Photon Tools for Fuel Spray Studies in Aerospace Propulsion Systems

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Fuel injection plays an important role in establishing stable and efficient combustion inside the combustor of a liquid-fueled aerospace propulsion system. Depending on the application of interest, fuel injection conditions range from high-speed crossflows in the air-breathing propulsion systems to quiescent environments with extremely high pressures in the rocket engines. In addition to the typical liquid atomization processes in a quiescent or crossflow environment, injectant phase transition from thermodynamic supercritical state to subcritical state, or vice versa, introduces additional challenges to fuel injection studies. Also, innovative injector designs typically generate complex flow fields, requiring advanced diagnostics with high temporal and/or spatial resolutions to adequately resolve the two-phase flows. Characterization of liquid fuel sprays has been carried out with satisfaction within the well-dispersed regions of the jets, such as the periphery of the jet and the far field, using various optical-base diagnostics. The near-field regions of these jets, however, are still fairly inaccessible to these diagnostics.

Recently, the application of photon tools for spray characterization has been tried out for several types of spray of interest to the United States Air Force Research Laboratory. Three X-ray diagnostics, including X-ray phase contrast imaging (PCI), X-ray radiography, and small angle X-ray scattering (SAXS) available at the Advanced Photon Source (APS) of the Argonne National Laboratory, were successfully utilized to characterize the dense near fields of sprays relevant to the aerospace propulsion systems. It was shown that the X-ray PCI technique gives both a qualitative understanding of microscopic structures, such the existence of small droplets, ligaments, and even bubbles, and also quantitative size distributions of the disintegrated small objects within the peripheries of the jets. The line-of-sight feature for X-ray PCI, however, limits its capability in depicting the dense spray core. It was demonstrated that the X-ray radiography can satisfactorily provide quantitative liquid mass distribution profiles within the near-field region of the jets or qualitative two-phase flow patterns within the injector. Attempts to exploit the time-resolved X-ray radiography data to derive the line-of-sight droplet size distributions were made with pending uncertainties. In a separate effort, SAXS was utilized to explore the condensed phase, such as droplet size and liquid volume fraction, within the supercritical jets. Droplet size on the order of 100 nm was successfully measured. Preliminary efforts to numerically model the droplet nucleation/growth processes, using the SAXS data, were also initiated. Capabilities and limitations of these photon tools will be discussed in details in the presentation. Outstanding issues and future opportunities for the application of photon tools to the studies of liquid sprays in aerospace propulsion systems will be highlighted at the conclusion of the presentation.