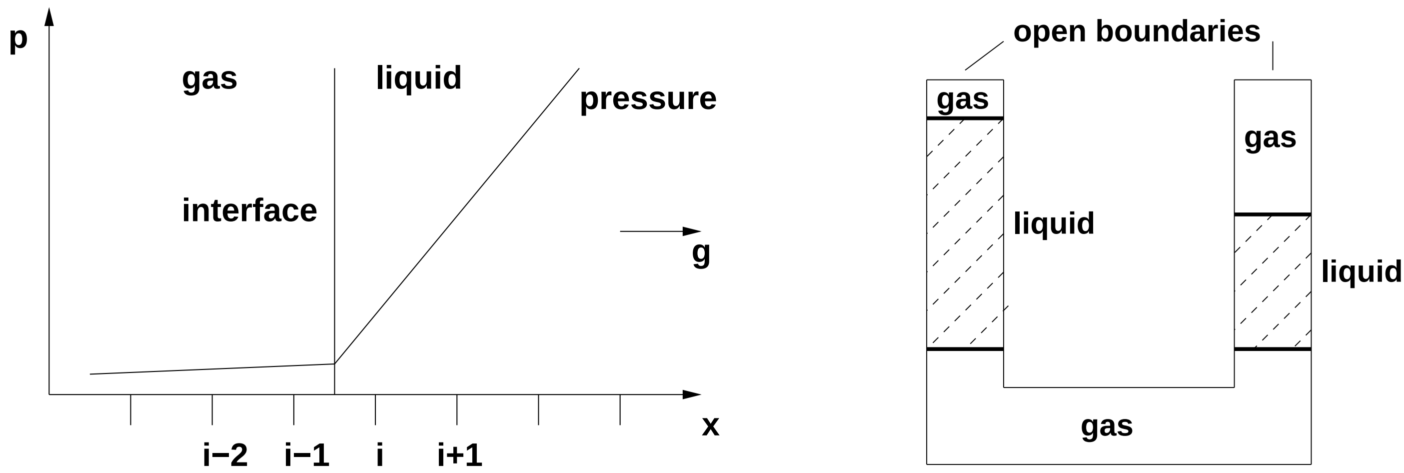
# VIOLENT FREE SURFACE MOTION: EXAMPLES

- Wave Breaking
  - Shores
  - Ships
- Extreme Wave-Structure Interactions
  - Sloshing
  - Slamming
  - Green Water on Deck
  - Offshore Platforms

## VIOLENT FREE SURFACE MOTION: OPTIONS

- Interface Tracking
  - Move Mesh With Free Surface
  - Free Surface = Boundary of Domain
  - Problems When Topology Changes (e.g. Wave Breaking)
- Interface Capturing
  - Gas/Water Both Treated
  - Free Surface ‘Captured’ in Domain
  - Allows for Arbitrary Topology
  - Not as Accurate

# INTERFACE CAPTURING: MODEL PROBLEMS




Hydrostatic Pressure Distribution and Communicating Tubes

- Consider Air:
  - Discontinuity in Pressure Gradient
    $\Rightarrow$ Spurious Air Acceleration
    $\Rightarrow$ Neglect Air

- Neglect Air:
  - Air Pocket Can Not Push on Water

# DESCRIPTION OF INTERFACE

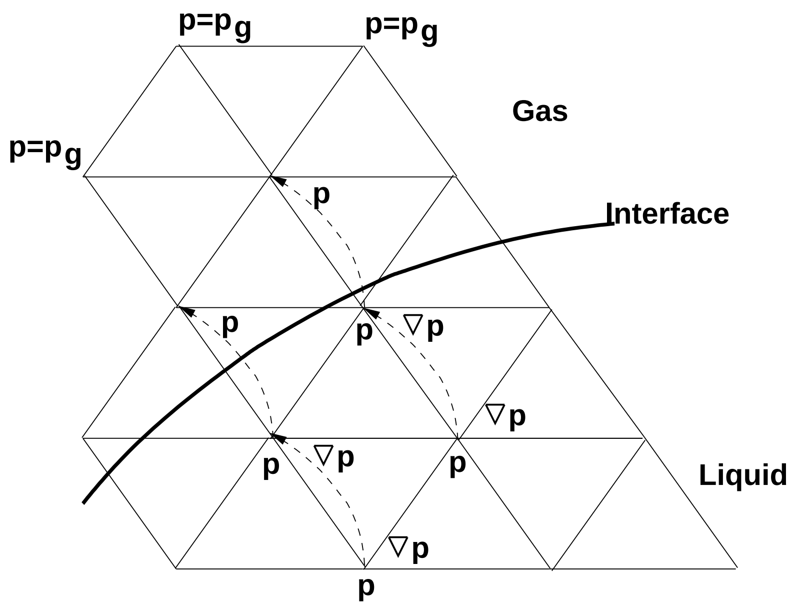
Liquid-Gas Interface:

$$\Phi_{,t} + \mathbf{v}_a \cdot \nabla\Phi = 0$$

<u>Interpretations of $\Phi$</u>:

- Volume of Fluid (VOF): Density of Material (Nichols'75, Hirt'81, Many Others...)
- Pseudo-Concentration (PC): Percentage of Liquid
- Level Set (LS): Signed Distance to Interface (Osher, Fedkiw, Many Others...)

