Preliminary Results on Turbulence Production and Dissipation by Spray Particles in a Round Jet Using OpenFOAM

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Background

- Mixing of fuel vapour and air in diesel spray is strongly affected by spray particles.
- In LES+LPT diesel spray modeling problems regarding model consistency at high liquid volume fractions appear leading to e.g. uncertainity regarding validation of breakup models.
- Thus, we introduce a reduced model problem: spray = turbulent free round jet loaded with spherical particles.
- In this presentation preliminary results gathered during the last month are presented.

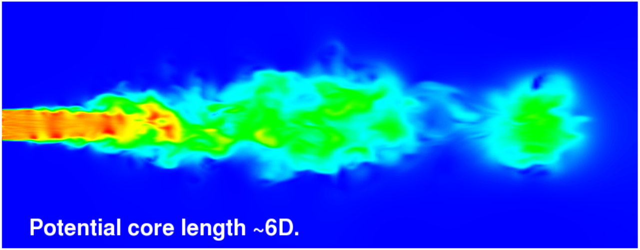
Structure of the Presentation

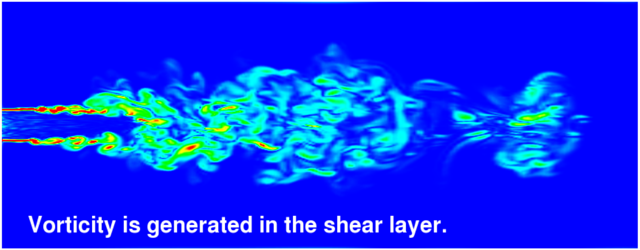
- Similarities between sprays and jets
- OpenFOAM - freely available CFD source code
- Numerics and Large Eddy Simulation
- Simulation setup
- Particle Laden Jet - comparison between large and small droplets.
- Summary

Similarities Between Sprays and Jets

(a) diesel injection in an optical engine
(b) diesel spray/spray bomb (courtesy of *P.Rantanen*)
(c) smoke plume
(d) steam and smoke
(e) exhaust gases
(f) geysir
(g) fountain
(h) low water fall
(i) high water fall.

Jets in Brief





Particle in Turbulence

Stokes number:

$$St = \tau_V \frac{u}{\delta} \tag{1}$$

where $u =$ characteristic velocity and $\delta =$ characteristic length scale of an energy containing eddy. The momentum relaxation time $\tau_V =$ characterizes the scale at which the particles velocity drops to 63% of it's original velocity in a flow stream and is defined by

$$\tau_V = \frac{\rho_d}{\rho_g} \frac{D^2}{18\nu_g} \tag{2}$$

where $\nu_g =$ kinematic viscosity of the gas.

OpenFOAM in Brief

- OpenFOAM is a freely available open source control volume CFD code
- Numerical methods, RANS, LES, Lagrangian spray library, moving and sliding mesh, MPI for parallel message passing.
- OF includes tens of ready made CFD *solvers* = top level script code utilizing implemented libraries.
- User may write a new solver or modify an existing one to simulate a particular purpose.
- OF includes also command line *utilities* for pre-and postprocessing, a simple mesh generator and postprocessor.
- Good documentation is available. Participation in the discussion group provides the key access to the code.

Guidelines for Setting up a Spray LES-Simulation with OpenFOAM

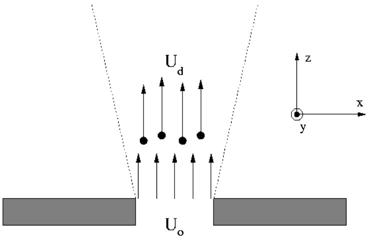
- Combine the Xoodles tutorial and dieselEngineFoam codes. This requires changing of a couple lines in Xoodles top-level solver by adding a spray momentum source term to the momentum equations. Instructions are in the discussion forum.
- Copy-paste of spray input files to the Xoodles.
- Compile and that's it!
- As a newbie (and unexperienced in CFD) it took me less than a month to struggle myself to a situation where I had a complete parallel LES-LPT spray solver available.
- The support from the discussion group was of key help!

Why Large-Eddy Simulation?

- Dynamical simulations require the turbulent spectrum. LES can produce it.
- In LES a subgrid model is required to model the SGS processes below the filter resolution.
- If computational power is available *implicit filtering* is possible.
- The mesh is refined until the turbulent energy cascade can be seen and no energy accumulation to the small scales is observed.
- The numerics works then as a SGS model and one source of uncertainity (i.e. the SGS model) is removed.
- In a diesel spray computation SGS modeling might be needed later on but implicit LES gives a pure start.

