Interaction between laser induced shock-waves and droplets

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Abstract: The interaction between laser induced shock-waves and droplets are investigated using Planar Imaging techniques for the shock-wave investigation and a 4D-Interferometrie Particle Imaging technique to measure position, size and velocities of droplets in the vicinity of the laser induced plasmas. According to the distance between the laser induced plasma and the droplets, different phenomenological behavior could be enlightened. Droplets may directly evaporate, may breakdown into 2 or 3 smaller droplets and or may have a sudden or slightly delayed differential acceleration. Those measurements show the necessity for real applications to take into account the faith of laser-induced plasma droplet interaction for a proper description of the spray.

1 Introduction

Laser induced plasma have a great potential to ignite different combustors with their ability to change the location of the spark and hence avoiding the interaction with walls. However, several issues have to be better understood prior applying LIP to liquid fuel. It has been shown in well controlled cases that the laser induced spark, inducing a shock-wave and other dynamics effects [2], strongly influences the dynamics of the droplets [3]. On the other hand, the presence of droplets do modifies the focal point of the system and plasma may be created in different locations at the same time due to breakdown of the droplet surface and the lens effect of droplets [4]. Usually, fundamental experiments are performed with uniform droplets with typical sizes higher than 100 µm. In practical applications, the initial diameter of the liquid fuel droplets may be smaller than that and it is important to investigate the interactions between a Laser-induced Plasma and droplets.

2 Experimental setup

To investigate the interaction between laser induced plasma and droplets, a specific setup has been developped and is presented in figure 1. It is based on a laminar counter flow burner. The gases are homogeneously injected to each counter nozzle through plenum. The dodecane droplets are created through an ultrasonic atomizer. The mass flowrate is adjusted with a mass flow controller (Brooks) and air (4 l/min) is also injected to ensure that droplets are carried out from the injector. An optical access, just below the piezzo-electric device enables to check that droplets are well created. The main gas (air) is injected through four different holes. Two of them (180°form each other) are fed with a constant flowrate of air (10.3 l/min). The two others are fed with a mean flowrate of 6 l/min of air. This split allows possible fluctuations of the mean air flow to be imposed. The Reynolds number of the top burner (without taking into account the acceleration induced by the discrete phase) is 1100. A coflow of nitrogen (6.5 l/min) is used to prevent air entrainement inside the reaction zone.

The droplets generated have a typical diameter between 10 and 40 µm, as shown by the typical probability density function displayed in figure 1.

The optical setup used to create the laser induced plasma is presented in figure 2. It consists in a pulsed Nd:YAG laser with typical outpur energy around 50 mJ for a pulse duration of 8 ns. A lens with focal length of 100 mm is used to create the plasma. For diagnostics, a continuous laser is used in order to illuminate the droplets. A high-speed camera (Photron Fastcam SA-5 10kHz - 896×848) equipped with a 105 mm objective (aperture 2.8) records the Mie scattering images. An ICCD camera (Princeton - 512×512) is synchronized with the pulsed laser in order to acquire an image few nano-seconds after the creation of the laser induced plasma. This image enables to determine the number of plasma created, as well as their position and size. In presence of droplets, the number of plasma may increase and the location may be shifted.

3 Laser induced shock-wave

At first, before studying the global effects of laser induced plasma on droplets, it is important to quantify the effects of laser induced plasma on the airflow. It is known that the dynamics is first governed by the shock wave issued from

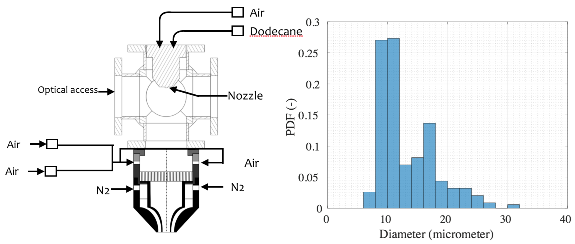

Figure 1: Schematic representation of the experimental setup.

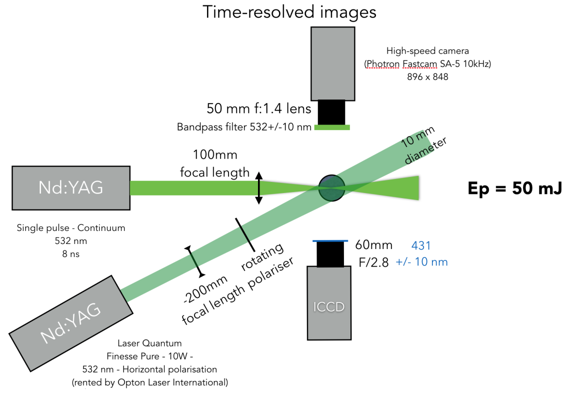

Figure 2: Schematic representation of the optical setup.

the plasma. The shock wave typically detaches from the plasma after few microseconds and has a velocity of more than 1,000 m/s [1]. After the shock wave, the gas has an increased temperature and a lower pressure than before. Due to these changes, the dynamics is changed and 3D structures are created. In order to measure the changes, seeding droplets are used. Those have typically a diameter between 1 and 3 µm, meaning they will follow relatively well the airflow. Their evaporation temperature is about 200°C, meaning that they will not be visible in regions with high temperature. Using planar images of Mie scattering, it is possible to characterize the flow. In figure 3, a typical sequence of images as well as velocity vectors is shown. One can see that the region above and below the plasma do not have strong Mie scattering signals, due to the evaporation of the seeding droplets. When processing the images with optical flow algorithms [5], one can infere the typical structures. In optical flow approach, it is possible to retrieve the instantaneous displacement for each pixel. For clarity purpose, only 1 vector over 15 is displayed in both direction in figure 3. One can first notice the mean flow of the air in regions that are not disturbed by the plasma. Ahead of the plasma, a symmetric pattern is formed, showing toroidial vortex creation. Along the laser line, entrainement of air is also measured. This is due to the lower pressure that is within the plasma itself.