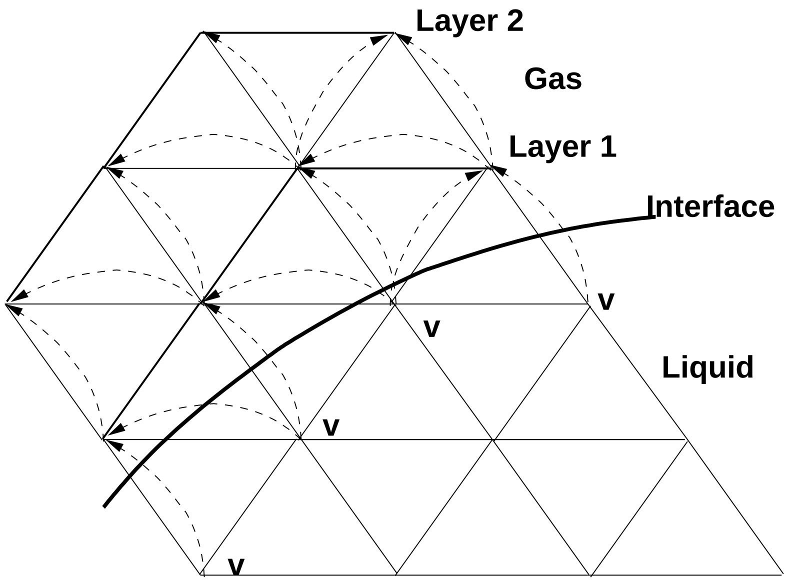
# PRESSURE EXTRAPOLATION




Extrapolation of the Pressure

1. Set $p_{gas}$ to Atmospheric/Bubble Value
2. Obtain $\nabla p$ Close to Interface
3. Extrapolate $\nabla p$ to Interface Points
4. Obtain Pressures in Gas Region

# VELOCITY EXTRAPOLATION




Extrapolation of the Velocity

1. Set $\mathbf{v}_{gas} = 0$
2. Extrapolate $\mathbf{v}$ From Liquid to Gas [Layers]

# IMPOSITION OF CONSTANT MASS

Observation: Mass Not Constant (Small, But Significant)

- At the End of Each Timestep:
  Restore by Adding/Removing
- Make Proportional to Interface Velocity

$$v_n = \left| \mathbf{v} \cdot \frac{\nabla \Phi}{|\nabla \Phi|} \right|$$

- Convergence Usually Very Fast (2-3 Iterations)

# DEACTVATION OF AIR REGION

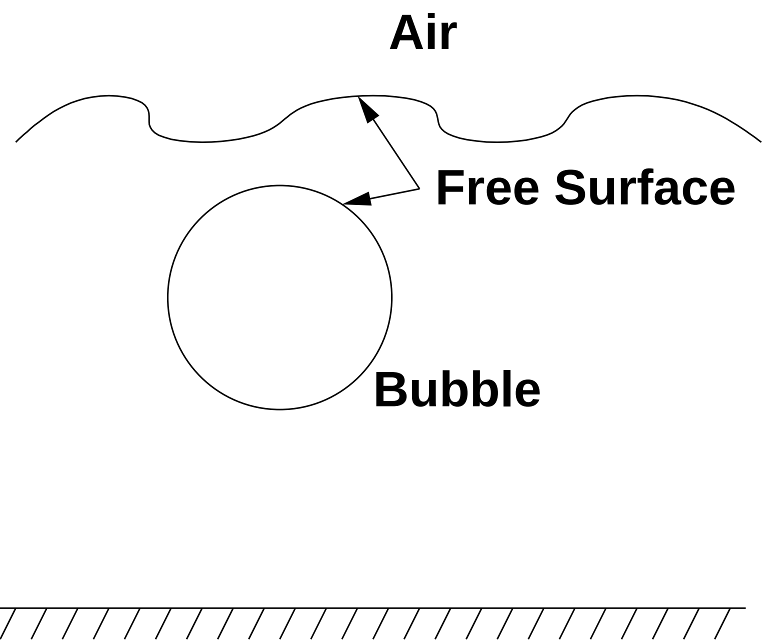
Air Region Not Updated $\Rightarrow$ Avoid Work

- Mark/Deactivate Edge-Groups in Air Region

## TREATMENT OF BUBBLES (1)

Assumption: Pressure in Bubble Constant

- Timescales
  - Speed of Sound/Bubble Size (1/100 sec)
  - Bubble Growth/Collapse (1 sec)




Bubble in Water

# TREATMENT OF BUBBLES (2)

Isentropic Gas:

$$\frac{p_b}{p_{b0}} = \left(\frac{\rho_b}{\rho_{b0}}\right)^\gamma$$

Bubble 'Marker' Equation:

