Experimental and computational investigations of shock-accelerated gas bubbles

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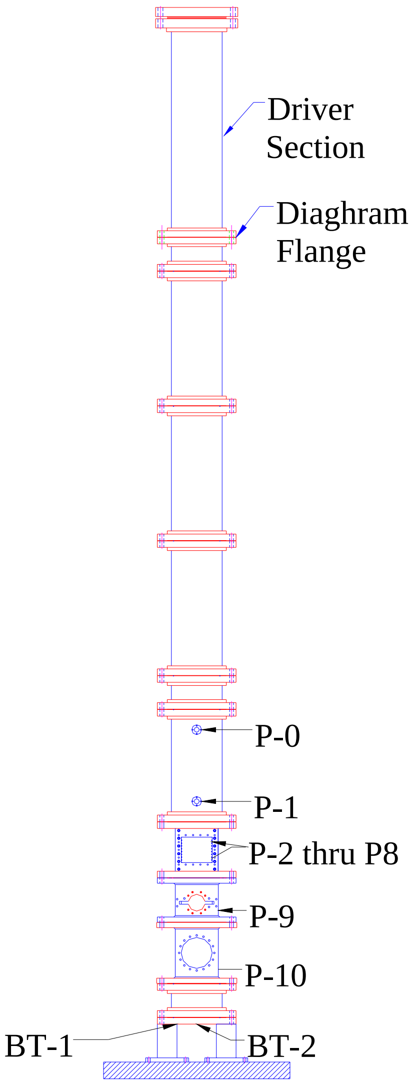
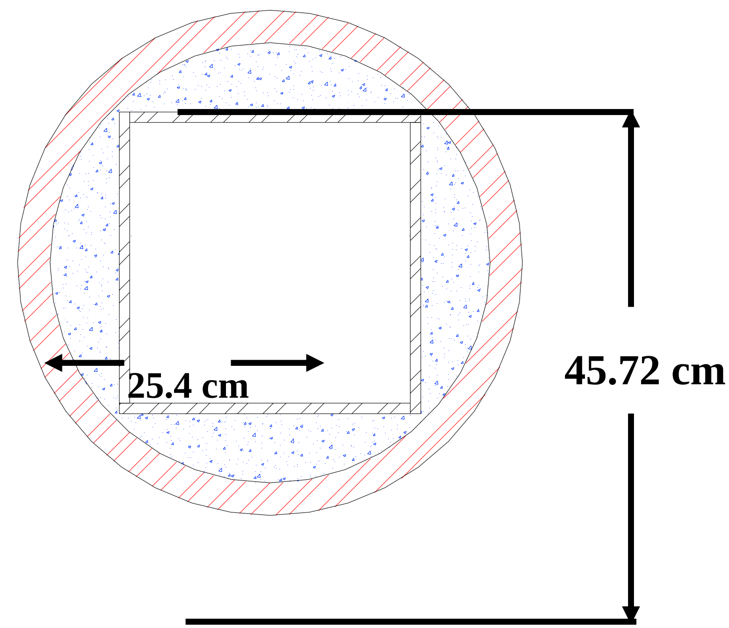
Overview

- Planar shock wave accelerates spherical soap bubble: Ar inside, N_2 outside, A_{init}=0.176
- Time evolution of geometrical properties
- Mach number effects
  - M=2.88, u_p=745 m/s, A_{shock}=0.00216
  - M=3.38, u_p=907 m/s, A_{shock}=-0.0219
- Laboratory and computational experiments
- Comparison with RAPTOR (2D and 3D model)

