

# Investigations on the flamelet inner structure of turbulent premixed flames

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## Introduction:

Interactions between flame and turbulence are of primary importance to understand the combustion mechanisms in all practical combustion systems. Numerous studies have been performed to classify premixed turbulent flames and investigate their regimes [1-9]. Numerical simulations [4, 3] have shown that the flamelet regime, which corresponds to the regime where the flame front behave like a quasi-laminar flame, can be extended away from the Klimov-Williams criterion, where small turbulent eddies enter the preheat zone but are not energetic enough nor small to disturb the reaction zone. Bray [1] and Peters [2] have presented combustion diagrams taking in account these extensions.

In the present study, we investigate the flamelet inner structure of Bunsen type turbulent premixed flames by using planar Rayleigh measurements. We mainly focus on curvature/flame front thickness interactions.

## Experimental setup

A stainless steel cylindrical combustion chamber shown in Figure 1-a has been developed enabling to work under pressure up to 1 MPa. The burner, shown in Figure 1-b, is a classical axisymmetric Bunsen burner, fed by premixed methane-air. The internal burner diameter is 25 mm. A perforated plate is located 50 mm upstream the burner exit and generates the flow turbulence. An annular laminar methane-air pilot flame stabilizes the turbulent main flame.

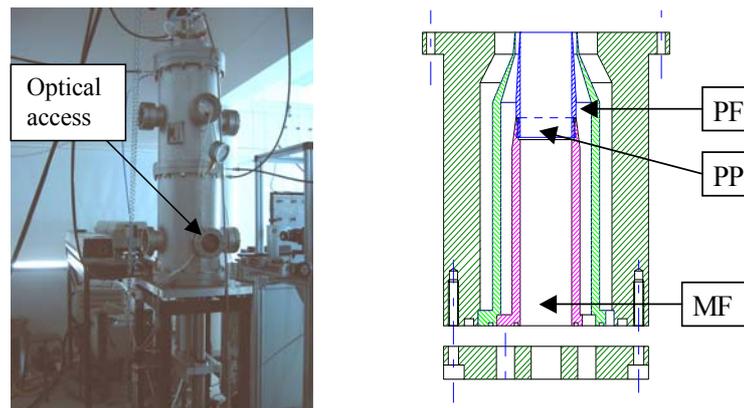


Figure 1 : a) Combustion chamber.

b) Schematic view of the burner (PF = pilot flame; PP = perforated plate; MF = main flow).

A 15 Hz pulsed Nd-Yag laser at 532.5 nm is used for Rayleigh scattering. The pulse energy is 180 mJ. The laser beam passing through a 500 mm focal length spherical lens and a -50 mm focal length cylindrical lens produces a light sheet 50  $\mu\text{m}$  thick and approximately 50 mm high.

The Rayleigh scattered light is collected at 90° to the sheet by an intensified camera. The field of view of the camera is 14\*14 mm<sup>2</sup>. The overall resolution is 27.3 μm/pixel.

### Image treatment:

Temperature profiles through instantaneous flame fronts are determined together with the flame front curvature from Rayleigh scattering images. Correlations between these two quantities are then examined. To obtain the local flame front thickness, we use the thermal thickness definition as  $\delta_{th} = \frac{T_p - T_r}{(dT/dz)_{max}}$ , with  $T_p$  and  $T_r$  products and reactants temperature respectively.

For each Rayleigh image, the flame contour at  $c=0.5$  ( $c = \frac{T - T_r}{T_p - T_r}$ ) is identified. Segments perpendicular to such contours are determined every 50 pixels of the contour to obtain the local instantaneous temperature profiles as shown in Figure 2-a.