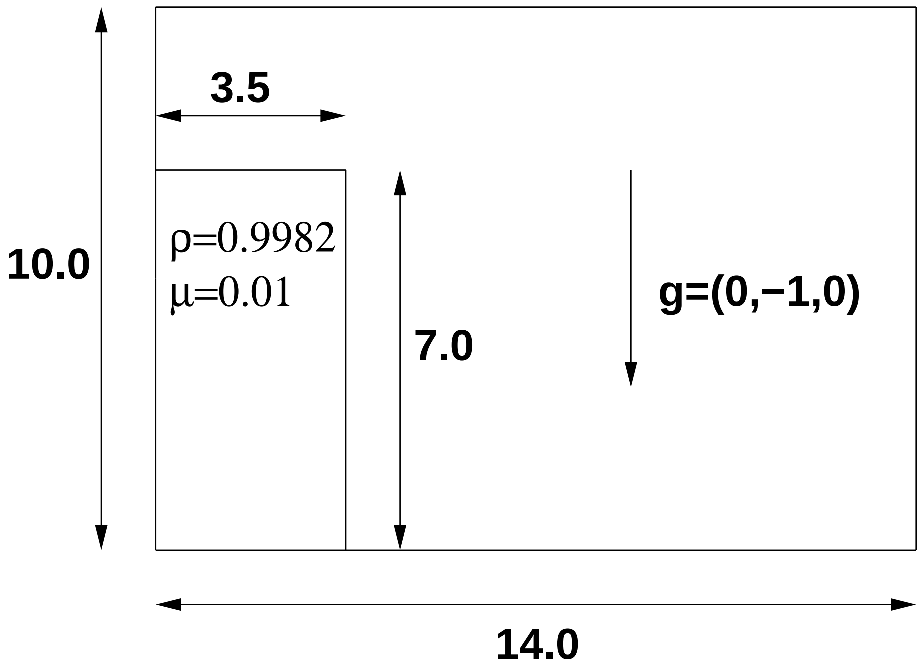
$$b_{,t} + \mathbf{v}_a \cdot \nabla b = 0$$

If Bubble Contacts Air: Extend Volume $\Rightarrow p \rightarrow 0$

# VOF TIMESTEP

- If Required: Update Bubble Pressure
- Extrapolate Pressure
- Predict Velocity
- Update Pressure
- Correct Velocity ($\nabla \cdot \mathbf{v} = 0$)
- Extrapolate Velocity Field
- Update Scalar Interface Indicator
- Enforce Mass Conservation

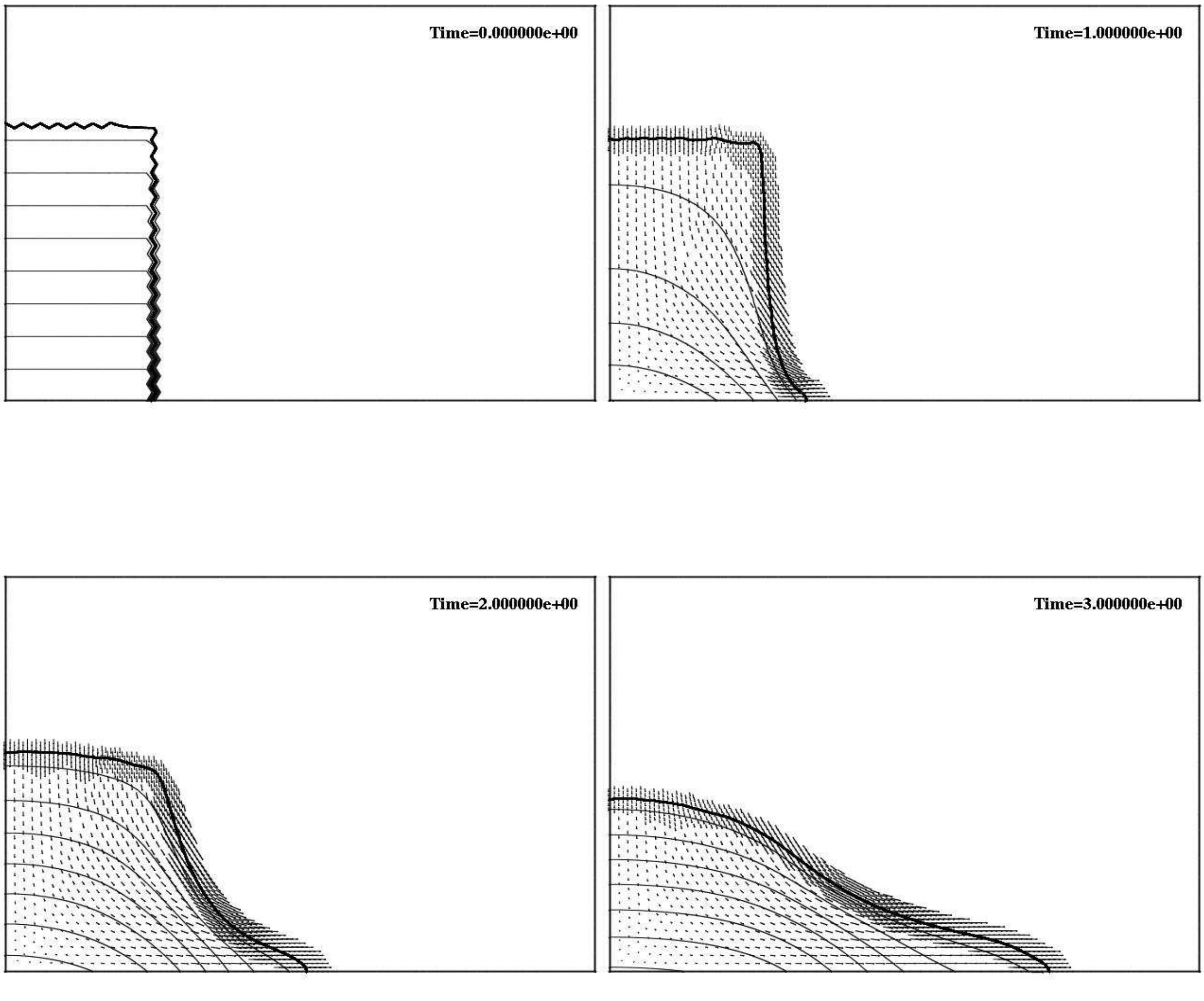
# BREAKING DAM (1)




