# Optical and PolyCo-based X-Ray Radiography/Tomography Investigations on High-Dense Transient Fluids

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In the last years, the main interest of the international community on internal combustion engines has been focused on the energy saving and pollutant reduction for the citizen health safe. The combustion in the engines is a quite complex matter involving the combination of multiple physical and chemical processes: fluid dynamic of the intake air, fuel atomization, mixture preparation, drop transportation, combustion, and pollutant production.

Two important events leaved a mark in the improvement of these processes: i) high-pressure apparatus for direct fuelling in the engine cylinder resulting in a good atomization of the fluid and ii) massive use of electronic devices for controlling and metering the air/fuel mixture. In a parallel way, the development of multidimensional numerical codes has permitted to advance previsions on the behavior of the combustion, once calibrated on the elementary processes occurring in the engine.

The main objective of the researchers in the recent years has been to develop methodologies and techniques to "look inside" the event combustion without (or limiting) any interference in observing the evolution of those elementary processes. A variety of imaging techniques has been adopted including Phase Doppler based devices for droplet sizing and velocity measures, Mie-scattering imaging for liquid fuel visualization, shadowgraph/schlieren for the evaporation phase, laser-induced incandescence for soot measurements, and chemiluminescence for combustion detection.

The knowledge of spatial and temporal distribution of the fuel density and the droplet diameter distribution is fundamental for the mixture formation and the combustion control both from experimental and numerical approach. Typically, the insertion of these liquids happens by means of transient actions (0.2 – 3.0 ms in duration) with velocity distribution of the fluids ranging around 100 – 300 m/s, highly dense (200 - 500 kg/m$^3$) and producing finely atomized droplets down to submicron. They are produced through multi-hole nozzles having diameters of the order of 100 μm and, during their evolution, undergo breakup and coalescence mechanisms that continuously change their dimensions as well as cavitation effects in so narrow ducts.

Unfortunately, the use of optical-based techniques for the investigation on the dimension/density/velocity is successful only in areas at low density of the liquid (low injection pressure, boundary of the spray) while, in optically dense regions, multiscattering effects extinguish the incident light losing any carried information.

Significant improvements have been obtained by radiographic techniques, using soft X-ray or neutrons. X-ray are highly penetrative in dense materials due to their intrinsic low cross section, producing negligible multiple scattering. Time-resolved X-ray radiography and tomography make use of pulsed and high-brilliant synchrotron radiation sources. They overcome the limits of conventional tube sources, continuous in time, dispersed in wavelengths and non-collimated, providing monochromatic beams, highly collimated, pulsed in time-structure and greatly time-resolution. On the contrary, these facilities have restricted access to experimental campaigns because of a few and highly expensive plants worldwide-dislocated, no friendly-available, busy beamlines with poor duty cycles and dedicated instrumentation managed by specialists.

Recently, tabletop laboratory sources, friendly-users, have been developed as alternative to the restricted-access facilities using storage rings. They use microfocus X-ray sources in combination with polycapillary lenses for radiography and tomography measurements. The polycapillary lenses permit the shaping of the divergent X-ray beams from the sources into parallel ones enabling additionally to suppress multiple scattering. They showed great in optimizing the beam geometry for applications on fuel sprays. The use of such kind of setup has permitted tomography and extinction measures through high dense sprays of gasoline for automotive applications. Arduous areas of few millimeters downstream the injector tip have been explored enabling investigations on the structure, morphology and density of the jet. Suitable image processing and reconstruction algorithms have permitted three-dimensional visions of multiple-jet sprays with useful and unique information on their internal structure and spatial-temporal behavior.