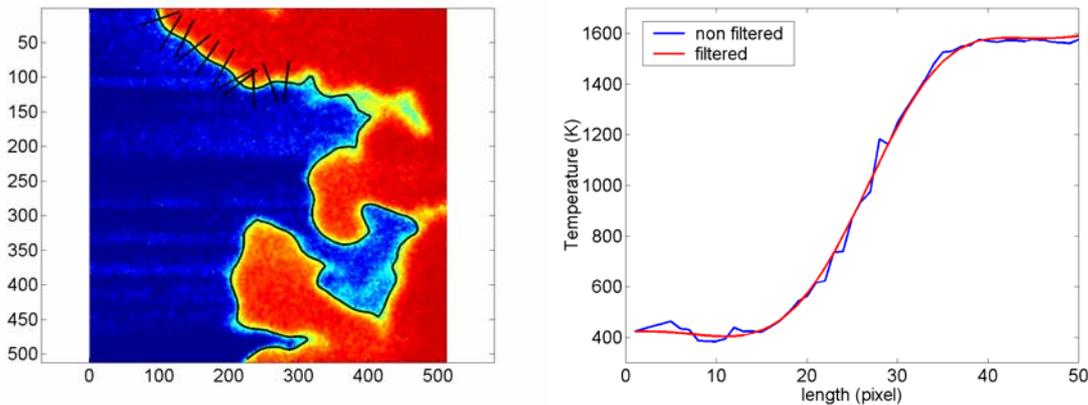


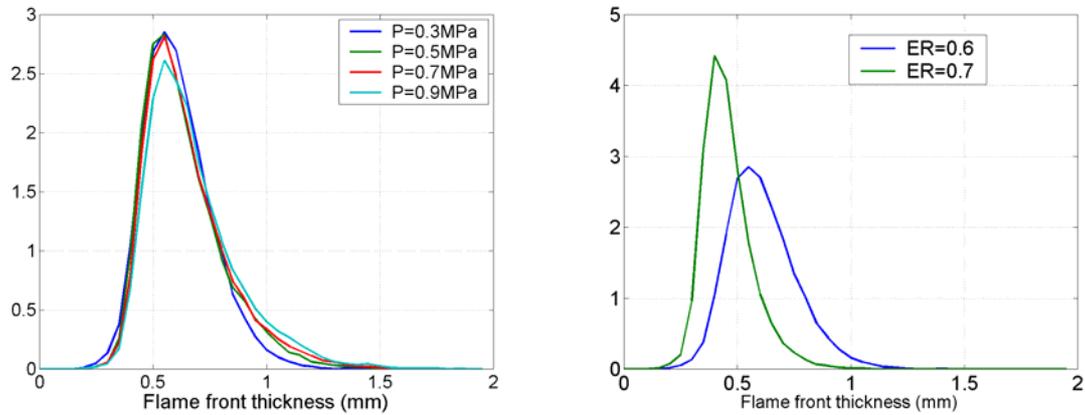
Figure 2 : a) 2D Rayleigh picture. b) Example of local temperature profile filtered and non filtered.

Each temperature profile is filtered and the maximum gradient of this profile is calculated. We use 500 pictures to construct the PDFs of flame front thickness. In addition, the PREMIX code is used to calculate the laminar thermal flame thickness. The used chemical kinetic mechanism is the GRI mechanism.

### Results:

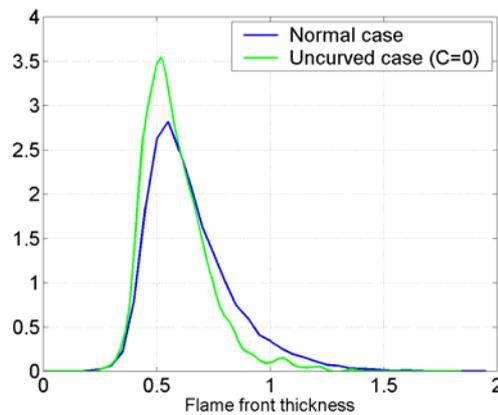
PDFs of flame front thickness are first studied (Figure 3-a). No pressure effect is observed on the average value of the instantaneous and local thermal thickness whereas computations show a decrease of the laminar thickness with pressure increase at constant equivalence ratio. However, when we consider the effect of the equivalence ratio for a fixed pressure (Figure 3-b), we remark a modification of the PDF: when we increase the equivalence ratio from 0.6 to 0.7, the mean thickness decreases. This is coherent with laminar flame computations.

The image analysis we performed allows to obtain simultaneously the flame front thickness and curvature for all the positions on the flame edge. So we can concentrate our study only on uncurved flame fronts, in order to obtain uncurved flame front thicknesses.



**Figure 3 : a) pdf of flame front thickness for different pressures, ER=0.6.  
b) pdf of flame front thickness for different equivalence ratio, P=0.3MPa.**

Differences are obtained with the PDFs of uncurved flame front thickness (Figure 4), but pressure effect is almost always the same.