Breaking Dam: Problem Definition

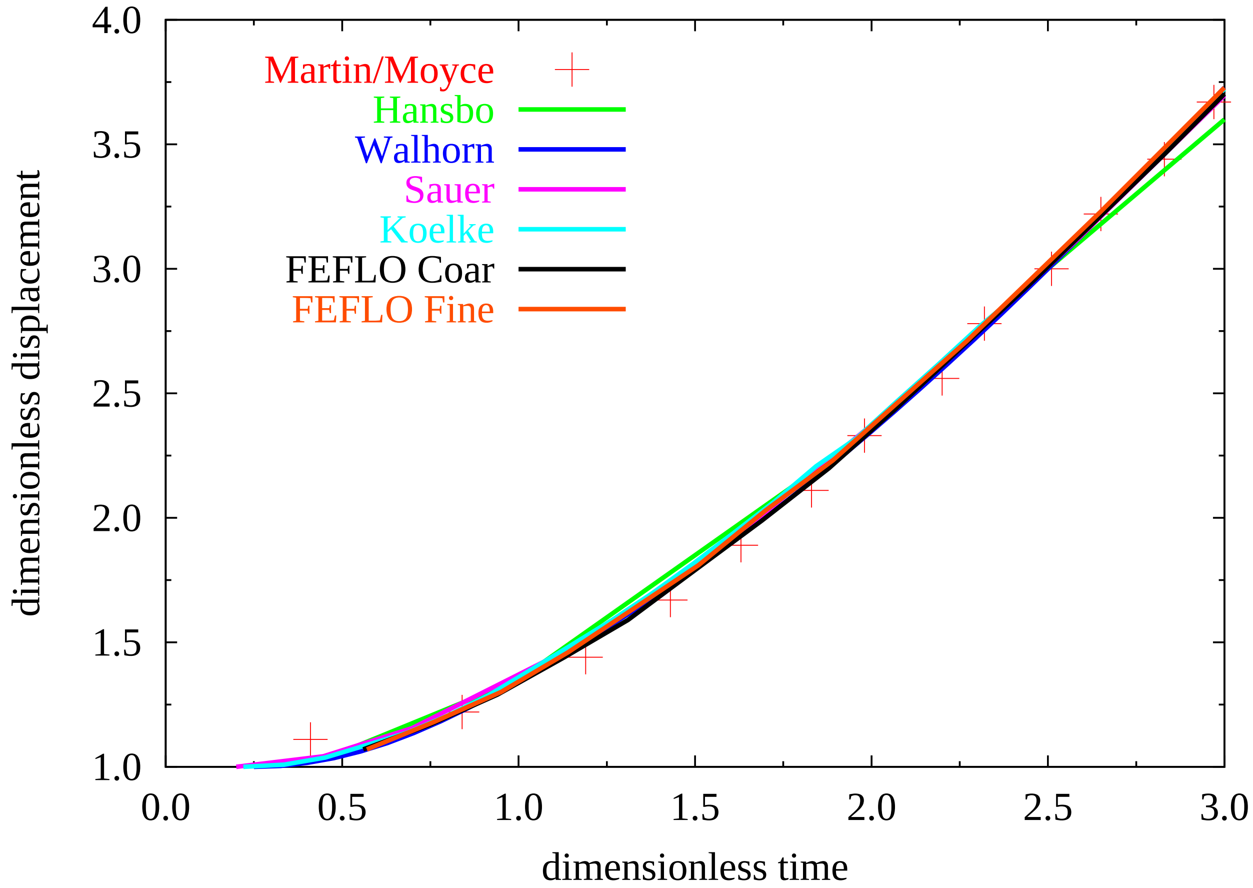
- Classic Testcase
- Some Experimental Measurements