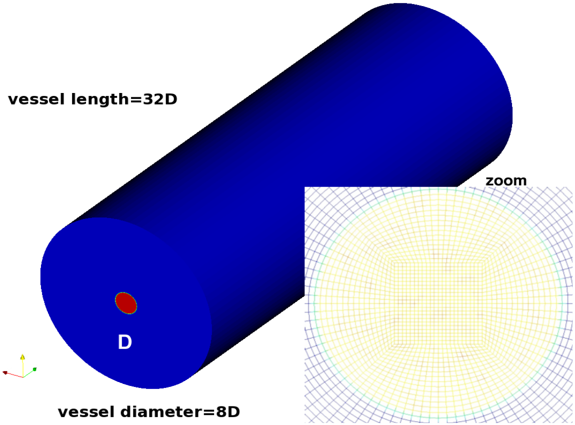
The Computational Setup

- A jet enters a 5bar N2 chamber. Drops are uniformly injected on the jet area. Jet diameter $D = 2mm$.
- Isothermal, no-slip wall boundary conditions; temperature and fluctuating velocity given at inlet; Dirichlet condition at outlet.
- Introduce gas velocity at the inlet $U_o = 80m/s$, droplet velocity $U_d = 110m/s$, gas flow rate $\dot{m}_g = 1.5mg/ms$, duration of injection $1ms$ mass loading ratio ϕ.



The Computational Mesh

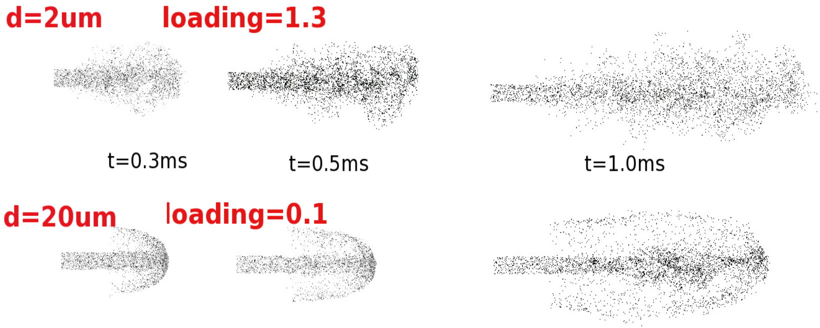
- 3M cell mesh consisting of 100by100by300 cells.
- In the finest region cell size $40 by 40 by 100 \mu m$.



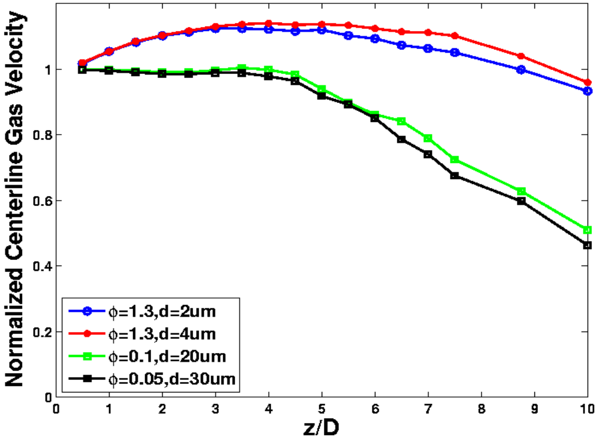
Some Details About Computations

- Compressible solver but low compressibility limit since $Ma = 0.3$.
- PISO based pressure correction.
- 'Believed' to be 2nd order accurate in space but no clarity so far about the accuracy of convection.
- Implicit Euler first order time discretization.
- Pre-conditioning of the equations for convergence.
- $CFL_{max} \approx 0.1$, $\Delta t = 0.75 \cdot 10^{-7}$.
- Ran in parallel on 2*12 processors. This took 30 hours clocktime.
- Excellent scalability BUT the droplets cause load imbalance. $N_{parc} = 250000$.

