# Smoothed Particle Hydrodynamics

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# Why mesh-free particle methods?

- Traditional Eulerian techniques (FDM, FVM, FEM,...) have limitations in dealing with
    - deformable bodies
    - large distortions
    - tracking free-surface
  - Remedies: re-meshing techniques
    - would be computationally expensive and complicated
- Mesh-free methods (SPH, MPS,...)
  - Mesh is replaced with moving points so dealing only with the displacement of points within the domain

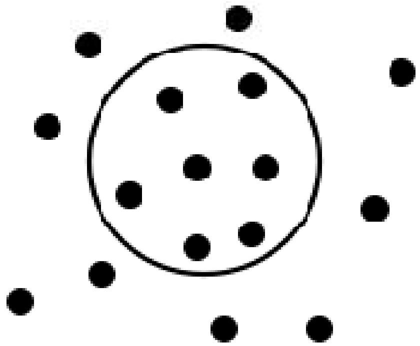
# SPH method

## Smoothed Particle Hydrodynamics

Particle properties are determined by taking an average over neighbouring particles

The fluid is replaced with a set of particles

Fluid dynamics



- Only neighbours contribute to the average
- Closer Particles contribute more than distant particles

**A weight function is needed for taking average**

# SPH method

The fluid is represented by an ensemble average of particles *i*, each carrying mass $m_i$, momentum $m_i v_i$ and hydrodynamic properties (pressure, temperature, internal energy, etc.). The time evolution is governed by the equation of motion plus additional equations to modify the hydrodynamic properties of the particles. Hydrodynamic observables are obtained by a local averaging process.

# SPH sets of equations

- The momentum equation is written

$$\frac{d\mathbf{v}_a}{dt} = -\sum_\eta m_\eta \left( \frac{P_a + P_\eta}{\rho_a \rho_\eta} + R_{a\eta} + \Pi_{a\eta} \right) \nabla_a W_{a\eta}$$

- where repulsive force is

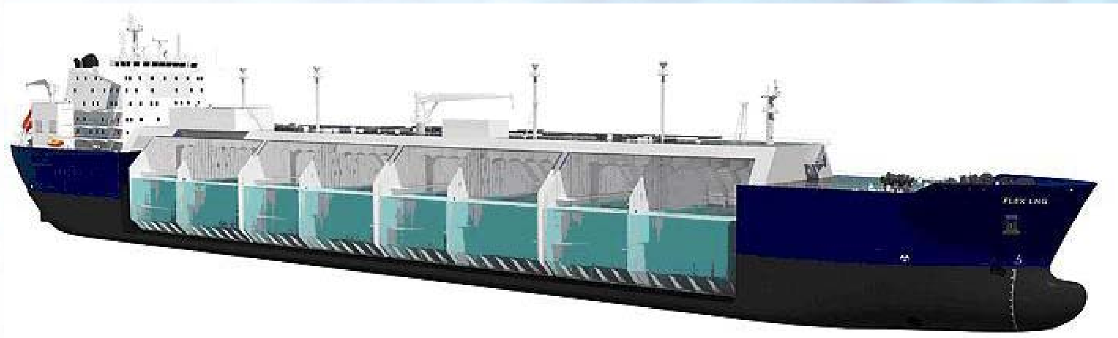
$$R_{a\eta} = \epsilon \left| \frac{\rho_{0_a} - \rho_{0_\eta}}{\rho_{0_a} + \rho_{0_\eta}} \frac{P_a + P_\eta}{\rho_a \rho_\eta} \right|$$

- and the viscous stress term

$$\Pi_{a\eta} = -\frac{16}{\rho_a \rho_\eta} \frac{\mu_a \mu_\eta}{\mu_a + \mu_\eta} \frac{\mathbf{v}_{a\eta} \cdot \mathbf{r}_{a\eta}}{\mathbf{r}_{a\eta}^2 + 0.01h^2}$$