# BREAKING DAM (2)



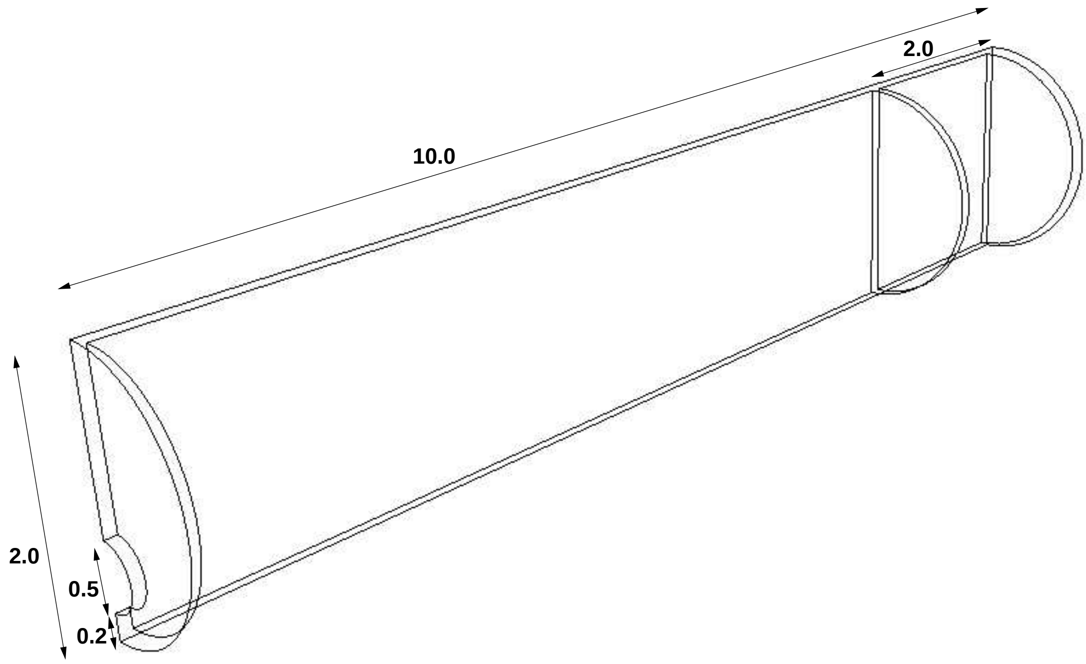

Breaking Dam: Flowfield at Different Times

# BREAKING DAM (3)




Breaking Dam: Horizontal Displacement

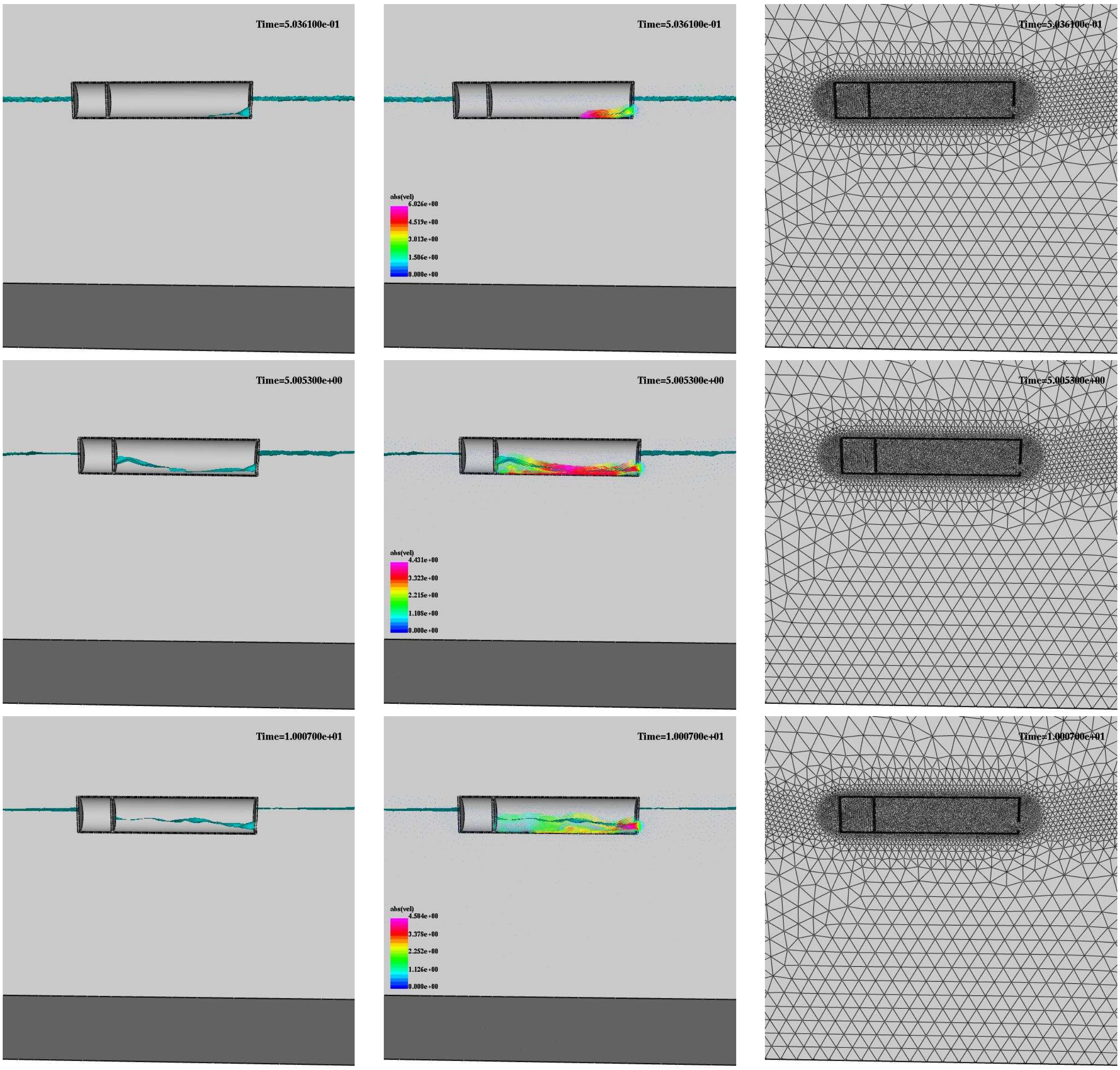
# SINKING TANK (1)



