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LIQUID JET SIMULATION USING ONE-DIMENSIONAL TURBULENCE

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Abstract The liquid jet exiting into a gas is an issue of great interest with many applications such as jet cutting, fuel injection, or firefighting. To simulate the breakup correctly, the simulation of the whole liquid jet starting with the channel or pipe flow, the non-breaking and the breaking part of the jet up to the final breakup has to be simulated accurately. Due to the limitation of direct numerical simulations (DNS) to moderate Reynolds numbers (Re), a stochastic 1D ansatz based on the one-dimensional turbulence (ODT) model is used to simulate a rectangular liquid jet with a high lateral resolution. ODT permits an affordable high resolution of interface and single phase property gradients, which are key for understanding the local behaviour. ODT is a stochastic model simulating turbulent flow evolution along a notional 1D line of sight by applying instantaneous maps to represent the effect of individual turbulent eddies on property profiles. The occurrence of an eddy itself is affected by the property profiles, resulting in self-contained flow evolution that obeys the applicable conservation laws. Results are based on an ensemble average of several realizations. A detailed introduction is given by Kerstein [3] and extended by Ashurst, Kerstein and Wunsch [1, 4, 9].

PRELIMINARY RESULTS

The liquid jet simulation is divided into two parts, a short temporal channel flow and an also temporal non-breaking liquid jet part. The change between parts is implemented by switching the boundary conditions from no-slip - for the channel flow part - to a free-slip boundary condition for the subsequent jet. The velocity profile thereupon transitions from a channel flow to a bulk flow profile, which results in a transient simulation. The channel flow part is needed to generate an inlet profile for the jet simulation that is statistically uncorrelated with the inlet profles in other simulated realizations. Therefore, the simulation can be expressed as: 1. Starting the simulation with an instantaneous channel flow profile, 2. simulating the short channel flow part, 3. saving the calculated instantaneous channel flow profile as the next starting profile, 4. switching the boundary conditions, and 5. simulating the liquid jet part.

In the first simulated realization, the initial velocity profile is generated by a previous channel flow simulation. The simulation matches the bulk Reynolds number $Re_{\mathrm{av}} = u_{\mathrm{av}} D \nu^{-1}$, where u_{av} is the bulk velocity, ν is the kinematic viscosity, and D is the channel width. The simulations are performed with an extension of the BasicODT [1] code. Figure 1 and 2 show the lateral profiles of the normalized mean streamwise velocity and the normalized mean streamwise turbulence intensity compared to planar jet measurements by Wolf [8] for a Reynolds number of $Re_{\mathrm{av}} = 23000$. The first profiles are the result of a previous channel flow reproducing the mean streamwise velocity and showing an already known discrepancy in the streamwise turbulence intensity [7]. The velocity profile for $x/D = 5$ shows a significant discrepancy caused by neglecting 3D effects at the outlet of the channel. The next two profiles $x/D = 10$ and $x/D = 15$ show a good comparison to the measurements. In contrast, the ODT results for the turbulence intensity shows first a decay in the outer region for $2y/D > 0.2$ increasing to the boundary and further an overall constant decay. This is not seen in the measured results, where the decay starts in the outer region for $2y/D > 0.4$ while staying constant elsewhere forming a plateau and resulting in a nearly flat profile for $x/D \geq 10$. The limited capability of ODT to simulate free-slip boundaries was already presented by Gonzalez-Juez [2]. Within figure 3 the decay of the streamwise turbulence intensity is plotted showing a power law of roughly -1. This would suggest a power law for the turbulent kinetic energy (TKE) of -2 not seen in figure 4. Instead, a power law of -1 is seen also notized by Mansour's round jet measurements [6].

FIRST CONCLUSIONS

As the velocity profiles and the streamwise turbulence intensity show, there are major 3D effects at the free-slip boundary not captured by 1D ODT. Therefore, further simulations for the final paper will be based additionally on temporal ODTLES [2]. Numerical difficulties at the orifice generated by property jumps, e.g. the surface tension, in a spatially developing simulation are not present in a temporal simulation. Nevertheless, there could be artifacts of the physical modeling assumptions - including the temporal advancement - that circumvents the numerical difficulty. These will be assessed by comparing results to measurements and DNS and corrective changes will be made as needed.