# Numerical simulations

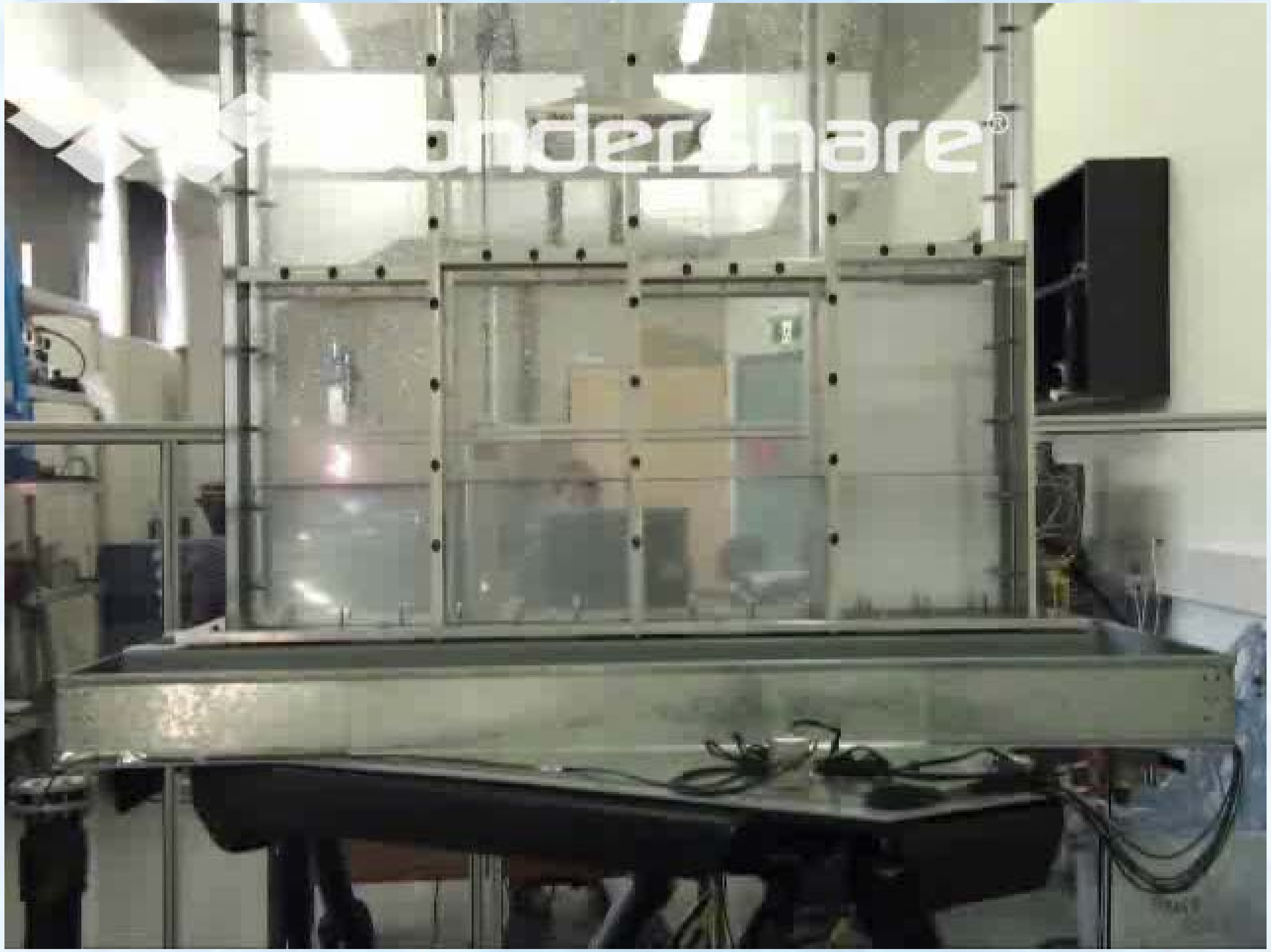

# SLOSHING



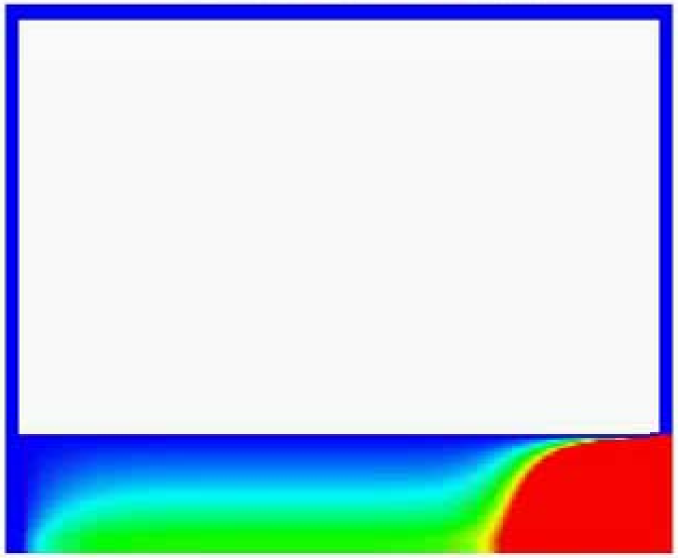
# Sloshing

- The phenomenon of fluid motion in a partially filled tank due to the tank motion is known as sloshing
- The resonance condition may be connected with complex motions of the filled liquid that can couple with ship motions and can represent a danger for the tank structure and for the stability of the ship.
- certain filling ratios it may also create high impact loads on the ceiling of the tank causing significant structural damage.

