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Target Simulations

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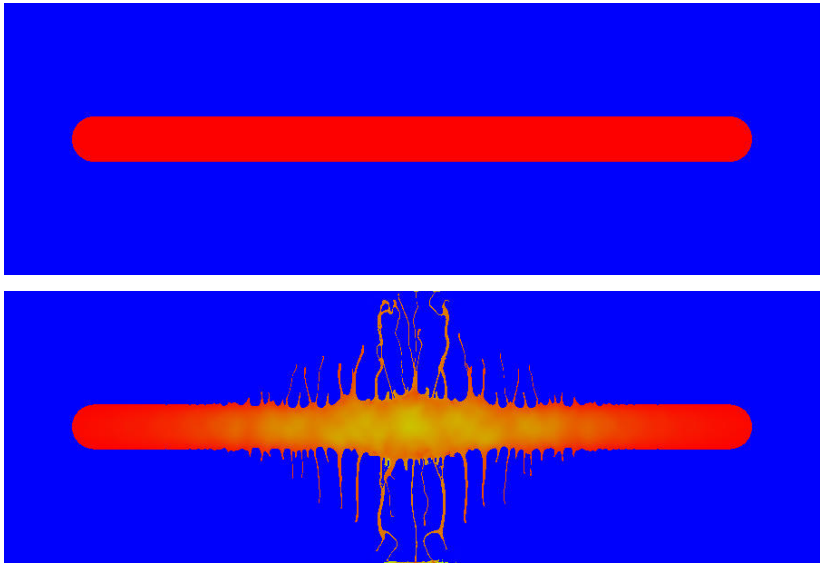
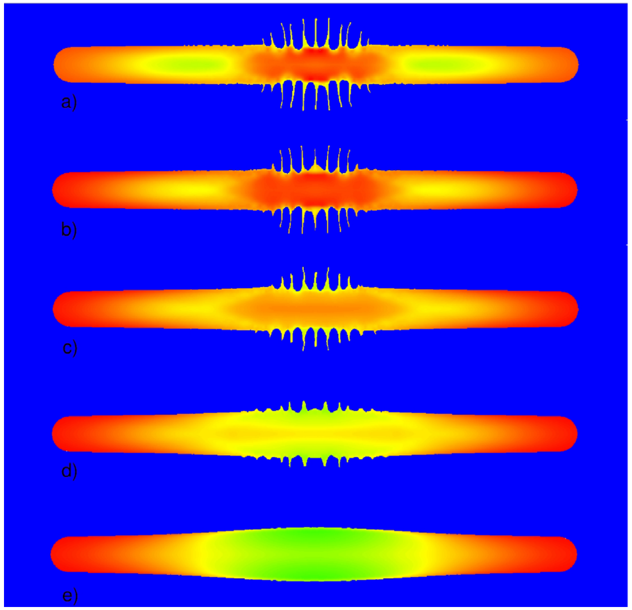
Main results reported in 2003





2D simulations of the Richtmyer-Meshkov instability in the mercury target interacting with a proton pulse. Left: B = 0. Right: Stabilizing effect of the magnetic field.

a) B = 0
b) B = 2T
c) B = 4T
d) B = 6T
e) B = 10T

Analysis of previous simulations

Positive features

- Qualitatively correct evolution of the jet surface due to the proton energy deposition
- Stabilizing effect of the magnetic field

Negative features

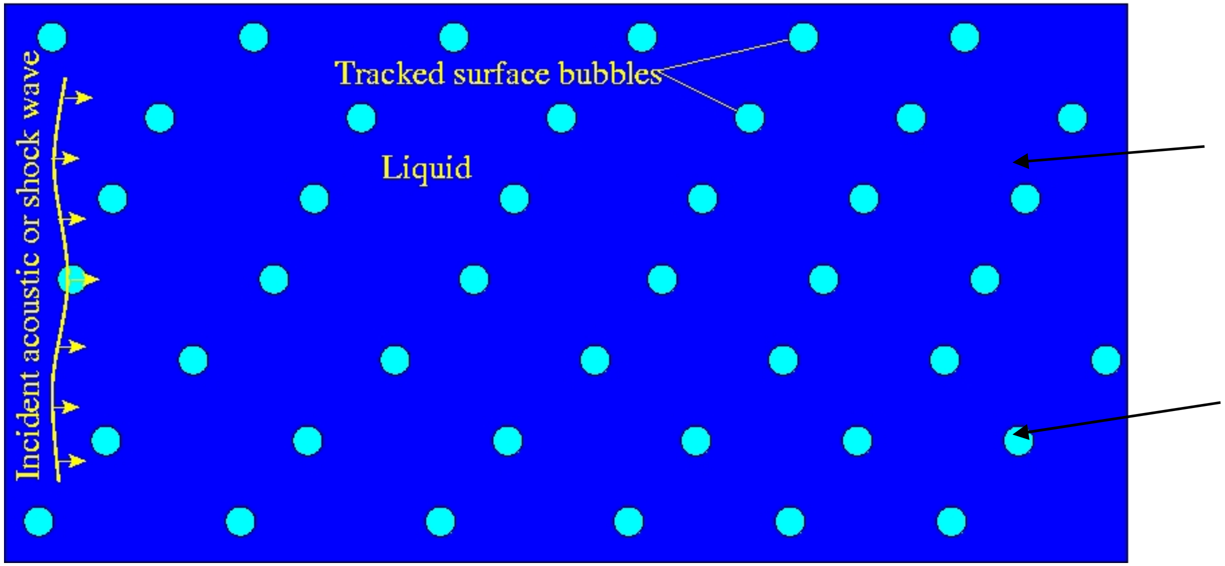
- Discrepancy of the time scale with experiments
- Absence of cavitation in mercury
- The growth of surface instabilities due to **unphysical** oscillations of the jet surface interacting with shock waves
- 2D MHD simulations do not explain the behavior of azimuthal modes

