

Application of Laser Induced Ignition Interferometry and Plasma Spectroscopy (LI3PS) to Spray Ignition

Laurent Zimmer

*Laboratoire EM2C, CNRS, CentraleSupélec, Université Paris-Saclay, Grande Voie des Vignes, 92295 Châtenay-Malabry, France
Corresponding author: laurent.zimmer@cnrs.fr*

Abstract: Different measurement techniques are developed to help understanding the ignition phenomena of practical aeronautical combustion chamber. They allow having instantaneous information on the local equivalence ratio within each sparks. Using Laser Ignition, it is also possible to have direct measurements of droplets interacting with the laser pulse and measure their position in 3D, as well as their actual size. Using high-speed approach with Mie scattering images, it is possible to understand the dynamics of the spray under an initial flame kernel development. Using simultaneously all those techniques can provide useful information on conditionally resolved events.

OCIS: (300.6365) Spectroscopy, laser induced breakdown ; (100.6890) Three-dimensional image processing ; (010.7060) Turbulence.

1. Introduction

Current aeronautical operating conditions, relying on lean combustion to fulfill the emissions target, require the use of novel strategy for ignition. Igniting an aeronautical chamber relies on several mechanisms: from the initial energy deposition to the first flame kernel creation before its convection towards the injection system for its global stabilisation. Looking at the complete dynamics of the system requires having a good knowledge of different quantities. This is easily done with numerical simulations ([1]). The main drawback of numerical simulations is that the comparison with real experiments is not easy, especially as it would require running a huge number of test cases to cover all the possible dynamics. Therefore, experimental approaches are usually used to characterize the complete success of the ignition, based on statistical approaches ([2]). However, the different quantities required to fully understand the faith of each attempt are usually not provided and only their mean, usually uncorrelated, quantities are provided. Among others, laser ignition has several advantages over conventional spark plugs. It can be focused in the middle of the chamber to create a spark that would not suffer from heat losses at the electrodes. Furthermore, using advanced optical system; it is possible to have multi-sparks [3] and also to have a perfect control of the timing, within nanosecond accuracy. It is possible hence to synchronize optical measurements in order to obtain instantaneous measurements, before, within and after the spark. Three different techniques are presented below and their availability to be used for Laser Ignition is discussed.

2. Laser Induced Interferometry.

When investigating ignition of sprays, knowing the positions and sizes of droplets along the laser beam and around the laser induced plasma is mandatory to predict the faith of the plasma formation and the evolution of the flame kernel. This requirement leads to the need for a three-dimensional measurement technique that could be synchronised with the laser pulse. Using Mie scattering [4] theory, it is possible to relate the images of interferences within each droplet to their physical size, if reflection and first order refraction intensity are similar in intensity. This technique, called Interferometric Particle Imaging, or Interferometric Laser Imaging for Droplet Sizing required on the elastic scattering. Usually, a nano-second laser pulse is used and images are taken with Couple Charged Device camera, for which the exposure time is not an issue. It becomes more complicate when using the same laser for both Induced Ignition and measurement. As the plasma is created only after its irradiance overcomes the breakdown threshold, the fist 1 to 2 nanoseconds of the laser pulse leads only to Mie scattering effects (see Figure 2). Therefore, having a camera that can be exposed as short as 1 nanosecond is required to detect the droplets within the laser beam. Together with a precise synchronisation, the camera is equipped with an interferential filter centred around the wavelength of the laser (usually 532 nm). In Figure 2, an ICCD with a 512x512 pixel resolution is used to measure all signal within a 14 mm long volume. The reference for the horizontal axis is the focal point of the system. One can clearly notice that a droplet with 4 interference fringes can be detected ([5]). Its apparent size is linked to its position with respect to the focal plane of the camera. If the density of droplets becomes an issue for the imaging, advanced imaging techniques can be used, so as to compress most of the signal into linear information ([6]).

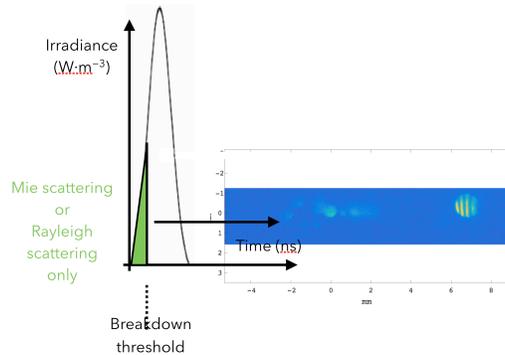


Fig. 2. Typical temporal configuration for ILIDS measurements in Laser Induced Ignition approach ([5]).

3. Laser Induced Plasma Spectroscopy.

Once the plasma created, it is possible to use a spectroscopic approach to determine the composition of the plasma. First, mainly ionic then atomic emissions are detected [7]. Taking benefit from those emissions, it is then possible to relate the ratio of atomic emissions of hydrogen (or carbon) versus oxygen (or nitrogen) to the local equivalence ratio ([8]). When using such an approach, it is very important to ensure that the plasma is in the same thermodynamic conditions as the one obtained during calibration. It is possible to estimate a global excitation of the plasma (linked to plasma temperature) by using well-known emission line. Among the different possibilities, the alpha and beta line of the Balmer's series show a strong sensibility and may be used to have an estimation of the electronic temperature. The estimation of the temperature, together with the ratio of atomic emission, is then used to determine an accurate local equivalence ratio measurement. This strategy can be used with single-shot spectra and a typical accuracy for lean methane-air cases may be around 0.05% ([9]) (see figure 3), much lower than strategies based on energy.

