Measurements of fuel distribution and flame structure in kerosene-fuelled combustors using planar laser-induced fluorescence and OH* emissions

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Abstract

Increasingly stringent regulations on pollutant emissions, such as NOx, COx and soot, require to improve combustion efficiency and overall operability of kerosene-fuelled aeronautical gas turbines. Among key parameters likely to fulfil these goals, the injection system is one of them where substantial improvements can still be achieved. Innovative concepts like LP (Lean Premixed), LPP (Lean-Premixed-Prevaporised) and RQL (Rich burn, Quick quench, Lean burn) injectors have emerged over the last decade as promising systems. For its range of applications, Turbomeca chooses the lean combustion technology and is developing this concept. The challenge remains to achieve the best balance between emission reductions and combustion stability. In particular, increasing the vaporisation rate of the liquid fuel and improving mixing efficiency between fuel vapour and air prior to combustion is still the subject of intensive research in the laboratories as well as in industry. It remains however an ambitious challenge to measure these parameters in real combustors, because of the high pressure and temperature ranges encountered (3.0 MPa, 2300 K).

Recently, spectroscopic studies were performed to measure the dependence of kerosene fluorescence on temperature, pressure, oxygen molar fraction and fuel composition [1]. As a result, a strategy for measuring fuel spatial distribution in kerosene/air combustors, using planar laser-induced fluorescence (PLIF), has been developped. Kerosene-PLIF consists of using laser excitation at 266 nm and detecting kerosene fluorescence over the spectral range 270–420 nm by means of an ICCD camera equipped with appropriate optical filters.

In this article, kerosene-PLIF was successfully applied to a LPP injector for various operating conditions (air temperature up to 730 K, pressure between 1 and 5 bars, fuel-air ratio between 0.030 and 0.050) at firing conditions. 2D-maps of instantaneous kerosene vapour spatial distribution in the combustor were measured. Chemiluminescence emissions from OH* radical was also recorded to determine the global flame shape and to correlate it with fuel distribution. For example, Figures 1 and 2 show single-shot and average 2D-maps of kerosene and OH* distributions at the outlet of the injector for air inlet temperature of 650 K, with fuel-air ratio of 0.040, at 5 bars. The green rectangle on the left of the images represents the LPP injector. As can be seen, kerosene seems to be slightly concentrated at the edges of the injector and the kerosene/air jet exhibits little radial expansion. The liquid fuel disappears at medium axial distance downstream for the LPP injector, and this indicates that combustion starts close to the outlet of the injection system. OH* chemiluminescence shows that the flame is anchored at the exit of the injector. However, it is likely that the flame is already developing slightly inside the premixing duct of the LPP injector. Kerosene spatial distribution exhibits numerous wrinkled structures, and this indicates that the flame is highly turbulent. As a result, the position of the flame front exhibits large spatial and temporal fluctuations, and so does the location of kerosene removal. Consequently, kerosene and OH* mean spatial distributions are located at similar positions. No instabilities or flame flapping is noted. The flame exhibits a yellow colour and its length is less than 8–9 cm.

Experiments presented in the current paper demonstrate the capability of kerosene-PLIF for measurements of fuel distribution in reactive two-phase flows with air temperature up to 730 K, at pressure up to 5 bars. The next step is to extend the method to higher temperature and pressure representative of real operating conditions in gas turbines.

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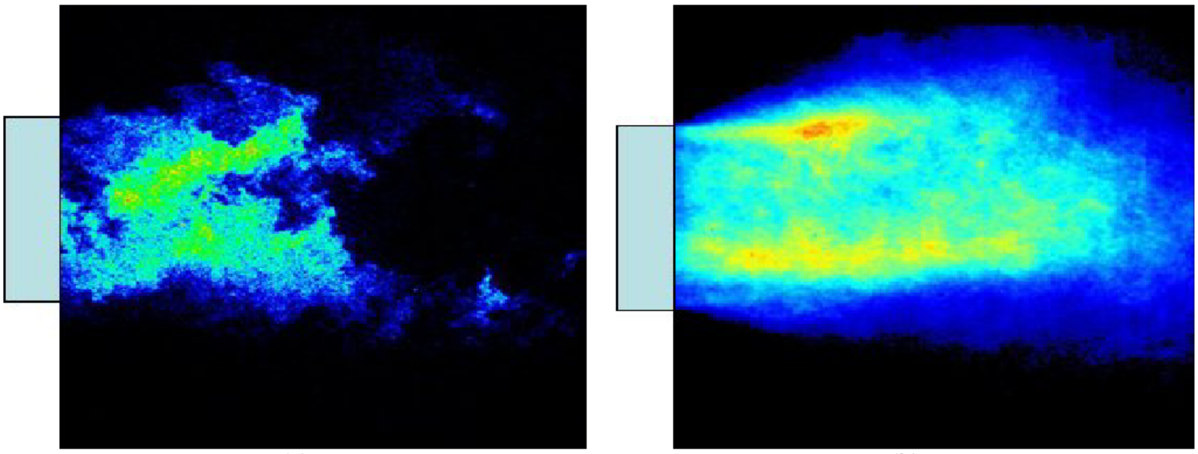

(a) (b)

Figure 1. Instantaneous (a) and average (b) maps of kerosene distribution in a LPP injector, T_{air}=650 K, P=5 bars.

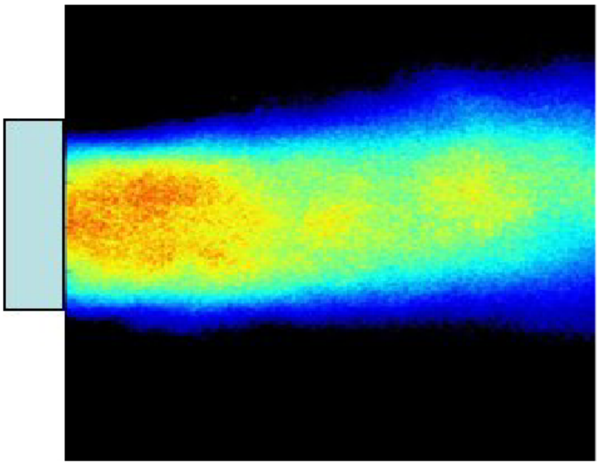

Figure 2. Average map of OH* chemiluminescence distribution in a LPP injector, T_{air}=650 K, P=5 bars.

References

[1] Baranger P., Orain M., Grisch F., Fluorescence spectroscopy of kerosene vapour: application to gas turbines, AIAA-2005-828 (2005).