of the radius over time; therefore the scattering of the results is reduced from an experiment to another. Our study shows that the resolution of the CCD has a higher impact on the laminar flame speed and Markstein length than the framing rate.