# Experiment

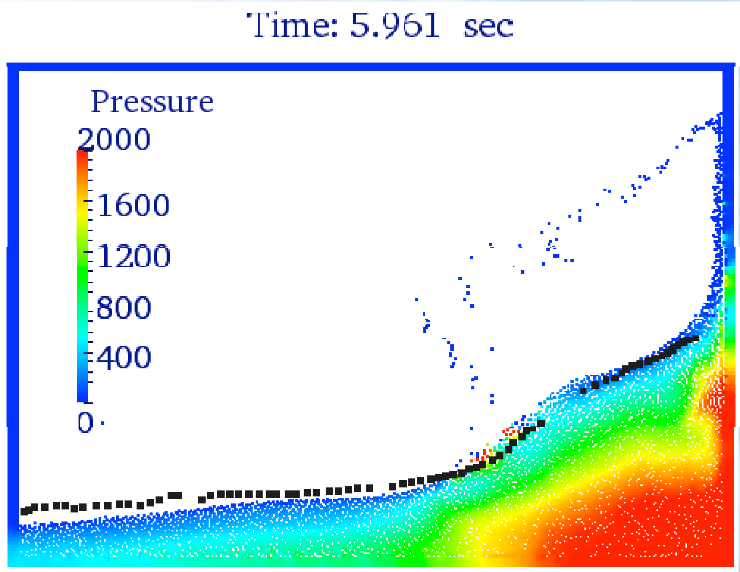


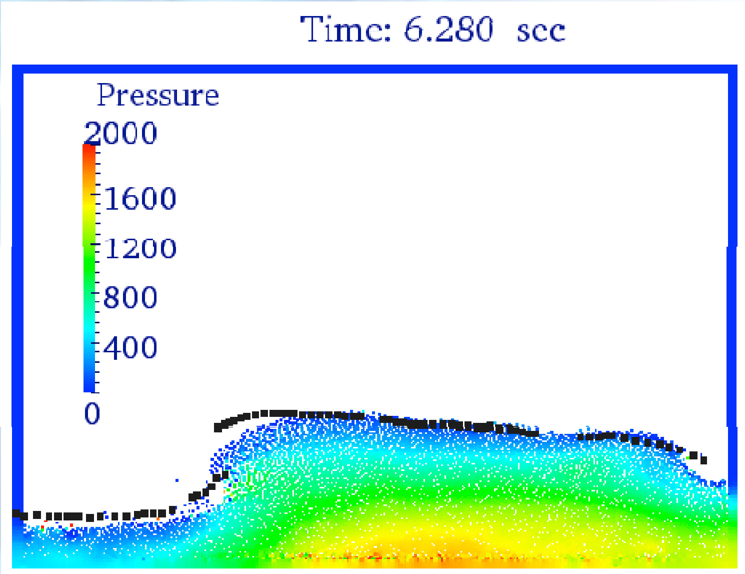
# SPH simulation




*Particles pressure in incompressible SPH*

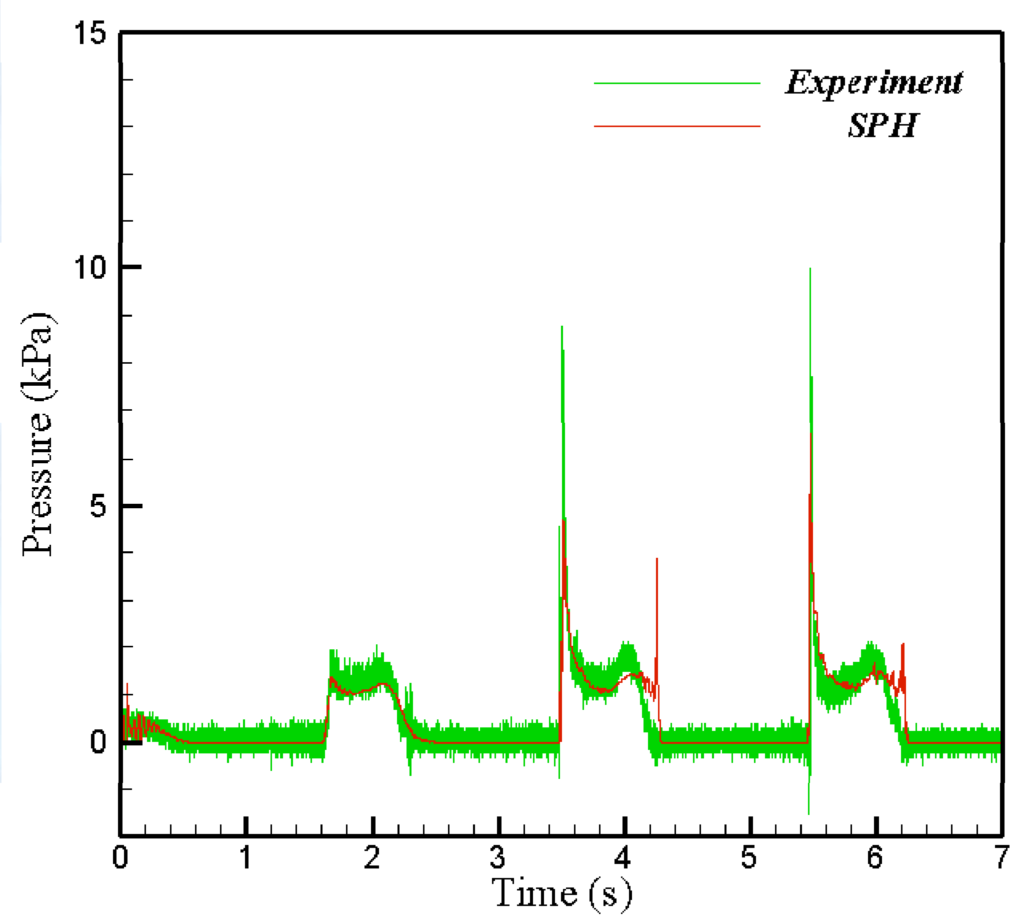