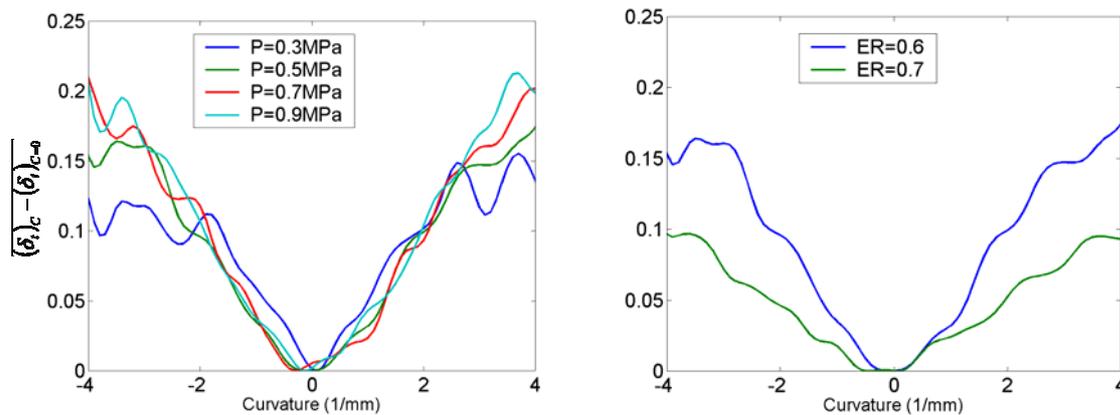


**Figure 4 : PDFs of flame front thickness for the normal case and the uncurved one.**

Finally, we investigated the curvature effect on the average flame front thickness. Pressure effects on flame front curvature were described in [10].

We first observe that the average thermal thickness increases with curvature and that curvature effect is the same for positive and negative curvatures. Moreover, for a fixed equivalence ratio, the pressure effect is pressure independent (Figure 5-a).

However, when we change the equivalence ratio of the mixture, important differences are observed (Figure 5-b). The effect of curvature on the flame front depends therefore mainly on the mixture and according to our results, the dependence of the flame front to curvature decreases when the equivalence ratio is increased.



**Figure 5 :** a) Curvature effects on flame front thickness for different pressures, ER=0.6.  
b) Curvature effects on flame front thickness for different equivalent ratios, P=0.5 MPa.

## Conclusion

Planar Rayleigh scattering measurements were performed to investigate the inner structure of flamelets in premixed turbulent Bunsen flames. Pressure was varied from 0.3 to 0.9 MPa for two equivalence ratios (0.6 and 0.7). Local information regarding the thickness and the curvature of the flamelets were obtained. PDFs of flame front thickness were constructed. Contrary to the laminar case, the mean thermal thickness of the flamelet is almost the same when the pressure is increased from 0.3 to 0.9 MPa. Concerning the impact of the equivalence ratio, the results are in accordance with laminar flame computations.

We also investigated the impact of curvature on the flame front thickness. The curvature has the same effect on the flame front thickness when the mixture is the same, whatever the pressure. However, when we change the equivalence ratio, the impact of curvature on the flame front thickness is different. The dependence of the flamelet thickness to curvature is decreased when the equivalence ratio is increased from 0.6 to 0.7.

## Acknowledgments

This work has been supported by the Centre National de la Recherche Scientifique, the region Centre and the European commission [AFTUR project (Alternative Fuels for industrial Gas Turbines), Contract N°: CEE ENVK5-CT-2002-00662]. FH is supported by a grant from the CNRS and the Conseil Regional Centre.

## References

- [1] K. N. C. Bray, *Proceedings of the Combustion Institute*, 1996, pp. 1-26.
- [2] N. Peters, *Cambridge Monographs on Mechanics*, 2000.
- [3] T. Poinso, et al., *Proceedings of the Combustion Institute*, 1990, pp. 613 - 619.
- [4] T. Poinso, et al., *Prog. Energy Combust. Sci.*, 1995, pp. 531-576.
- [5] A. Buschmann, et al., *Proc. Comb. Inst.*, 1996, pp. 437-445.
- [6] A. Soika, et al., *Proc. Comb. Inst.*, 1998, pp. 785-792.
- [7] L. P. H. de Goey, et al., *Proc. Comb. Inst.*, 2004.
- [8] C. Kortschik, et al., *Comb. & Flame*, 2004, pp. 43-50.
- [9] C. J. Sung, et al., *Comb. & Flame*, 1996, pp. 168-183.
- [10] T. Lachaux, et al., *Proc. Comb. Inst.*, 2004.