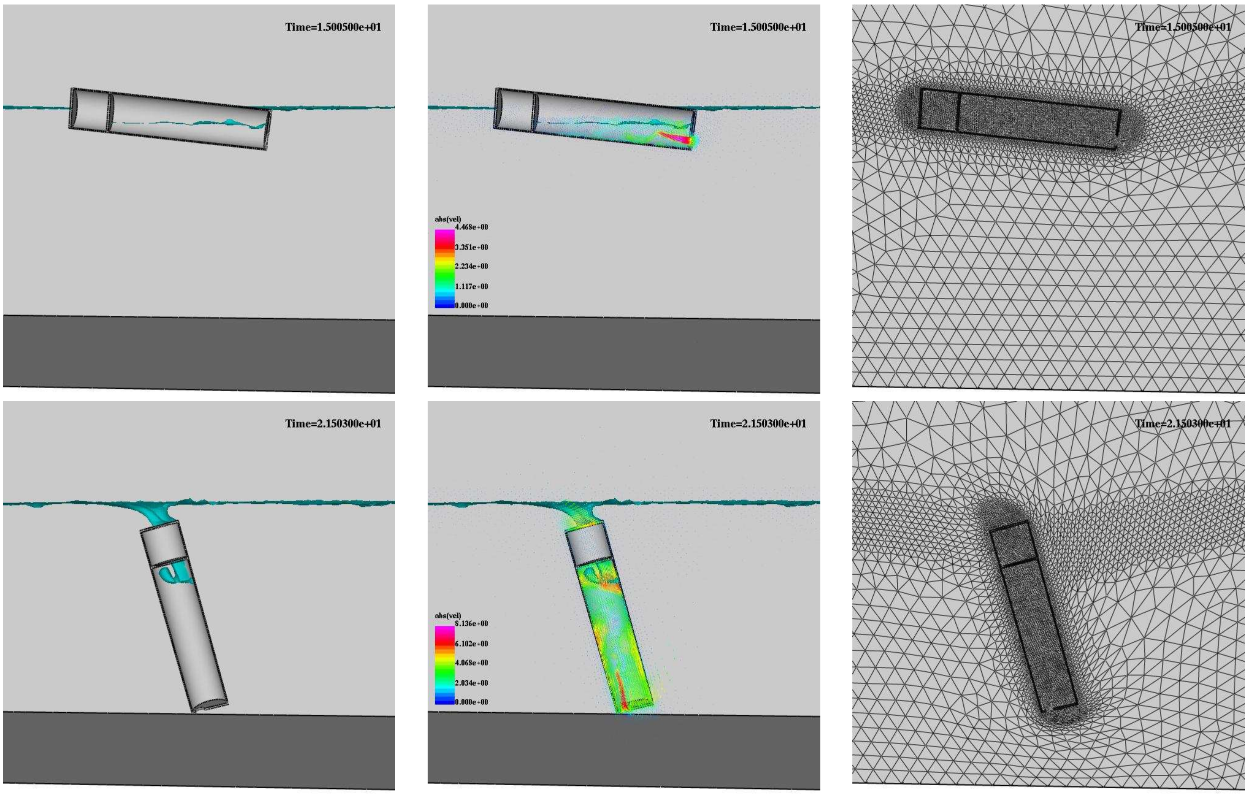

Sinking Tank: Problem Definition

- Moving Body
- ALE
- Automatic Remeshing

# SINKING TANK (2)

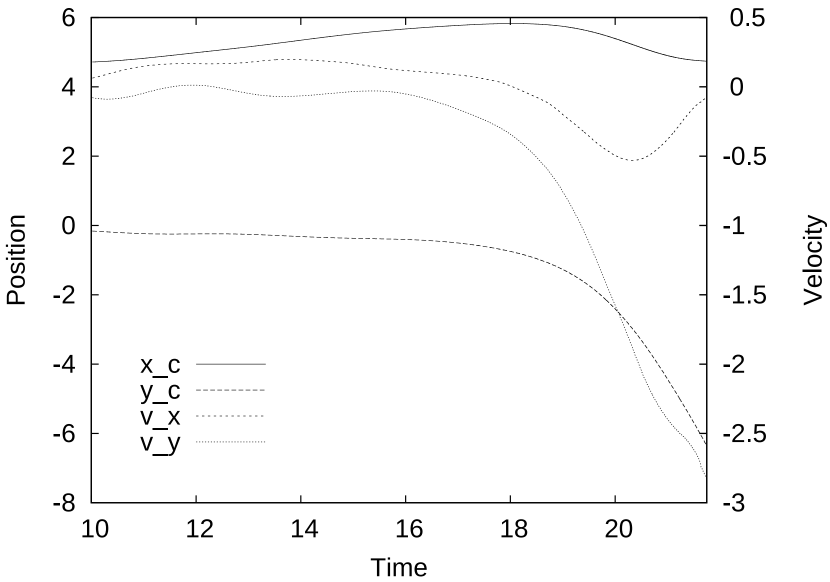