# SPH .vs. Experiment

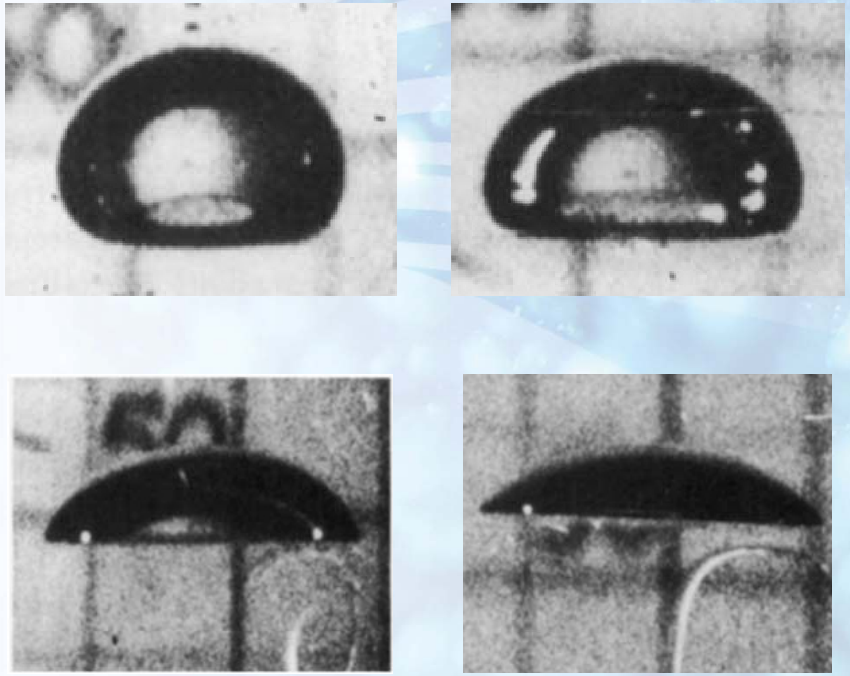



- Particles are coloured by their pressure and the black dots represent the experimental free-surface.

