Part I
Injection Systems and Mixture Formation

In modern low emission aero-engine combustors, spray combustion is used extensively. It follows three preliminary steps: injection of liquid fuel, vaporization of the droplets, and mixing of the oxidant and the fuel. The characteristics of the fuel spray, such as droplet size and velocity distributions, have a great influence on the efficiency and the emissions of the engines. Future compliance with stricter emission regulations demands a deeper physical understanding of the fragmentation processes and the resulting characteristics of the final spray. Presently, the primary atomization used in gas turbine combustors, either using empirical models or using a direct numerical simulation, is inadequately predicted to be of use in optimization studies. Therefore empirical data are generally obtained on a case-by-case basis, in an attempt to capture the most important dependencies of the droplet velocity and size distribution. Without doubt there is a deficit in this area, in particular for atomizers operated at elevated pressures. Even for simple pressure atomizers, the influence of chamber pressure appears ambiguous. For airblast atomizers there exist no reliable models for predicting the resulting spray.

The focus of Part I is to investigate the effect of the main operating parameters on the atomization process of an airblast atomizer. In particular, the flow inside the nozzle is determinant. Primary spray formation in the pressure swirl injector is followed by drop breakup and evaporation during flight, spray impact onto the wall of the atomizer, formation of a liquid film on a wall surface, its breakup and the final or secondary atomization into the chamber. Under real gas turbine conditions these phenomena are influenced also by the swirling hot air flow through the primary swirler and high ambient pressure and wall temperature inside the atomizer.

The investigations presented in Chap. 1 focus on the spray atomization, transport and impact on a solid substrate under cross-flow conditions, as used in airblast atomizers with prefilmers for aero engines and gas turbines. It includes both theoretical analyses and experimental characterization of the spray. The phenomena are observed using a high-speed video system and the spray is characterized using the phase Doppler technique. The governing mechanisms of drop formation, wall collision and aerodynamic breakup are identified. Especially, an atomization model is developed, which accounts for primary atomization, wall film formation and aerodynamic breakup.

Chapter 2 deals with the liquid film evolution on a wall surface, especially with shear-driven liquid film flows as occurring in several locations of fuel preparation systems, e.g. inside air-driven atomizers or in Lean Pre-mixing Pre-vaporizing (LPP) combustion chambers of modern gas turbines. The fundamentals of gravity-driven as well as air-driven film flow and evaporation on unstructured and micro-structured wall surfaces are investigated experimentally and numerically.

The objective of Chap. 3 is to develop and validate a thermodynamically consistent spray module for Large Eddy Simulation that allows describing accurately the essential processes featuring spray combustion in gas turbine combustion chambers. Besides the injection of liquid fuel, these include the turbulent droplet dispersion, the vaporization of the droplets and mixture formation and the subsequent spray combustion.