Conclusion

- Cavitation is very important in the process of jet disintegration
- There is a need for cavitation models/libraries to the FronTier code
- 3D MHD simulations are necessary

We have developed two approaches for cavitating and bubbly fluids

- **Direct numerical simulation method:** Each individual bubble is explicitly resolved using FronTier interface tracking technique.



Stiffened Polytropic EOS for liquid

Polytropic EOS for gas (vapor)

- **Homogeneous EOS model.** Suitable average properties are determined and the mixture is treated as a pseudofluid that obeys an equation of single-component flow.

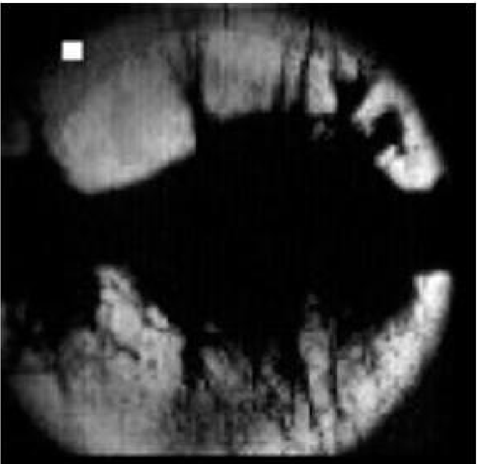
Homogeneous two phase EOS model

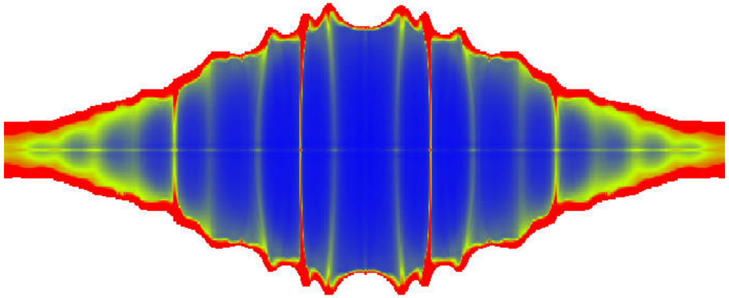
- Applicable to problems which do not require resolving of spatial scales comparable to the distance between bubbles.

- Accurate (in the domain of applicability) and computationally less expensive.

- Correct dependence of the sound speed on the density (void fraction).

- Enough input parameters (thermodynamic/acoustic parameters of both saturated points) to fit the sound speed to experimental data.

