The primary breakup of a generic prefilming airblast atomizer using the embedded DNS (eDNS) concept

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Abstract

Lean premixed and prevapourized (LPP) combustion is the concept desired for future aircraft engines. Thus, a high demand to fuel preparation and fuel atomization is required. An improved understanding of the breakup processes of two-phase flows is essential to effectively control the fuel atomization. A detailed insight into the phenomena of primary breakup is a major limitation in gaining this knowledge. Aircraft engines apply airblast atomizers to provide the fuel atomization. The geometries of airblast atomizers are complex, the operating conditions are characterized by high Reynolds- and Weber numbers. Consequently, Direct Numerical Simulations (DNS) of liquid breakup under realistic conditions and geometries are hardly possible. The embedded DNS (eDNS) concept aims to fill this gap.

The concept consists of three steps: (1) a geometry simplification, (2) the generation of realistic boundary conditions for the DNS and (3) the DNS of the breakup region itself. Airblast atomizers are described by two air flowing channels at high velocity and a fuel wall film at low velocity. At the trailing edge of the prefilmer the liquid sheet is subjected to high shear due to the high air velocities of the two channels resulting in a breakup process from large liquid structures to ligaments and droplets. The realistic annular airblast atomizer geometry is simplified to a Y-shaped channel representing a planar geometry. Inside this domain the embedded DNS is located downstream of the trailing edge. The embedded DNS domain requires the generation of boundary conditions. A single-phase LES of the Y-shaped air channel and a two-phase RANS of the liquid wall film are differentiated. The inflow of the single-phase LES is initiated by a synthetic turbulence inflow generator. Within the two-phase RANS, the liquid fuel enters the wall through a small liquid slit. The Volume-of-Fluid method (VOF) is used. Downstream of the slit, the data are stored as input to the lower channel of the DNS domain. The inlet to the upper channel, the bottom and the top edge of the embedded domain are generated by the single-phase LES. The fields are stored transiently for the DNS time steps. Linear interpolation in space and time is performed from the coarse LES to the fine DNS. Periodic boundary conditions are set for the lateral edges of the embedded domain. The DNS of the breakup region is computed using VOF. Inside the embedded domain, an equidistant grid is applied.

In a first parametric study the influence of the surface tension force on the primary breakup is investigated. For this study, the air flow conditions are kept constant at a bulk Reynolds number of around 11,000. The surface tension force is varied between 0.026 N/m and 0.0085 N/m corresponding to kerosene fuel temperatures between 300 K and 500 K. An equidistant grid spacing of 8 μm is set. The results provide an insight into the dynamics of the phase interface. A decrease of the surface tension force (corresponding to an increase in temperature) highly affects the stability of the liquid sheet. A series of instantaneous snapshots in time indicate the evolution of the liquid sheet deformation, the contraction and the generation of ligaments and droplets. For the low surface tension case, the entire interface is subjected to high shear resulting in strong topology changes and simultaneous collapsing of the liquid sheet at different sheet locations. The high surface tension case instead only generates a few single ligaments. The entire liquid sheet is stable.

This study proves the applicability of the eDNS concept for investigating breakup processes as the transient nature of the phase interface behaviour can be captured. The approach offers the potential of simulating realistic airblast atomizer geometries under realistic conditions.

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