# Impact Pressure



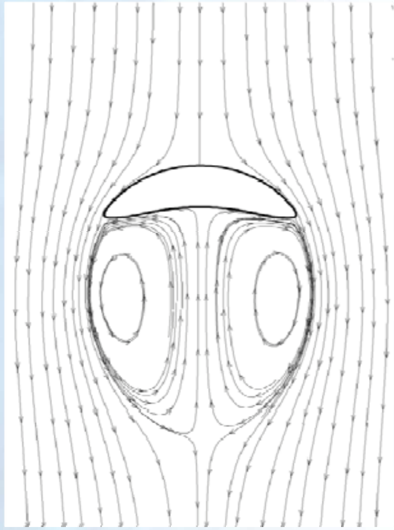


# Rising gas Bubble in liquid

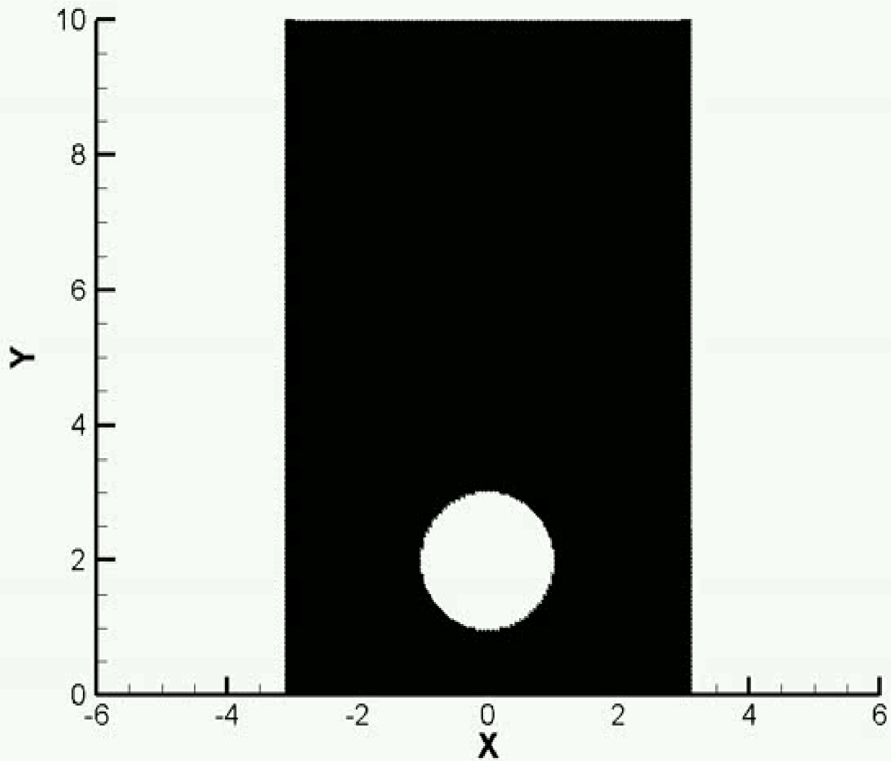
# challenges and goals

- High density and viscosity ratios
- Accurate description of moving and deforming surfaces

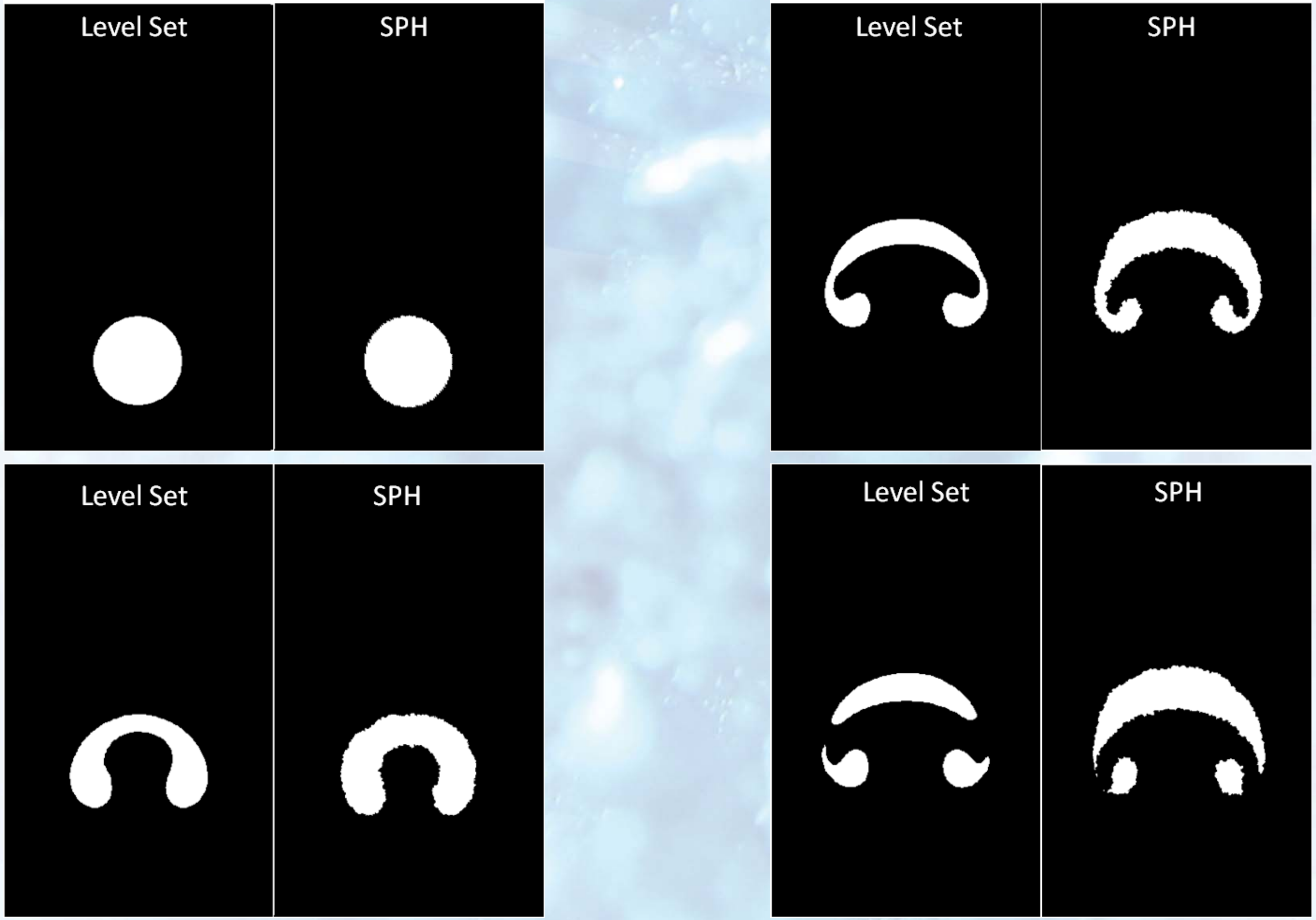
- Analysis of bubble induced turbulence in liquid
- studying vortex structures in the bubble wake