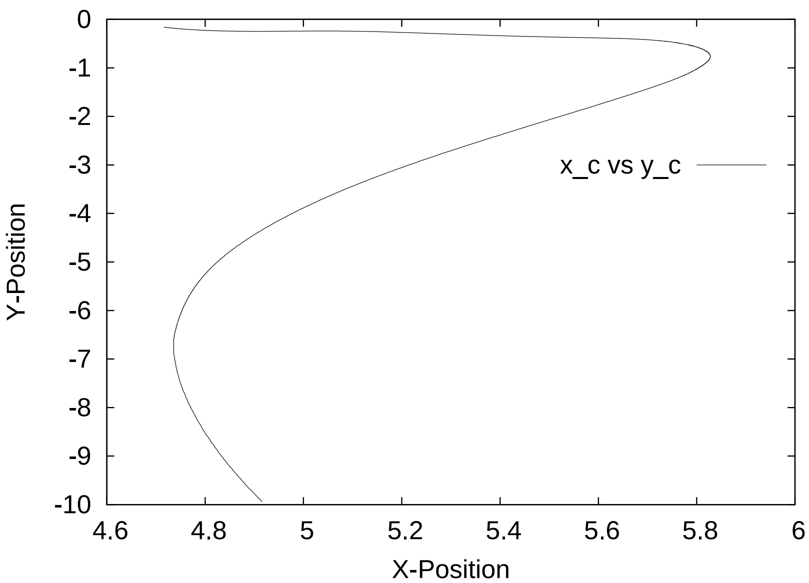
# SINKING TANK (3)




Sinking Tank: Flowfield at Different Times

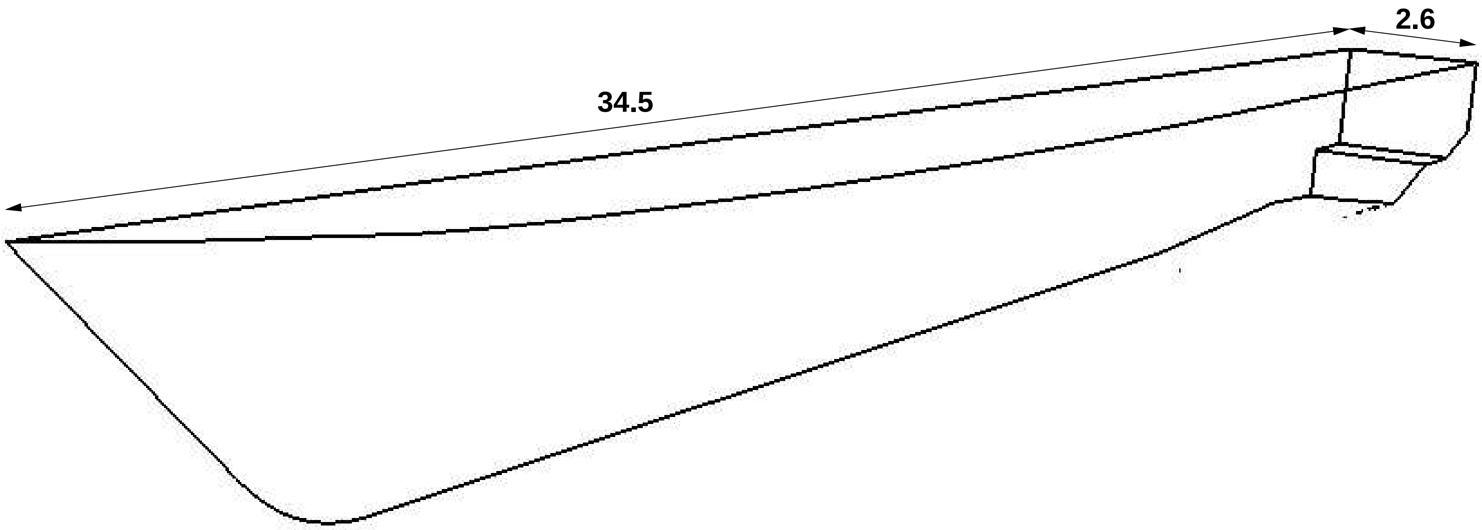
# SINKING TANK (4)