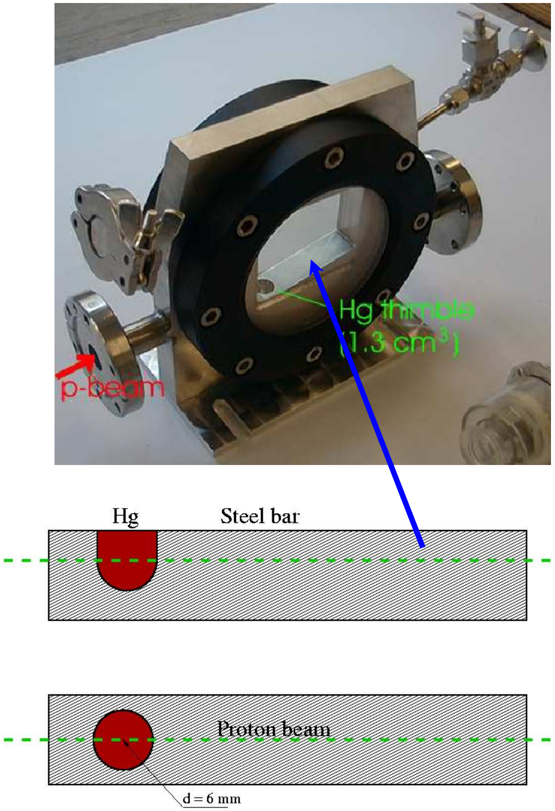


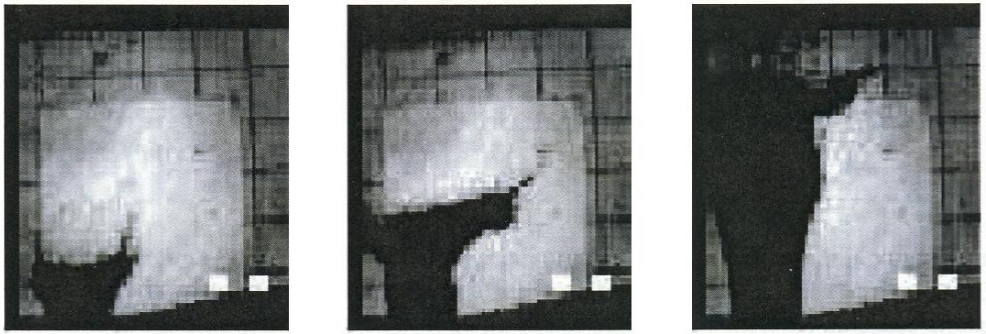


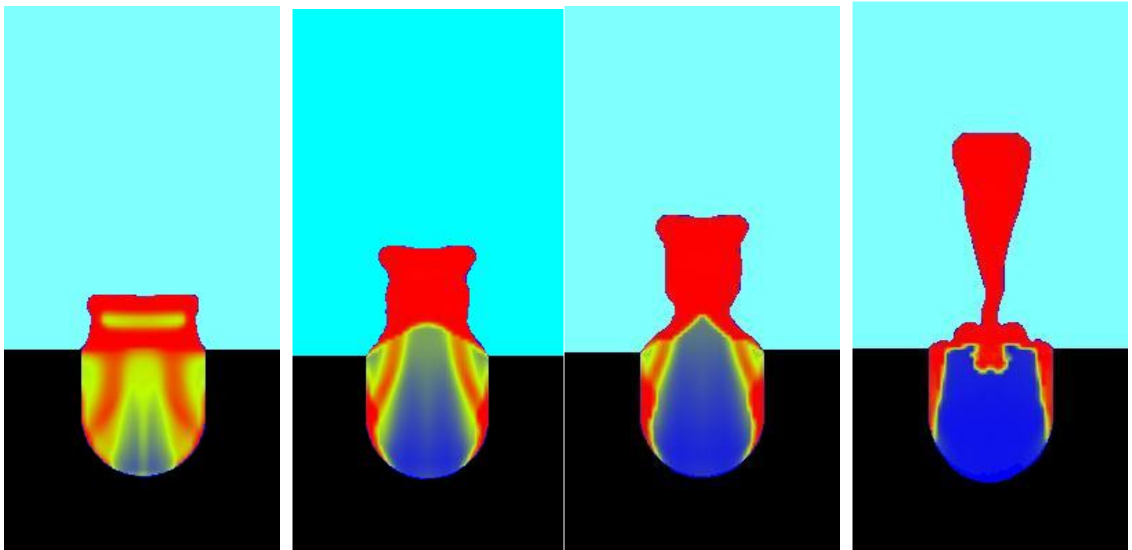
Experimental image (left) and numerical simulation (right) of the mercury jet.

Numerical simulation of mercury thimble experiments

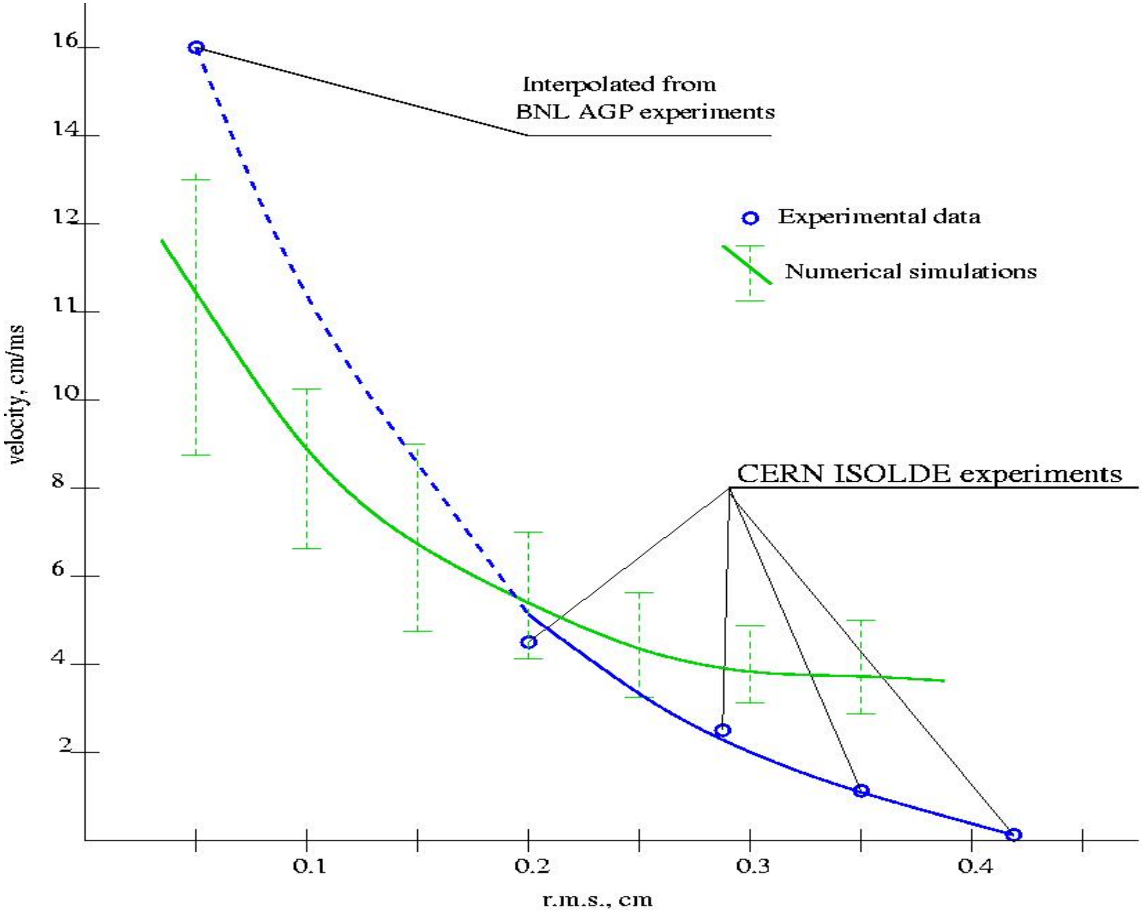
Evolution of the mercury splash due to the interaction with a proton beam (beam parameters: 24 GeV, 3.7*10^{12} protons). Top: experimental device and images of the mercury splash at 0.88 ms, 1.25 ms, and 7 ms. Bottom: numerical simulations using the FronTier code and analytical isentropic two phase equation of state for mercury.