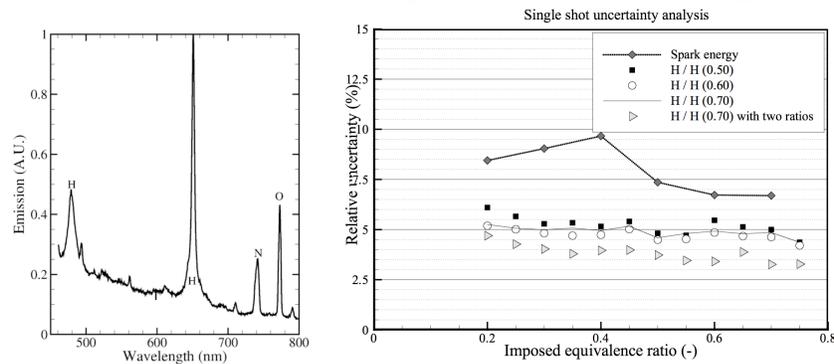


Fig. 3 Spectrally resolved data and typical single shot accuracy ([9]).

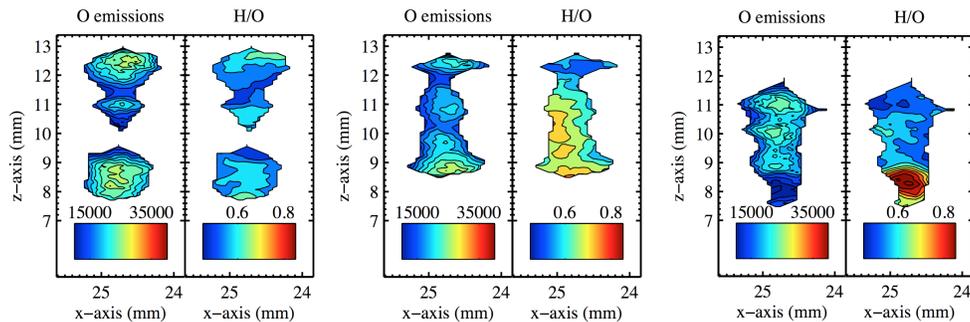


Fig. 4 Typical spatially resolved Laser Induced Plasma Spectroscopy in presence of liquid fuel ([10]).

It is possible to retrieve mixture fraction gradients using imaging approach. Using appropriate timing (typically 1500 ns after spark creation with an integration time of 50ns), it is possible to record, with interferential filters, images of atomic emissions. Similar to the full spectral approach, the ratio between two images can be computed to obtain two-dimensional resolved mixture fraction information ([10]). The accuracy of this approach depends of the spatial resolution and a compromise may be found, depending on the cases. For instance, in presence of droplets, a higher spatial resolution may be required to solve properly strong mixture fraction gradients (see figure 4).

4. High Speed Particle Image Velocimetry.

Using high-repetition rate laser, it is possible to track droplets in time and space and see how the laser induced plasma influences the dynamics of the spray as compared to the situation before the plasma. To measure individual velocity in three-dimensions, a tracking approach is required, that can be combined with the measurements of true sizes. One of the main caution is that during the plasma formation, the sensor has to be protected to avoid saturation or deterioration of the chip. This can be done by combing an interferential filter centred on the wavelength of the laser, together with liquid crystals that can be accurately controlled ([10]). For the 3D measurements, the same principle as the one presented in the Laser Induced Interferometry section can be used. In this case, the probe volume can be easily adjusted as a complete independent system may be used. In sequential ignition phenomena, time-resolved measurements can show that in some cases, the influence of a previous spark may lead to a better aerodynamic conditions (decrease in the typical frequency of the spray) before having the spark leading to ignition (see figure 5).

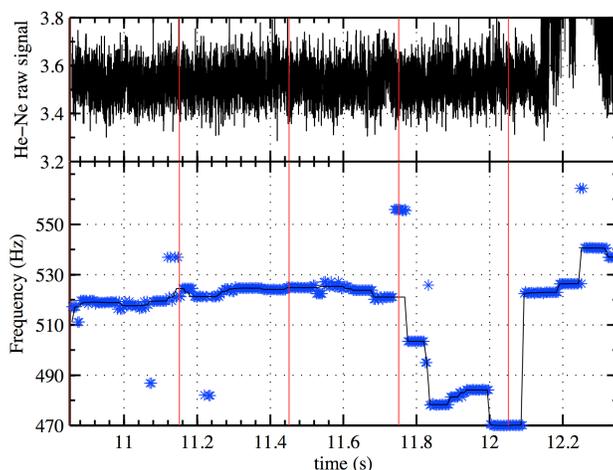


Fig. 5 Typical time-resolved measurements of the dynamics of droplets. Red signals indicate the laser induced plasma events, the last one leading to ignition ([10]).

5. Conclusions

Advanced measurement techniques can be used to provide local and instantaneous quantities that may be useful to understand ignition characteristics. They may be used to provide conditional analysis on the different parameters that may influence the faith of a spark. There is a need however for advances post-processing methods, dealing with numerous data, some of them providing high-speed images, showing strong non-linear behaviour. Ultimately, models may be derived to provide necessary and sufficient conditions for successful ignition in practical cases.

6. Acknowledgements

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7. References

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