Prediction of Primary Atomization using Smoothed Particle Hydrodynamics

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Long Abstract

Introduction

In civil aviation, fuel injection is one of the most crucial processes affecting engine performance and in particular emissions. Present state of the art is to empirically optimize the fuel injectors. Typically, expensive measurements of the injector performance in terms of droplet size and velocity are performed, and correlations like those proposed by e.g. Lefebvre [1, 2] are then used to extrapolate the experimental results to different operating conditions.

The prediction of the atomization process based on first principles was long time not feasible because of restricted computing resources. However, with modern super-computers providing 10.000 or even more CPUs, the prediction of the atomization process has come into reach. The Institut für Thermische Strömungsmaschinen (ITS) has started 7 years ago to develop a numerical method for predicting the primary atomization of air blast nozzles, which are typically used in jet engines. The methodology is based on the Smoothed Particle Hydrodynamics (SPH), which has originally been developed in the context of astrophysics. The method is advantageous over common grid based method like the Volume of Fluid (VoF) method when large deformations of the liquid surface are encountered and when surface tension plays a major role. Both is the case when considering primary atomization.

1. The SPH Method

Common methods used for computational fluid dynamics (CFD) are all of the Eulerian type, i.e. grid based. In contrast, the SPH method is of the Lagrangian type. The fluid is represented by particles, and each particle comprises a small volume of the fluid. All particles are moving with the local flow velocity. Particle methods are known to feature a better computing performance compared to grid based method when a high number, i.e. 1000 or more of CPUs are used.

A numerical code based on the SPH method has been developed by the ITS during recent years with particular emphasis on two phase flow phenomena. Our SPH code includes a full featured Navier-Stokes solver, modules for taking into account surface tension and the contact angles at the interface between liquid, solid surface and gas. The fluids to be considered could either be gases or liquids. The number of fluids is not limited. All typical boundary conditions, which may be present in two phase situations, like flow inlet and flow outlet are included. Provision is made to treat solid surfaces (walls) including wetting effects. All physical models have been validated separately using specific test cases. Recently, the code was parallelized using OpenMPI. As expected, the parallel performance of the code was found to be superior compared to grid based VoF codes, even commercial ones. This parallelized SPH code allows to perform detailed predictions of the atomization process.

2. Validation Experiments

In order to validate the predictions of primary atomization, a generic experiment resembling a typical air blast atomizer was set up. The atomizer geometry is plane instead of the annular design of real fuel injector nozzle [3]. The flat geometry enables better access for optical diagnostics. A sketch of the atomizer is shown in Fig. 1. Several series of atomization experiments have been performed using liquids of different surface tension and viscosity. In addition to varying the air speed and liquid loading, also different operating pressures have been looked at. The experimental results have been published at several occasions [4, 5, 6].

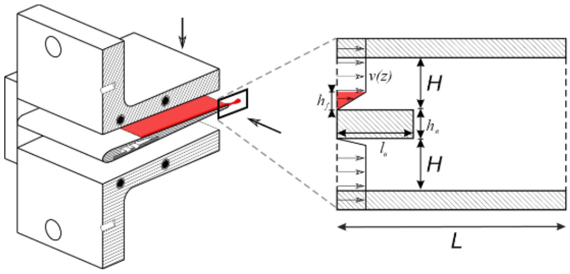

Figure 1. Flat air blast atomizer test section

One of the most interesting results was the finding that the thickness of the atomizing edge does affect the atomization process, as long as the edge is thicker than the liquid film. In particular it was found that the droplet generation frequency decreases and the size of the droplet increases when the atomizing edge becomes thicker [4]. These results are plotted in Fig. 2.

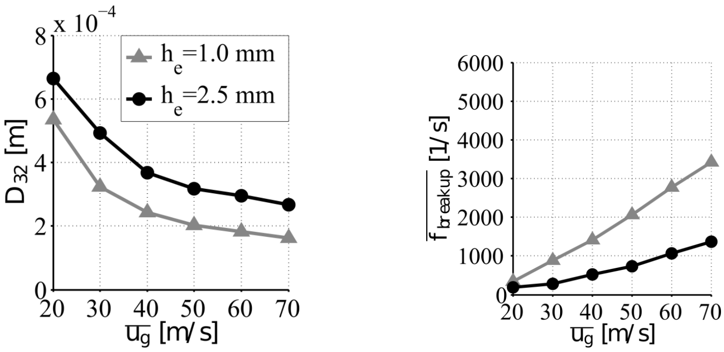

Figure 2. Effect of atomizing edge thickness droplet size and detachment frequency

3. Results of SPH Predictions

A typical result of a SPH simulation illustrating the primary atomization of air blast atomizers is shown in Fig. 3. The numerical setup comprised a volume of 6 x 6.3 x 2 mm^3, which is discretized by 38 Mio. particles, resulting in a particle dimension (partial resolution) of 10 μm. Air velocity was 50 m/s. The computing took 0.5 Mio. CPU*h on 960 CPUs for 5 msec wall time.

The objective of the SPH predictions was to elaborate the mechanism governing the effect of the trailing edge thickness. It was found that there is an accumulation of liquid in the wake of the atomizing edge. The volume of the this accumulated liquid depends on the thickness of the trailing edge. The volume of the droplet which will detach from the atomizing edge is proportional to the volume of the accumulated liquid. Thus, the droplet size will increase

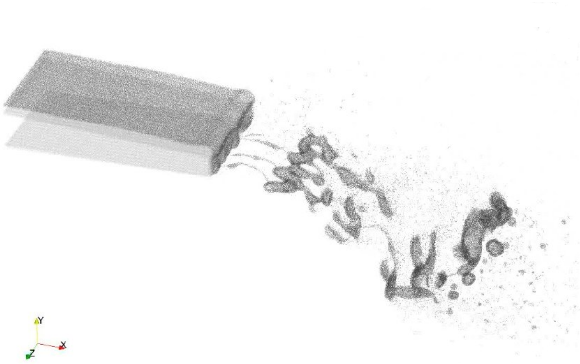

Figure 3. Snapshots of air blast atomization as predicted by the SPH method

if the trailing edge becomes thicker. Obviously, the time to fill up the liquid accumulation is longer if the volume of the accumulation is larger. Therefore, the frequency of droplet detachment will lower if the trailing edge becomes thicker. The mechanism is illustrated in Fig.4 by a series of snapshots of the 2D SPH predictions showing 4 atomizers which feature different edge thicknesses.

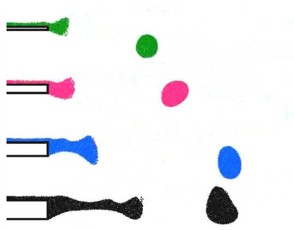

Figure 4. Effect of atomizing edge thicknesses on droplet size

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