Velocity as a function of the r.m.s. spot size

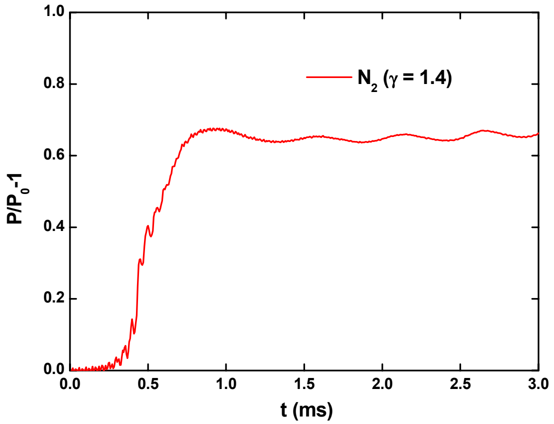


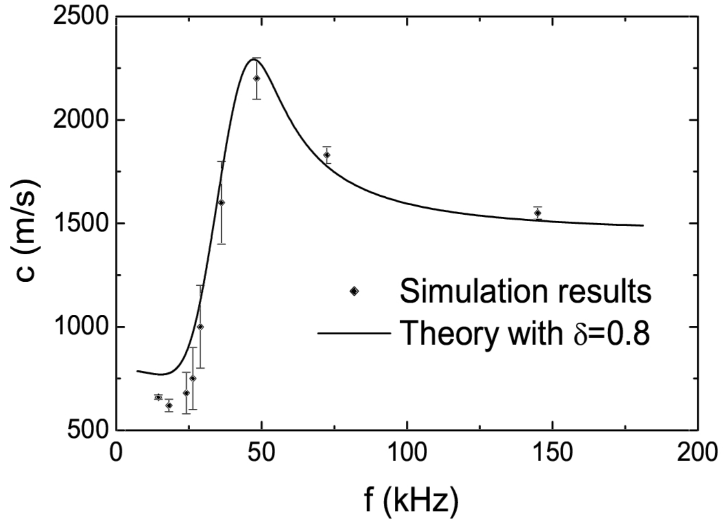
Features of the Direct Method

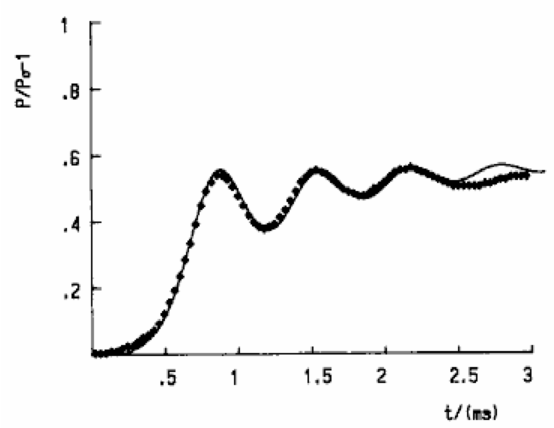
- Accurate description of multiphase systems limited only to numerical errors.
- Resolves small spatial scales of the multiphase system
- Accurate treatment of drag, surface tension, viscous, and thermal effects.
- Accurate treatment of the mass transfer due to phase transition (implementation in progress).
- Models some non-equilibrium phenomena (critical tension in fluids)

Validation of the direct method: linear waves and shock waves in bubbly fluids

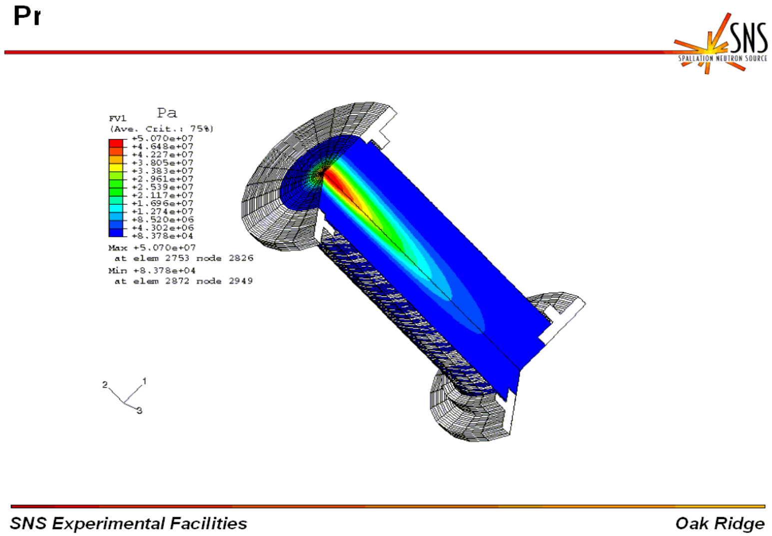
- Good agreement with experiments (Beylich & Gülhan, sound waves in bubbly water) and theoretical predictions of the dispersion and attenuations of sound waves in bubbly fluids
- Simulations were performed for small void fractions (difficult from numerical point of view)
- Very good agreement with experiments of the shock speed
- Correct dependence on the polytropic index







