Experimental study by high-speed particle image velocimetry of unsteady flame-wall interaction in turbulent combustion

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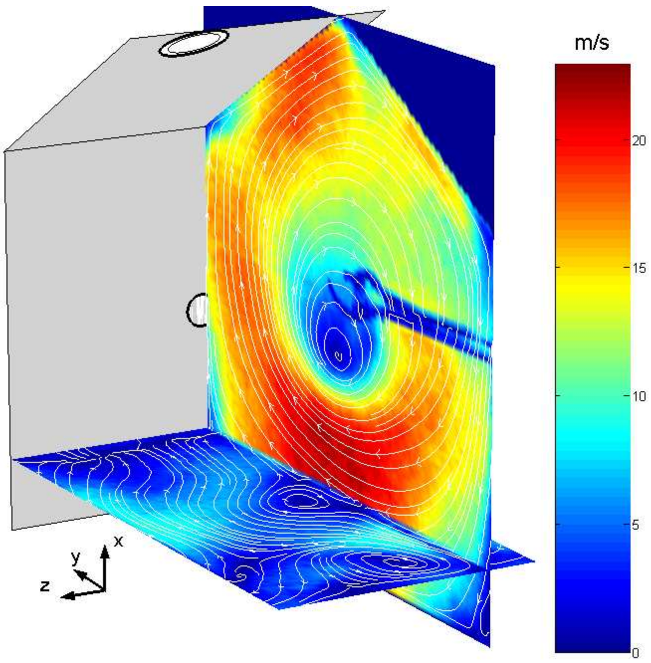
Keywords: Turbulent Combustion, Flame-Wall Interaction, Heat Transfer, PIV Post-Processing

The investigation of near-wall combustion is essential to improve critical aspects of combustion engines, such as emissions and efficiency. In the present study, focus is made on wall heat losses which modelling is still to be improved.

Turbulence and advection have a strong effect on the behaviour of combustion, and particularly on heat losses. Thus, wall heat flux is recorded with a thin film thermocouple gauge, and flow field is investigated through high-speed Particle Image Velocimetry (5 kHz). Indeed, laser techniques such as Laser Doppler Velocimetry are often performed in reciprocating engines. However, fluid seeding is usually preferred for lubrication requirements in engines, so measurements are limited to the flow field in fresh gases. In the present study, a single-shot combustion chamber of constant volume enables mineral seeding of the flow, since there are no moving parts. Hence gas velocity can be measured in both the fresh and burned gases. The three-dimensional structure of flow field is investigated through measurements in orthogonal planes.



In this configuration, engine-like transient combustion occurs in a tumbling flow generated by injection of lean methane-air mixture. The expansion of burned gases from the centre of the chamber has the effect of a compression that reduces the length scales of turbulence before ignition, as in piston engines.

One part of this work is related to the statistical analysis of single-shot PIV measurements. In the case of transient laminar flames, the behaviour of flame-wall interaction is imposed by flame dynamics. But in the turbulent regime, flame-wall interaction is driven mainly by flow motion. Therefore, the repeatability of combustion is reduced due to the presence of random structures in the flow field, which is usually referred to as cyclic fluctuations. In such conditions, non-repetitive flow field does not allow the ensemble averaging of experimental data.

Consequently, a specific post-processing dedicated to time-resolved PIV data is set up. It is adapted to near-wall gradients thanks to cycle-resolved analysis, as is usually done for the post-processing of Laser Doppler Velocimetry. The computation of turbulence fluctuation is found to be equivalent in the time or space domain. Flow field characterization is achieved through local and global investigation, which leads to increased information.

Another aim is to show the real-time effect of flow field on heat losses, which is shown through the evolution of flow field parameters recorded simultaneously.

Heat transfer seems to be governed at first order by pressure. Further investigation is needed to study the effect of large-scale velocity V, tumbling rate N, integral length scales L and turbulence intensity q’. But correlation of heat flux peaks versus velocity peaks is evidenced, which is a preliminary step towards modelling. The integral length scales of the flow compare well to relevant measurements in engines, whereas assessing integral time scales requires higher acquisition rates: thus, LDV is still needed in addition to multi-point techniques such as PIV.