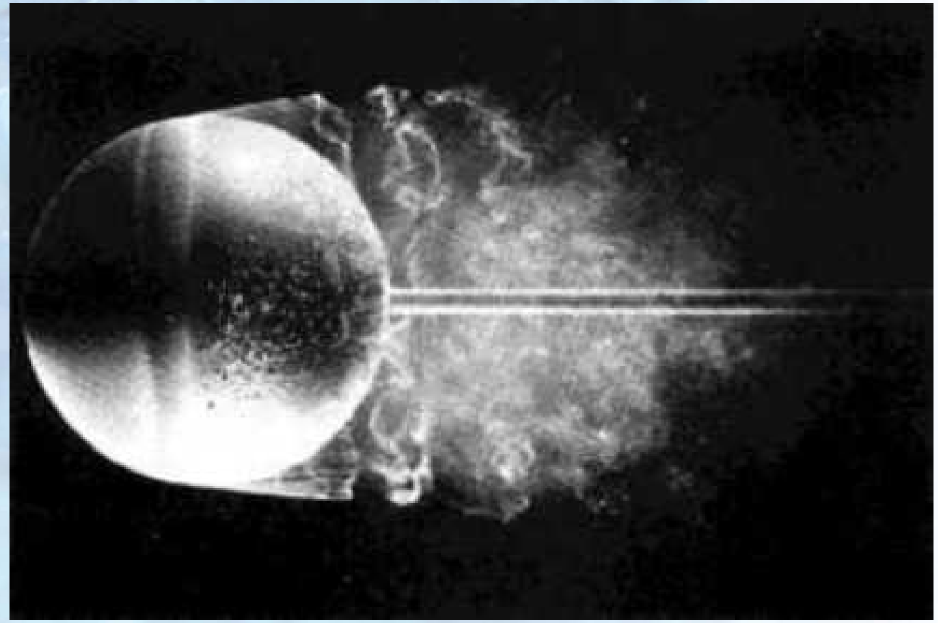


# SPH simulation



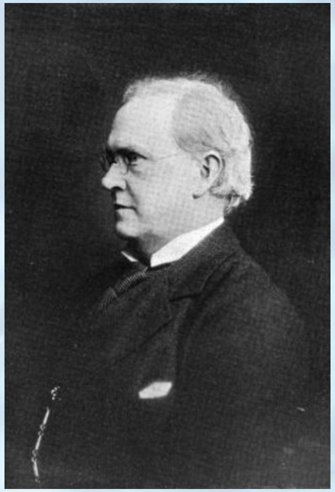
# SPH .vs. Level Set





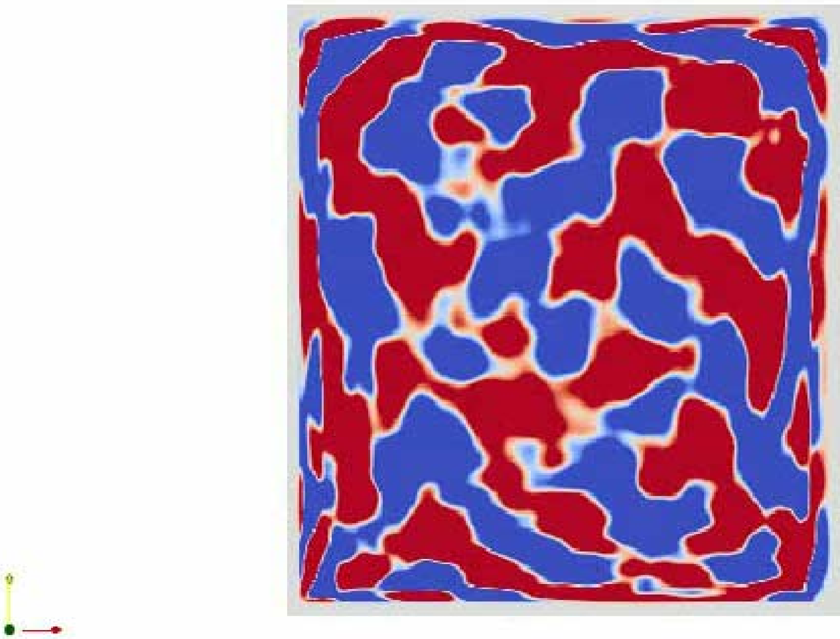
# Turbulent flow

*"I am an old man now, and when I die and go to heaven there are two matters on which I hope for enlightenment. One is quantum electrodynamics, and the other is the turbulent motion of fluids. And about the former I am rather optimistic."*