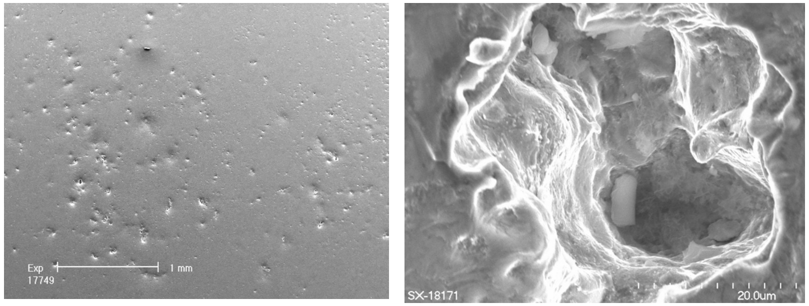
Application to SNS target problem



Pr

SNS Experimental Facilities

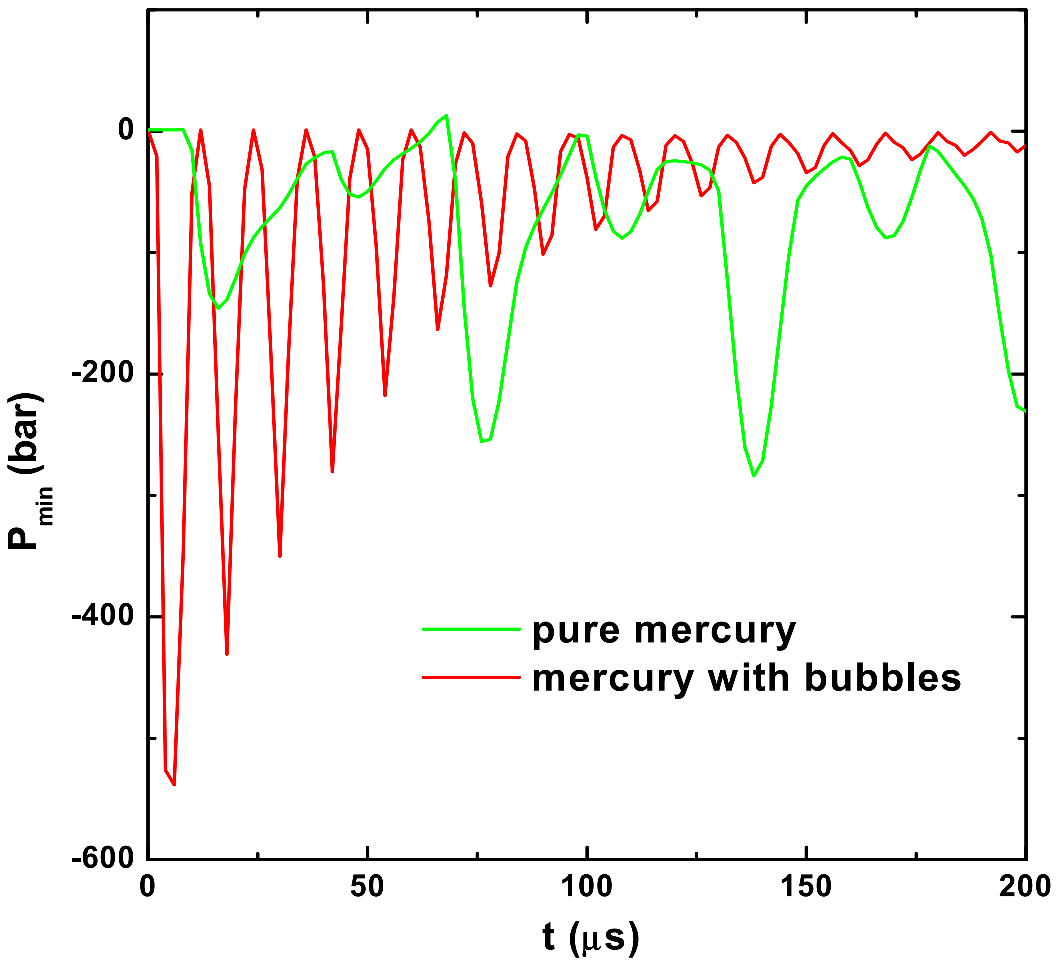
Oak Ridge



Left: pressure distribution in the SNS target prototype. Right: Cavitation induced pitting of the target flange (Los Alamos experiments)

- Injection of nondissolvable gas bubbles has been proposed as a pressure mitigation technique.
- Numerical simulations aim to estimate the efficiency of this approach, explore different flow regimes, and optimize parameters of the system.

