The Level Set Interface-Tracking Model Coupled to SPH Method

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Cavitation Physics

- Onset, Development & Collapse
- Modeling & Control
- Materials Erosion, Bio Effects

Max Flow Velocity: 50 m/s
Max Pressure: 20 bar
Optical Instrumentation: p-transducers

Unique Research Facility: High Speed Cavitation Tunnel
Cavitation Modeling by SPH

- **Methodology:**
  - Rayleigh-Plesset equation
  - Level Set equations for multiphase flows
    - Collaboration with Prof. Koumoutsakos, ETH Zürich
  - Adaptation of sph2000
    - Collaboration with University of Tübingen, Germany

- **Test cases using High Performance Computing:**
  - Bubble implosion
  - Oscillating drop
  - Bubble collapse
  - Instability of a liquid jet

- **Post-processing:** thanks to Paraview
The Level Set Method

- The two-phase mixture is as a single fluid
- Density, viscosity are smoothed across the interface
- The LS marker function is continuous and it is set to the signed minimum distance to the interface
- Reasons for using the LS function:
  - Minimal numerical diffusion since the function is continuous across the interface, with $|\nabla \phi| = 1$
  - Easy to interpolate phase properties across the interface in the two-fluids formulation
The Level Set Method

Non-conservative form of Level Set equations:

\[
\frac{\partial \phi}{\partial t} + \mathbf{u} \cdot \nabla \phi = 0,
\]

\[
\frac{\partial \phi}{\partial \tau} + \text{sign}(\phi_0)(|\nabla \phi| - 1) = \lambda |\nabla \phi| \delta_\varepsilon(\phi)
\]

Interpolation of phase properties across the numerical interface:

\[
\rho(\mathbf{x},t) = \rho_1 + (\rho_1 - \rho_2)H_\varepsilon(\phi(\mathbf{x},t))
\]

\[
\mu(\mathbf{x},t) = \mu_1 + (\mu_1 - \mu_2)H_\varepsilon(\phi(\mathbf{x},t))
\]

- Straightforward to couple Level Set and SPH
- LLSM = best mass conservation of the existing LS
- A parallel object-oriented SPH-framework

- Dr. Roland Speith’s PhD. Work, University of Tübingen, 1998

- C++ code by Sven Ganzenmüller, University of Tübingen, 2000-2006,..
Classic SPH modeling method

- Summation density or continuity equation
- Artificial viscosity ($\alpha=1$, $\beta=2$, $\epsilon=0.01$)
- Viscous stress tensor (Flebbe et al, 1994)
- Total Energy balance
- Surface tension (end of 2006)

- Kernel functions: a cubic spline (Monaghan, 1992)

- Boundary: Reflecting
- Ghost particles

- Integrator: RK1 (Euler) to RK5CashKarp (RK5 + error detection + step adjustment)
Finding interactions

- Uniform spatial grid with a cell size = $h$ cst

- To calculate rhs of SPH equations = 3 sums (one for the density, 2 for first and second order derivatives) $\rightarrow$ Interaction list

- This algorithm reduces the total memory requirement to about one tenth without increasing the overall computing time
SPH2000: Parallelization

- A cuboids region of the simulation domain to every processor
- Cuboids with different sizes which vary in time
- The interface to the other regions = real, physical boundary (like periodic boundary with communication to neighbour processors)
- The size of interaction list = a tuning parameter for a size versus speed tradeoff
- Communication between processors thanks to the Tübingen Parallel Objects (TPO++), an object-oriented message passing library for C++ with a load balancing function
IBM Blue Gene/L

- Processors: 8192 IBM 440, 700 MHz, 512 MB
- Memory: 2 TB
- LINUX (Suse Linux Enterprise Server 9)
  - frontend nodes for compilation job submission and debugging
- Space sharing:
  - one parallel job per partition
  - one process per processor
- SPMD model
- XL Fortran90, XL C/C++
- IBM MPI library
Our experiences with sph2000

- **Successful compilation:**
  - **release 5**
    - on bipro dual core PC under Linux Suse10
    - On High Performance Machine: IBM Blue Gene/L under Linux Suse Pro

- **Benchmark case on BG/L: 3D-simulation, 2 fluids:**
  - 1 million air particles,
  - 18,876 diesel particles on BG/L
  - Smoothing length: 1.2 E-5 m
  - Neighbor / particle: 30
  - 774 time steps, \( V_{\text{diesel}} = 20 \text{ m/s} \)
  - Iteration/sec/processor: 0.6 s
3D simulations on Blue Gene/L

- Post-processing with PARAVIEW
- P and V frames thanks to a Delaunay triangulation realized by Dr. Jean Favre from CSCS (Manno, Switzerland)
A glyph animation

- **Diesel particles**
- **Air particles**

1 million blue particles
18,876 red particles
Speed-up: 1 million particles, 10 time steps

- Utopic
- Tübingen
- BG/L