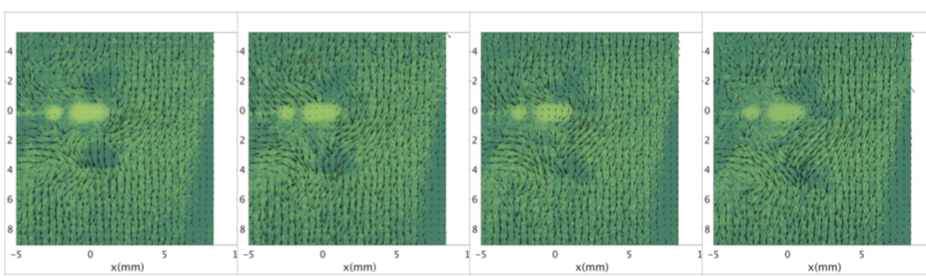

Figure 3: Typical airflow induced patterns following laser induced plasma. Each image is separated by 200 µs. The first image is acquired 100 µs after the laser induced plasma. 1 vector over 15 is plotted in each direction.

The analysis of several laser-induced shock shows some variation in the actual velocity pattern and magnitude but the main structure remains similar, as long as only one shock-wave is created. It would be interested to study the combined effects of two shock waves, each created by a laser induced plasma.

4 Effects on droplets

This flow pattern will affect the fuel droplets themselves. Due to their larger sizes, they may not follow exactly the same trajectories. Furthermore, they may split into smaller droplets. To investigate the phenomena and due to the fact that fuel droplets are not evenly distributed, a volume is illuminated (instead of a thin plane) in order to measure the displacement of droplets in 3D. The apparent size of the droplets do just depend upon the distance with respect to the focal plane. In figure 4, one can notice two droplets highlighted in the first frame. This image corresponds to the image of droplets 200 µs before the plasma. Images taken later show, for instance at 1,700µs after the plasma that one of the droplet broke into three droplets (in red), whereas the other droplet remained unchanged. From a velocity point of view, the three droplets had a lower velocity than the individual droplet. The main differene between the two cases is the initial distance to the plasma : 1.9±0.1 mm in the first case and 4.4±0.1 mm in the second case.

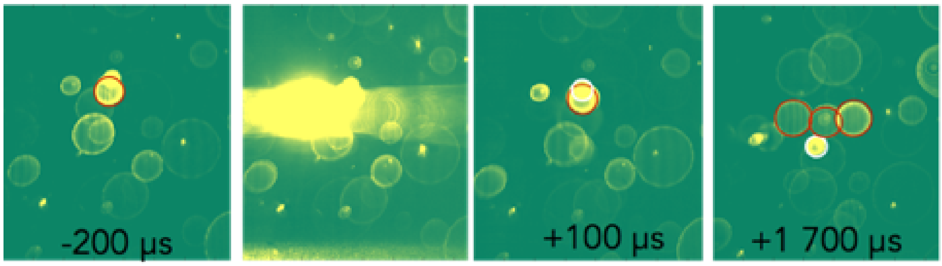

Figure 4: Typical interactions between plasma and droplets.

From a velocity point of view, effects may also differ as droplets may be accelerated or entrapped in some airflow patterns, as shown in figure 5. The initial distance between droplet and plasma is about 1.7±0.1 mm. The three droplets issued from the same original droplet have three different trajectories

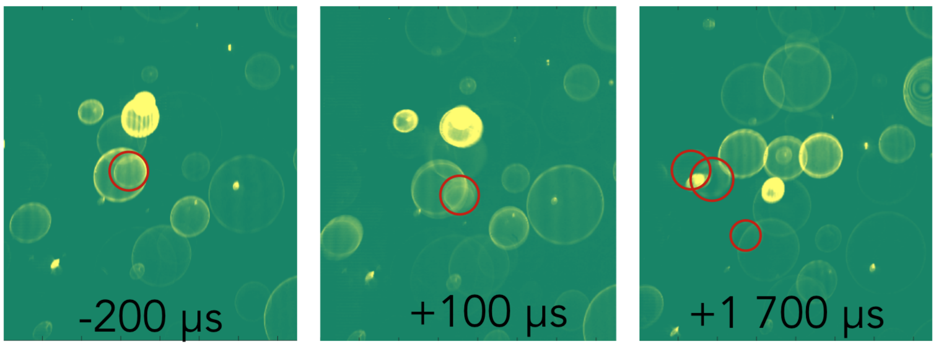

Figure 5: Droplets entrapped in airflow pattern.

5 Conclusion

The interaction between the laser induced plasma and the droplets may lead to seconday break-up, even for droplets with initial sizes lower than 50μm. From a velocity point of view, effects may also differ as droplets may be accelerated or entrapped in some airflow patterns. The key parameter is the initial distance from the plasma. After some distances, the effects of the laser induced shock-wave are too weak to really modify the droplets' dynamics. From an ignition point of view, it would be interesting to compare the effects for a similar energy between different plasma sources.

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