Furthermore, a two-phase adaptive ODT [5] implementation will be used to compare the free-slip boundary condition to a two-phase interface. This code will also be a basis for jet breakup simulations.

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[1] ODT Research Group - https://sites.google.com/site/odtresearch/codes

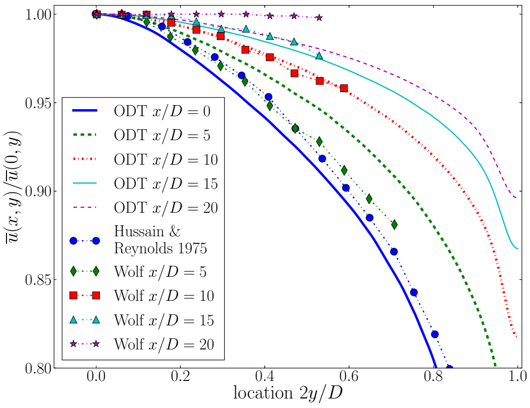

Figure 1. Lateral profiles of normalized streamwise velocity compared to measurements by Wolf [8]

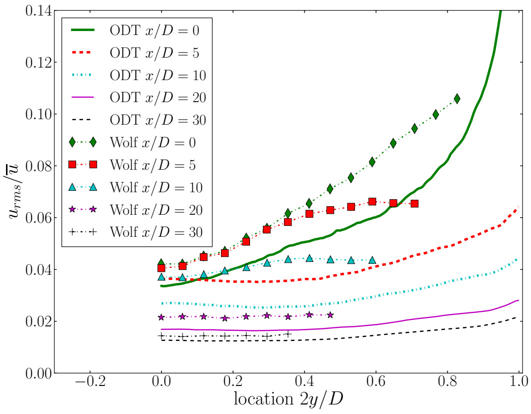

Figure 2. Lateral profiles of normalized streamwise turbulence intensity compared to measurements by Wolf [8]

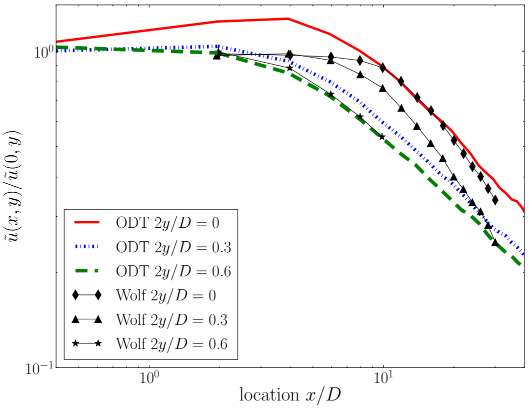

Figure 3. Spatial evolution of normalized mean streamwise turbulence intensity at several lateral positions compared to measurements by Wolf [8], $\tilde{u} = u_{\mathrm{rms}}/\overline{u}$

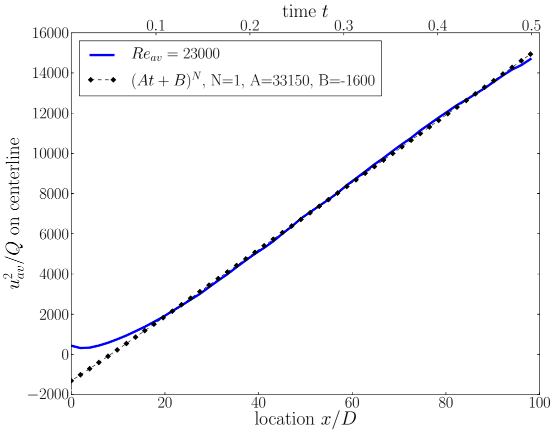

Figure 4. Measured [6] spatial evolution of normalized turbulence intensity showing a -1 power law based on bulk velocity u_{av}, turbulent kinetic energy Q

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