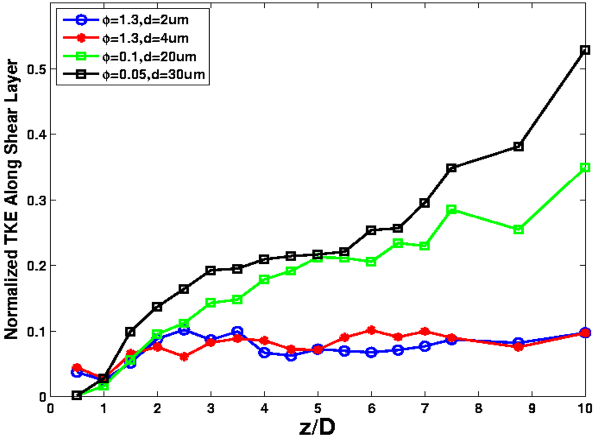
Comparison between small and large droplets



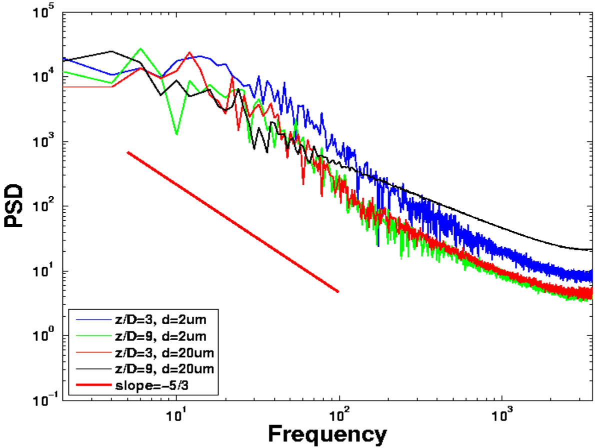
Mean Velocities Along the Spray Axis Reveal the Potential Core



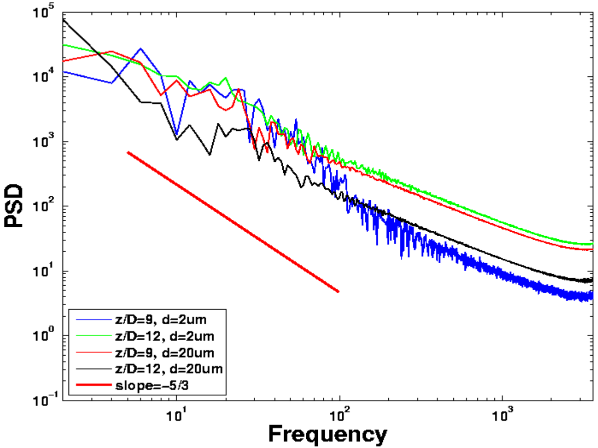
Turbulent Kinetic Energy along the Shear Layer



Look at the Spectra 3D vs 9D



Look at the Spectra 9D vs 12D



Comparison of vorticity

d=2um loading=1.3

t=0.3ms

d=20um loading=0.1

Comparison of vorticity

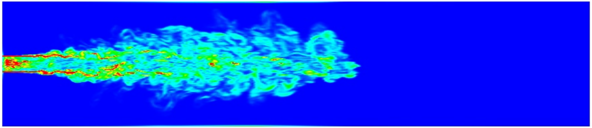
d=2um **loading=1.3**

d=20um **loading =0.1**

t=0.5ms

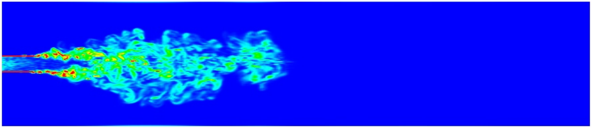
Comparison of vorticity

d=2um loading=1.3



d=20um loading=0.1

t=1.0ms



Summary

- Preliminary studies on LPT+implicit LES have been carried out and the method seems quite promising yet requires lots of computational power.
- No extra details needed from SGS modeling.
- Jets and sprays are very analogous.
- Droplets produce and dissipate turbulence. Scale interactions may amplify/dampen the differences between jets and sprays.
- These phenomena can be captured in implicit LES+LPT but the results are sensitive to SGS modeling, the chosen convection scheme etc.

Near Future Studies

- Validation of numerics on the round jet problem.
- 2nd order spatial accuracy necessary.
- Turbulent inlet condition needs to be developed from a pipe flow simulation.
- Pointwise measurement data from real sprays would provide very interesting comparison for present and future studies! In case of interesting measurement data or any other reason please don't hesitate to contact me!
- Thank you for your attention!

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