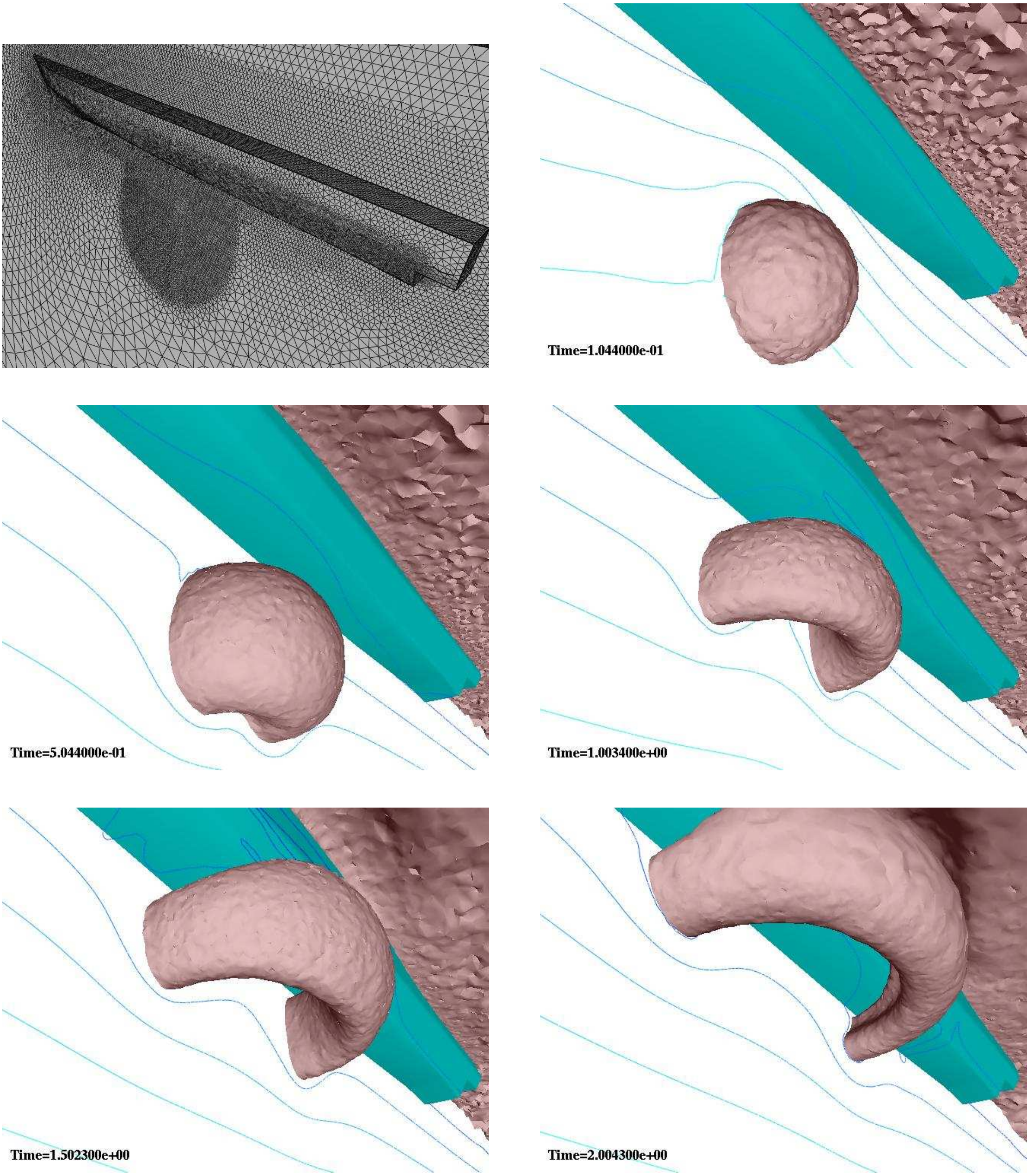




Sinking Tank: Trajectory of Center of Mass

# BUBBLE COLLAPSE (1)




Bubble Collapse: Problem Definition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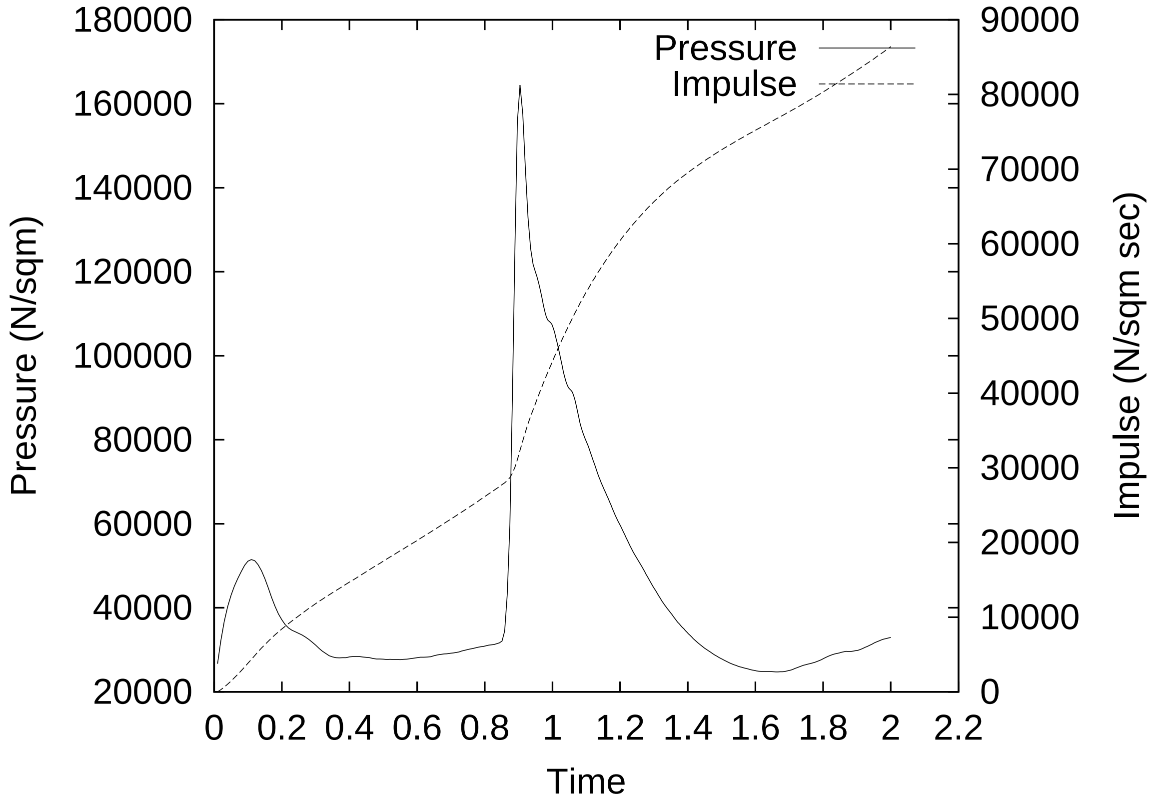
# BUBBLE COLLAPSE (3)




Pressure and Impulse Recorded at Midship on Hull