Application to SNS



Effects of bubble injection:

- Peak pressure decreases by several times.
- Fast transient pressure oscillations. Minimum pressure (negative) has larger absolute value.
- Cavitation lasts for short time

Dynamic cavitation

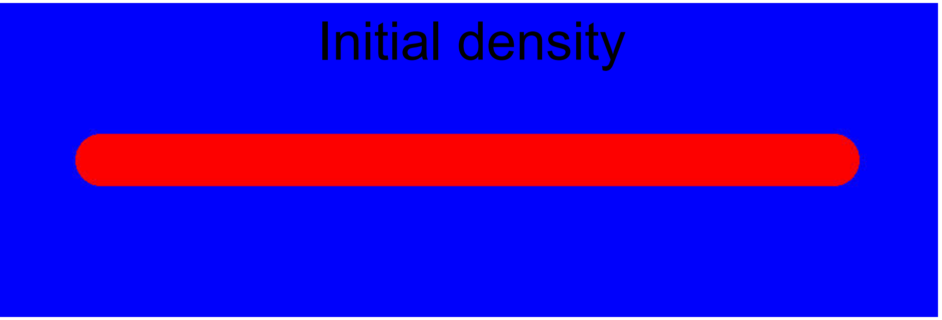
- A cavitation bubble is dynamically inserted in the center of a rarefaction wave of critical strength
- A bubbles is dynamically destroyed when the radius becomes smaller than critical. “Critical” radius is determined by the numerical resolution, not the surface tension and pressure.
- There is no data on the distribution of nucleation centers for mercury at the given conditions. Some theoretical estimates:

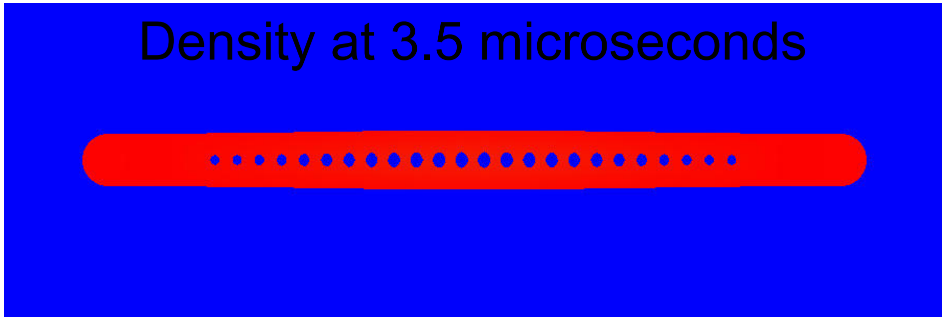
critical radius: $R_C = \dfrac{2S}{\Delta P_C}$

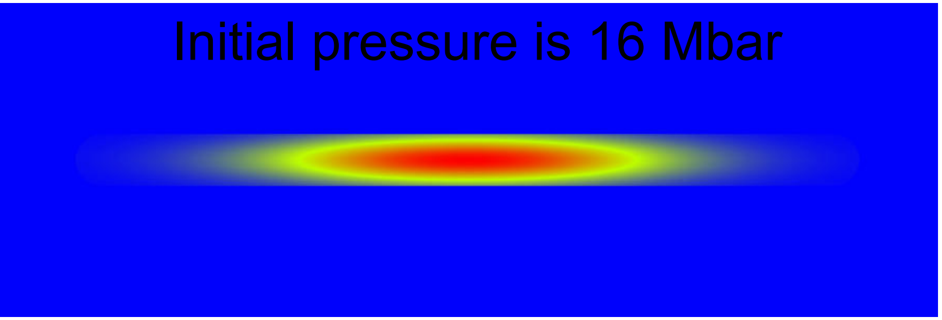
nucleation rate: $J = J_0 e^{-Gb}, \quad J_0 = N\sqrt{\dfrac{2S}{\pi m}}, \quad Gb = \dfrac{W_{CR}}{kT}, \quad W_{CR} = \dfrac{16\pi S^3}{3\left(\Delta P_C\right)^2}$

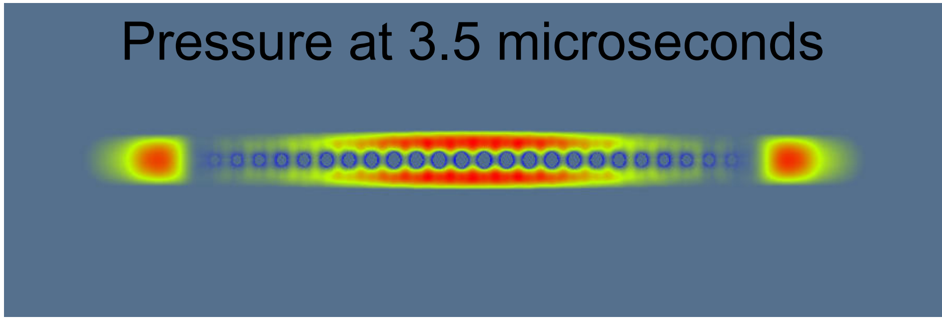
- A Riemann solver algorithm has been developed for the liquid-vapor interface. The implementation is in progress.