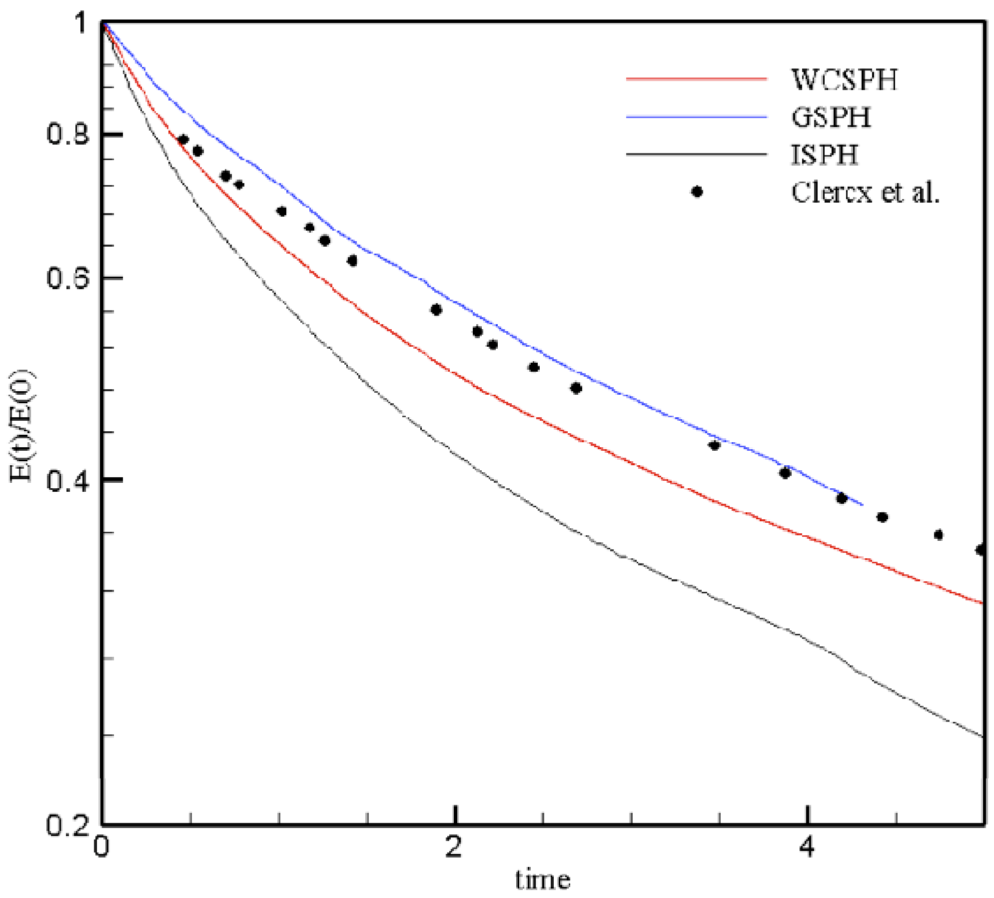


**Horace Lamb**, British Association for the Advancement of Science, 1932

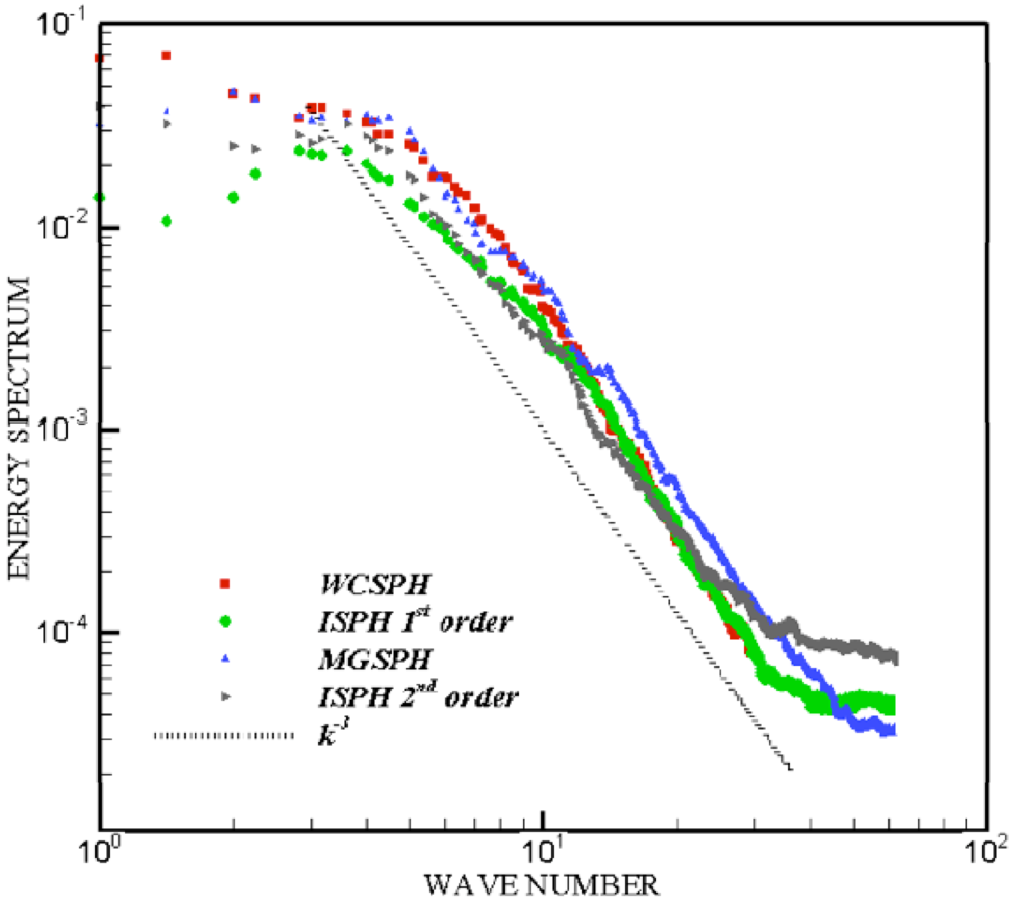
