

Impact of fuel and operating conditions on the atomization of a liquid jet in cross-flow.

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Abstract:

The present numerical work investigates the disintegration of a liquid jet in cross-flow. The outcome of the atomization process using conventional kerosene Jet A-1 is compared to the one of an approved sustainable aviation fuel: HEFA-SPK (Hydrotreated Esters and Fatty Acids - Synthetic paraffinic kerosene). The momentum conserving Volume-of-Fluid method implemented in the DNS multiphase-flow solver Basilisk together with the advantages of Adaptive Mesh Refinement is chosen, and extended by a Lagrangian Particle Tracking method developed recently. Simulation results for different operating conditions are compared with results from experiments performed at the German Aerospace Center. Additionally, cold start conditions are investigated.

Keywords: Liquid jet atomization in cross-flow, Volume-of-Fluid method, Lagrangian Particle Tracking, sustainable aviation fuels.

Introduction:

Motivated by the necessity to mitigate aviation's climate forcing and by enabling a European climate neutral aviation by 2050, sustainable aviation fuels (SAF) production pathways are being developed, approved for use in commercial aviation, and deployed at large scale as they currently constitute the main mitigation option. Research concerning the impact of SAFs on existing sub-systems (e.g. injectors) is therefore highly relevant. Hence, the first focus of the present work is on the currently most used sustainable aviation fuel HEFA. Moreover, as safety is a leading issue in the aviation sector, we consider different operating conditions, also at the border of the flight envelope.

Numerical Methods:

The simulations are mainly conducted with the free software Basilisk for Direct Numerical Simulation (DNS) of two-phase flows based on a interface capturing Volume-of-Fluid method. We refer to the web page of the free Software and references therein <http://basilisk.fr/>. Navier-Stokes equations for incompressible two-phase interfacial flows are solved at isothermal conditions. Mass conservation together with incompressibility lead to the transport equation for the volume fraction of fluid f : $\partial_t f + \nabla \cdot (f \mathbf{u}) = 0$. Moreover, we use the momentum-conserving formulation. Additionally, a Lagrangian Point-Particle approach (LPP) is adopted for droplets no longer anticipated to undergo breakup. Their trajectory in the gas field described by the Basilisk solver is computed following a Lagrange formalism. Moreover, we compute the additional source term in Navier-Stokes equations derived from the change in momentum of the point-droplets in Lagrangian framework. The point-droplets located too close to the dispersed phase in DNS are allowed to return to resolved droplets in DNS.

Results and discussion:

We consider operating conditions of the premixed duct defined by Rachner et al. [1] with the parameters: temperature T_{air} , pressure p_{air} and velocity U_g of the crossing air flow, and the liquid-to-air momentum flux ratio given by $q = \rho_l U_l^2 / \rho_g U_g^2$. Moreover, cold start conditions are applied, which definition can be found in [2] (Table 4, p. 217 for the AFRL referee rig and Table 2, p. 307). The implemented Lagrangian method is applied for each investigated case. In figure 1 (Jet A-1, baseline case) we show that jet penetration is well-captured by the simulations, either if it is coupled with the Lagrangian method or not. Correlations for near-field penetration according to Becker and Hassa (blue line), and Freitag, Hassa (orange line) are indicated. Only slight differences in droplet size distributions can be observed for pure DNS simulations between both fuels. Fuel HEFA presents a higher viscosity, resulting in larger droplets. The mean diameter $\bar{D}$ and its standard deviation s are

given for both fuels in the baseline case in figure 2. The resolution used gives a detailed insight into the breakup

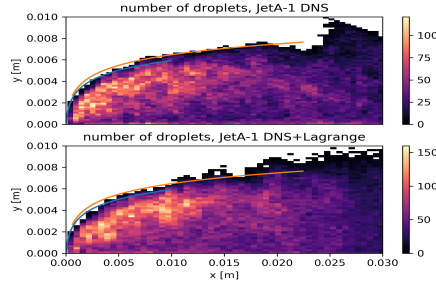


Figure 1: Droplets histograms for DNS and DNS coupled to Lagrange.

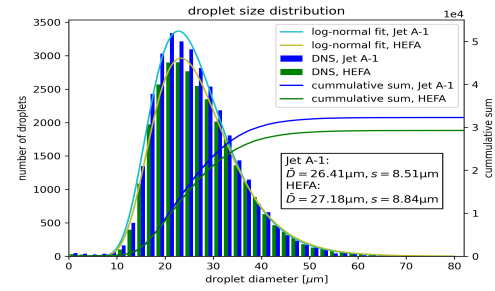


Figure 2: Droplet size distributions for Jet A-1 and HEFA.

mechanisms. Whereas surface and column breakup coexist in the cases shown in figure 3 and 4, boundary layer stripping is completely absent in the cold start case in figure 5.

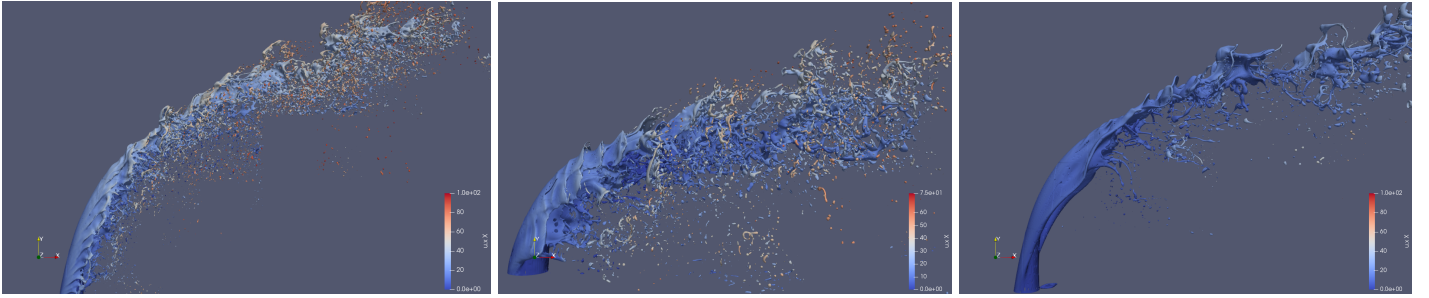


Figure 3: baseline case: $q = 6$, $T_{air} = 295 K$, $p_{air} = 5,8 bar$, $U_g = 100 m/s$; Figure 4: case U75q2: $q = 2$, $T_{air} = 295 K$, $p_{air} = 5,9 bar$, $U_g = 75 m/s$; Figure 5: cold start: $q = 6$, $T_{air} = 239 K$, $p_{air} = 1 atm$, $U_g = 100 m/s$

Figure 6: Visualization of the jet surface coloured by the velocity in air flow direction for fuel HEFA at $t = 1 ms$.

Conclusion:

The slight differences expected in droplet distributions for both fuels are captured well by the simulations. The results are in most cases in good agreement with correlations from literature regarding jet penetration and Sauter Mean diameter. The wavelength of Rayleigh Taylor perturbations are compared with predictions from linear stability theory. A close view at the jet and large ligaments just before they detach from the coherent liquid column enlighten the understanding of the primary breakup mechanisms in the different regimes examined.

Acknowledgments:

The authors gratefully acknowledge the Gauss Centre for Supercomputing e.V. (www.gauss-centre.eu) for funding this project by providing computing time on the GCS Supercomputer SUPERMUC-NG at Leibniz Supercomputing Centre (www.lrz.de).

References

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