Laser-induced ignition and plasma spectroscopy in a turbulent liquid fueled combustor

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Abstract: Laser induced ignition was applied in a turbulent two staged aeronautical combustion chamber. It was coupled to extensive on-line spectroscopic measurements to determine the local equivalence ration within each spark. This value was found correlated to the probability of ignition and it was shown that establishment of the complete flame in the combustor required not only the creation of an initial kernel but also favorable flow patterns. Criteria for ignition based on experimental results are proposed in a particular combustor but the techniques and subsequent analysis developed may be applied to other injection devices.

1. Introduction

For high altitude relight or aircraft engines, laser ignition may be an alternative to actual spark plug as it offers the possibility to create the initial kernel directly in the inner recirculation zone. This not only minimizes the ignition delays but also increases the probability of ignition due to absence of quenching at the wall and more favorable fluid flow conditions. However, the fate of a single shot is usually considered as being stochastic, mainly because it depends on many parameters. Many previous experiments dealing with laser ignition considered mainly statistical analysis ([1-2]) but it may be interesting to better understand the actual ignition process to have some deep insights of single events taken with a relatively large number of diagnostics. This approach would ease the development of models and may be more easily compared to numerical simulations, for which converging probability analysis is still a challenge.

2. Experimental devices

In the present case, a staged liquid fueled injector is used [3]. The fuel is injected through a central pressurized atomizer while air is swirled. Dodecane is introduced at an overall equivalence ratio of 0.7 with only air being pre-heated at 473K. A schematic view of both injection device and optical diagnostics is provided in Figure 1.

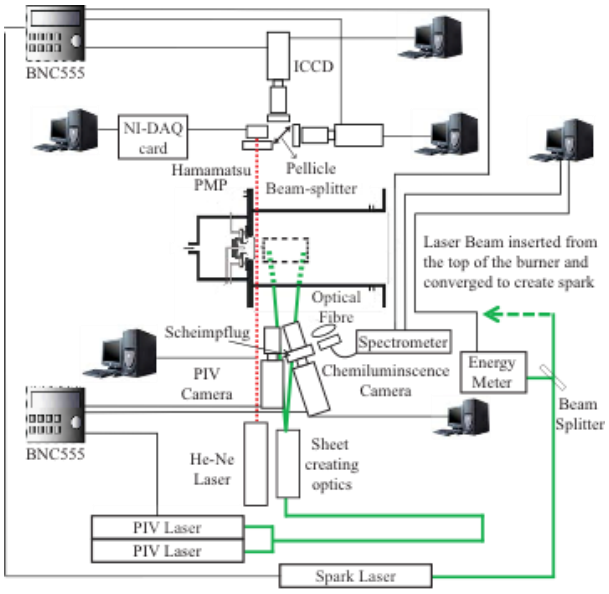


Fig. 1. Schematic view of the injector and the different optical diagnostics used.

Two different swirlers are used in co-rotating arrangement. Two quartz walls are used to allow a good optical access and several diagnostics are used simultaneously to provide conditionally based analyses. To actually measure the equivalence ratio as well as the deposition of energy and initial kernel size, a two-dimensional Laser Induced Plasma Spectroscopy technique (2D-LIPS) has been recently developed [4]. This requires the use of two ICCD equipped with interferential filters centered on specific atomic transition (hydrogen and oxygen). Without a precise calibration in presence of droplets, this technique only provides the atomic H/O ratio, which is monotonically linked to mixture fraction. Two high repetition rate lasers (10kHz) are synchronized with a fast camera (Photron, 20kHz) to actually image the droplets of the spray in a plane of the chamber. This allows also applying statistical analysis, such as correlation tools to estimate the displacement of droplets within two laser pulses. Laser induced ignition was achieved by focusing the second harmonic of a Nd:YAG through a lens of focal 100 mm. The position of the laser and the lens could be changed with respect to the chamber so as to investigate different points.

3. Results and discussions

Several experiments were performed in order to first investigate statistical properties of the laser-induced ignition. Some points had a very high probability of ignition (in the recirculation zone) whereas those located mainly in the outer recirculation zone of the spray had little success. It was decided to specifically concentrate on points with relatively low probability to sort out success and failures based on actual time resolved measurements. Among the main results, the actual H/O atomic ratio (representing the equivalence ratio), the size of the initial kernel are obtained by 2D-LIPS. To take into account the dynamics of the flow, dedicated post-processing tools have been used to estimate the actual growth/decay of the aerodynamic structure (PVC : precessing vortex core) based on planar measurements of Mie scattering by droplets. Seven ignition events were analyzed versus 12 failed cases. Overall results are displayed in Figure 2 with both local H/O ratio versus initial kernel and varying strength of the PVC. It can be seen that many igniting cases had a higher kernel size for a similar H/O as compared to failed attempts. This is explained by the existence of a critical kernel to overcome heat losses by convection. Among the eight sparks that had a good H/O together with an initial kernel above the critical size, the only case that failed corresponded to a case for which the PVC tended loose energy. PVC is considered as being an important feature for ignition in the inner recirculation zone as offering a region of lower pressure, hence easing the convection of an initial kernel towards the injector.

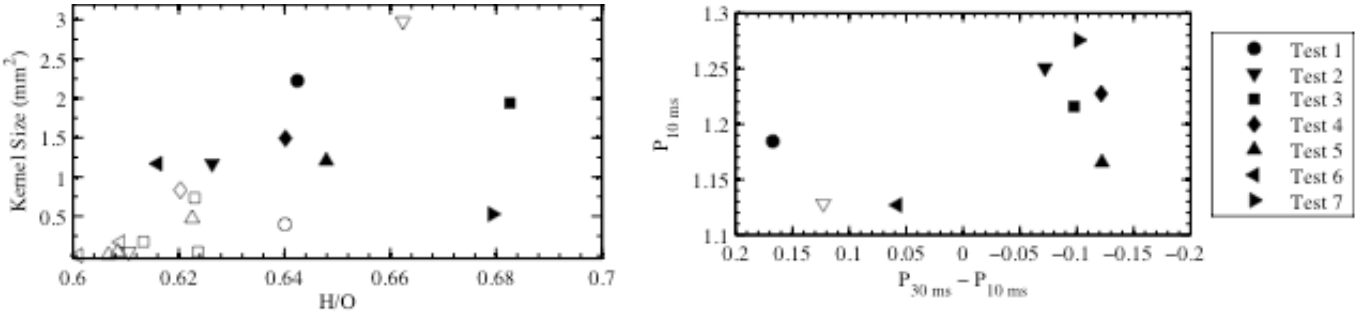


Fig. 2. Actual mean H/O ratio versus initial kernel size (left) and decay of the strength of the precessing vortex core 10ms before spark as compared to 30ms.

4. Conclusions

Combined measurements of H/O, kernel size and aerodynamic structures could explain most of ignition attempts. This strategy opens new experimental investigations based on the detailed characterization of single events rather than based on statistical analysis only. This may ease comparisons with numerical simulations for which statistically converged data remains out of reach.

4. References

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