# SPH simulation

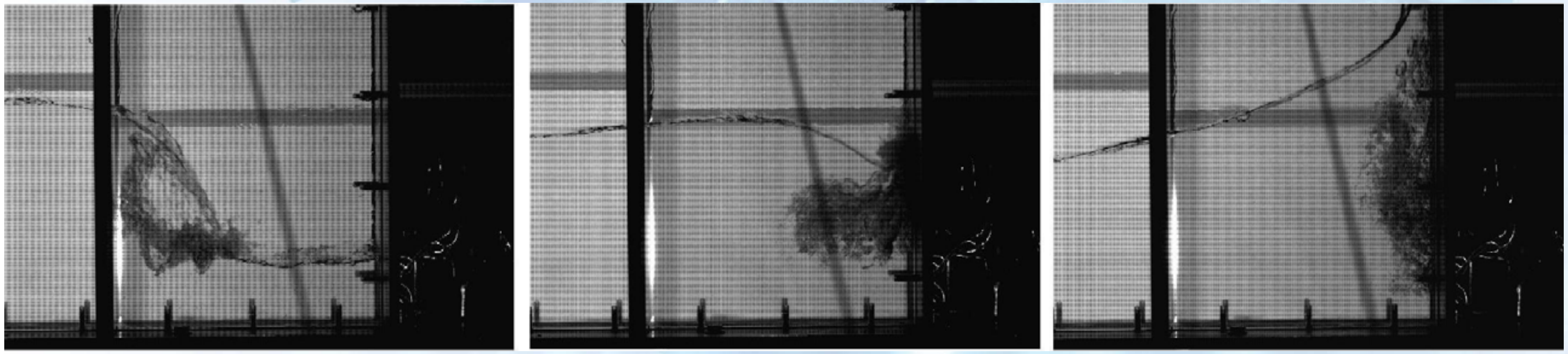


# Decay of Kinetic energy



# Energy Spectrum





*Thank you!*