Low resolution run with dynamic cavitation.
Energy deposition is 80 J/g

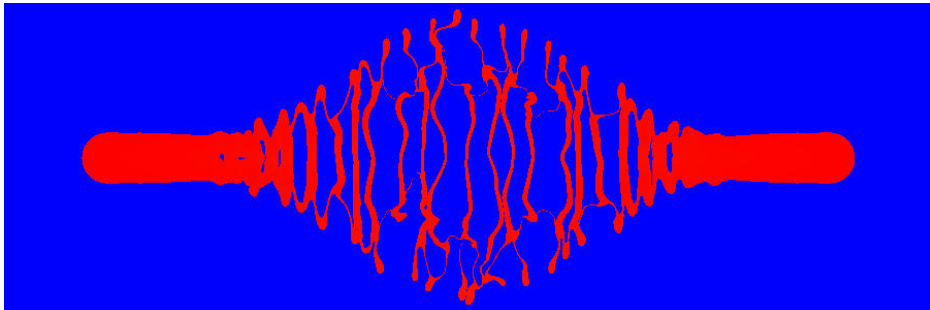

Initial density


Density at 3.5 microseconds


Initial pressure is 16 Mbar

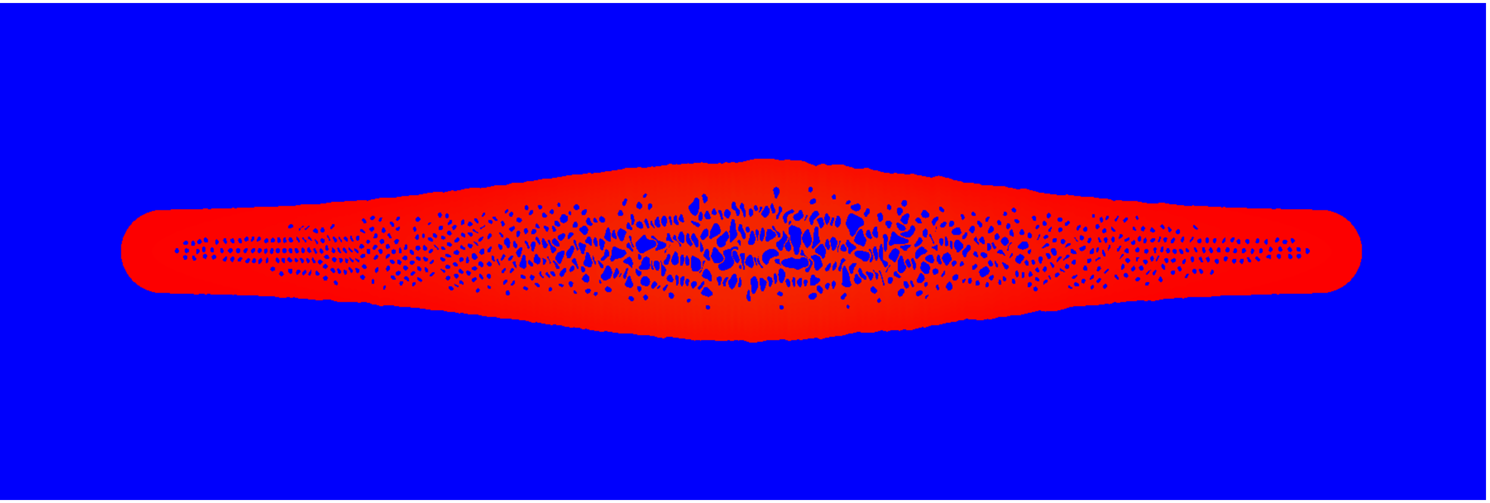

Pressure at 3.5 microseconds

Density at 620 microseconds

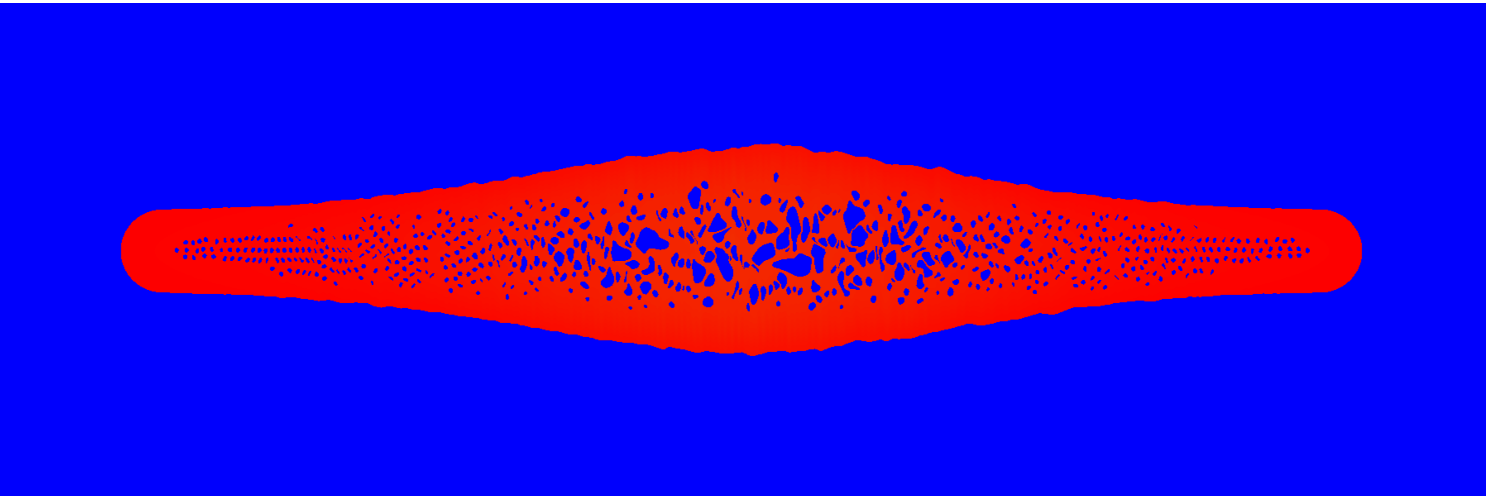


High resolution simulation of cavitation in the mercury jet

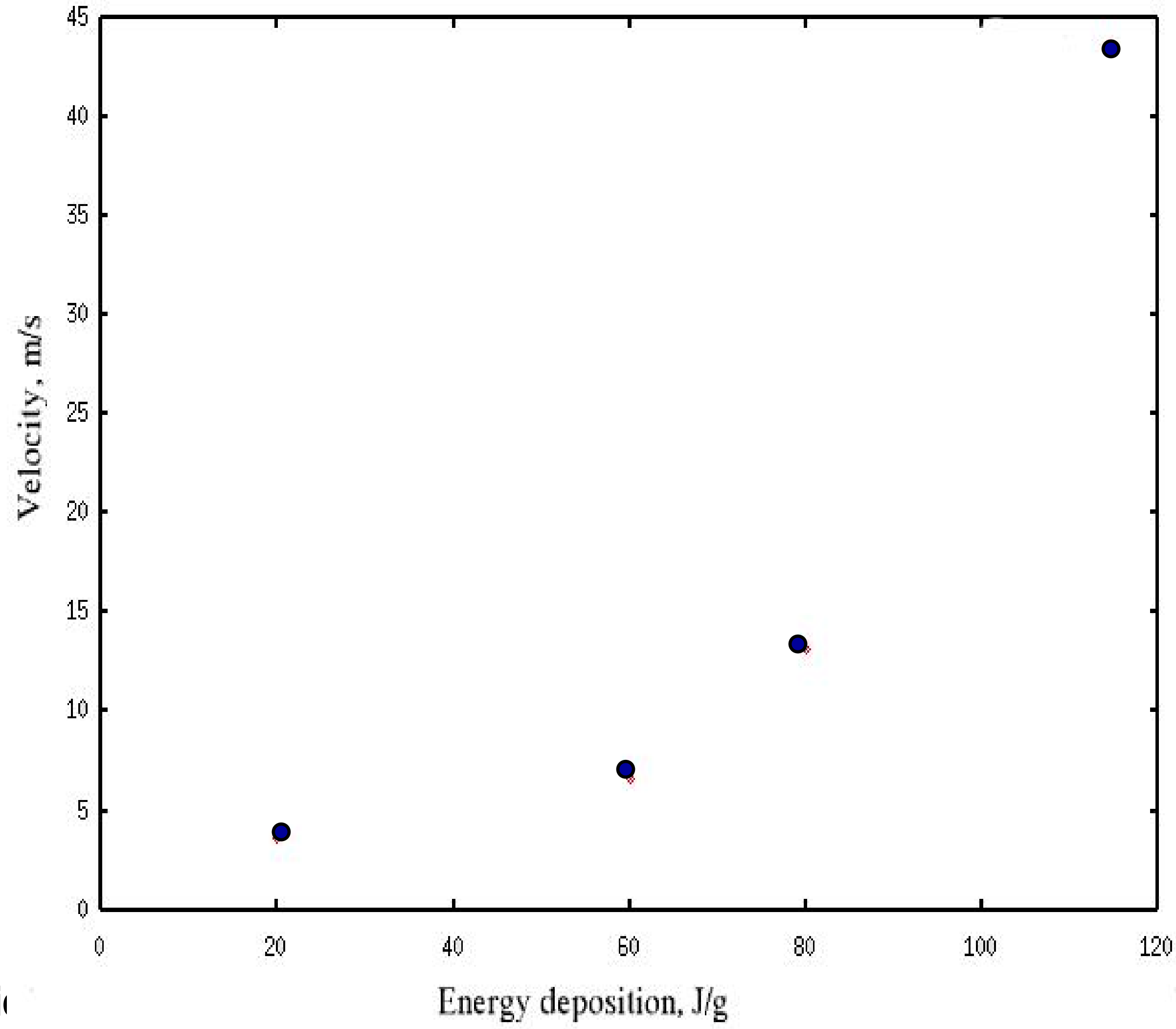
76 microseconds



100 microseconds



High resolution simulation of cavitation in the mercury jet



3D MHD simulations: summary of progress

- A new algorithm for 3D MHD equations has been developed and implemented in the code.

- The algorithm is based on the Embedded boundary technique for elliptic problems in complex domains (finite volume discretization with interface constraints).

- Preliminary 3D simulations of the mercury jet interacting with a proton pulse have been performed.

- Studies of longitudinal and azimuthal modes are in progress. Simulations showed that azimuthal modes are weakly stabilized (effect known as the flute instability in plasma physics)

Conclusions and Future Plans

- Two approaches to the modeling of cavitating and bubbly fluids have been developed
  - Homogeneous Method (homogeneous equation of state models)
  - Direct Method (direct numerical simulation)
- Simulations of linear and shock waves in bubbly fluids have been performed and compared with experiments. SNS simulations.
- Simulations of the mercury jet and thimble interacting with proton pulses have been performed using two cavitation models and compared with experiments.
- Both directions are promising. Future developments:
  - Homogeneous method: EOS based on the Rayleigh –Plesset equation.
  - Direct numerical simulations: AMR, improvement of thermodynamics, mass transfer due to the phase transition.
  - Continue 3D simulations of MHD processes in the mercury target.
  - Coupling of MHD and cavitation models.