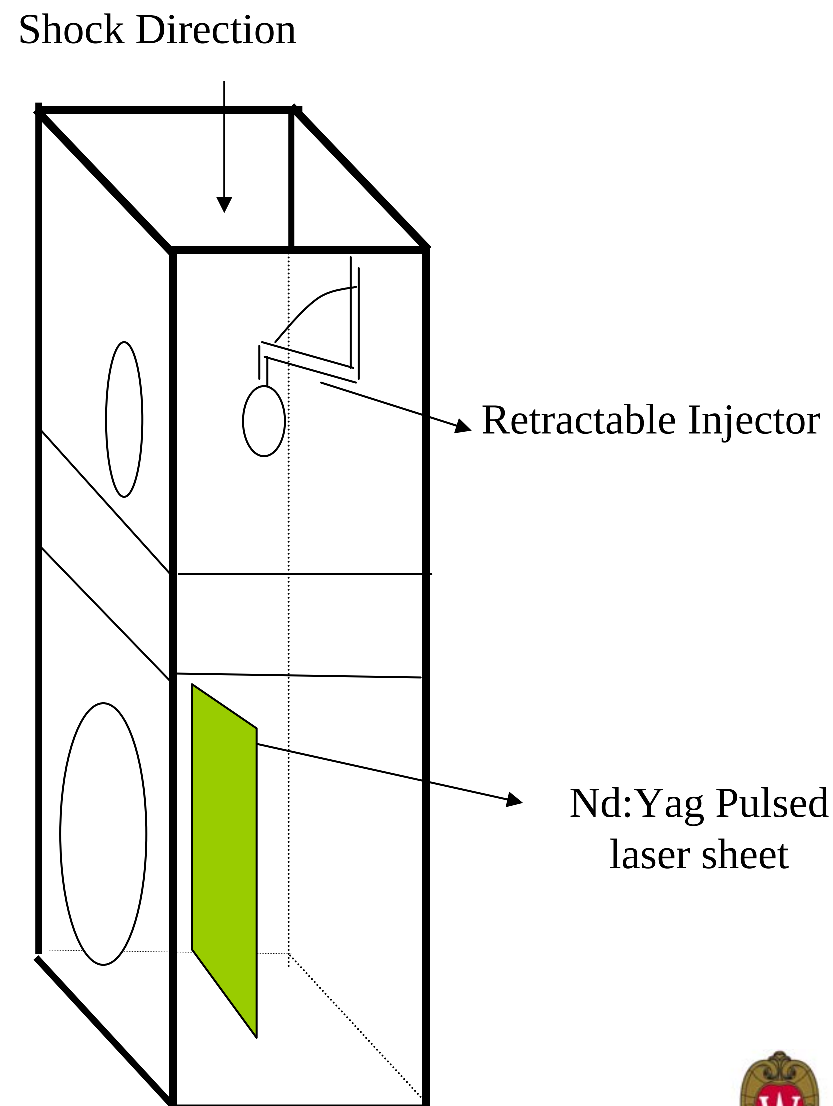
The Wisconsin shock tube



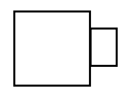
- Vertical
- Large internal cross-section (25 cm square)
- Total length 9.2 m, driver length 2 m
- Pressure load capability: 20 MPa
- Modular driven section



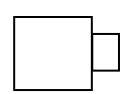
Details of R-M experiment



Planar shock wave
Spherical soap bubble D = 5 cm
Driver: He Driven: N_2 Test: Ar

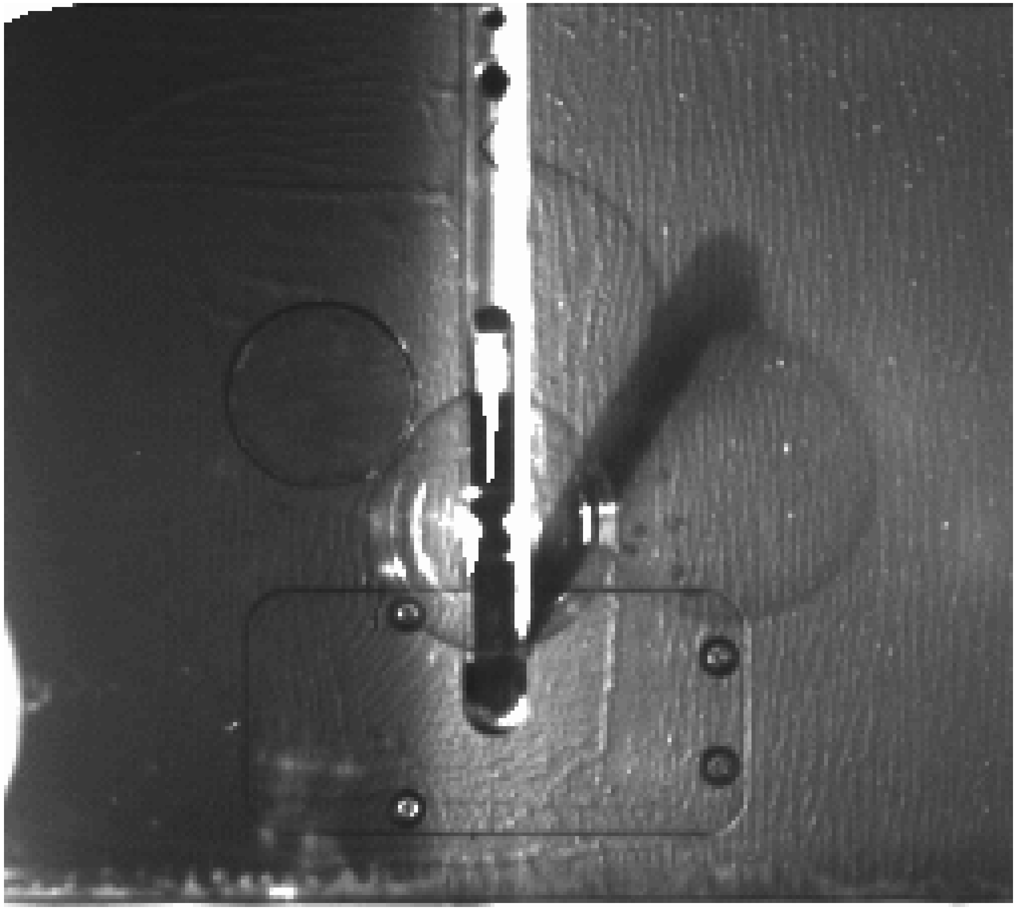


Initial conditions:
Continuous white light from the front
Motion picture at 220 fps



Post shock:
Mie-scattering from the soap film acting as flow tracer
2 laser pulses
2 images per run on same frame

Initial conditions

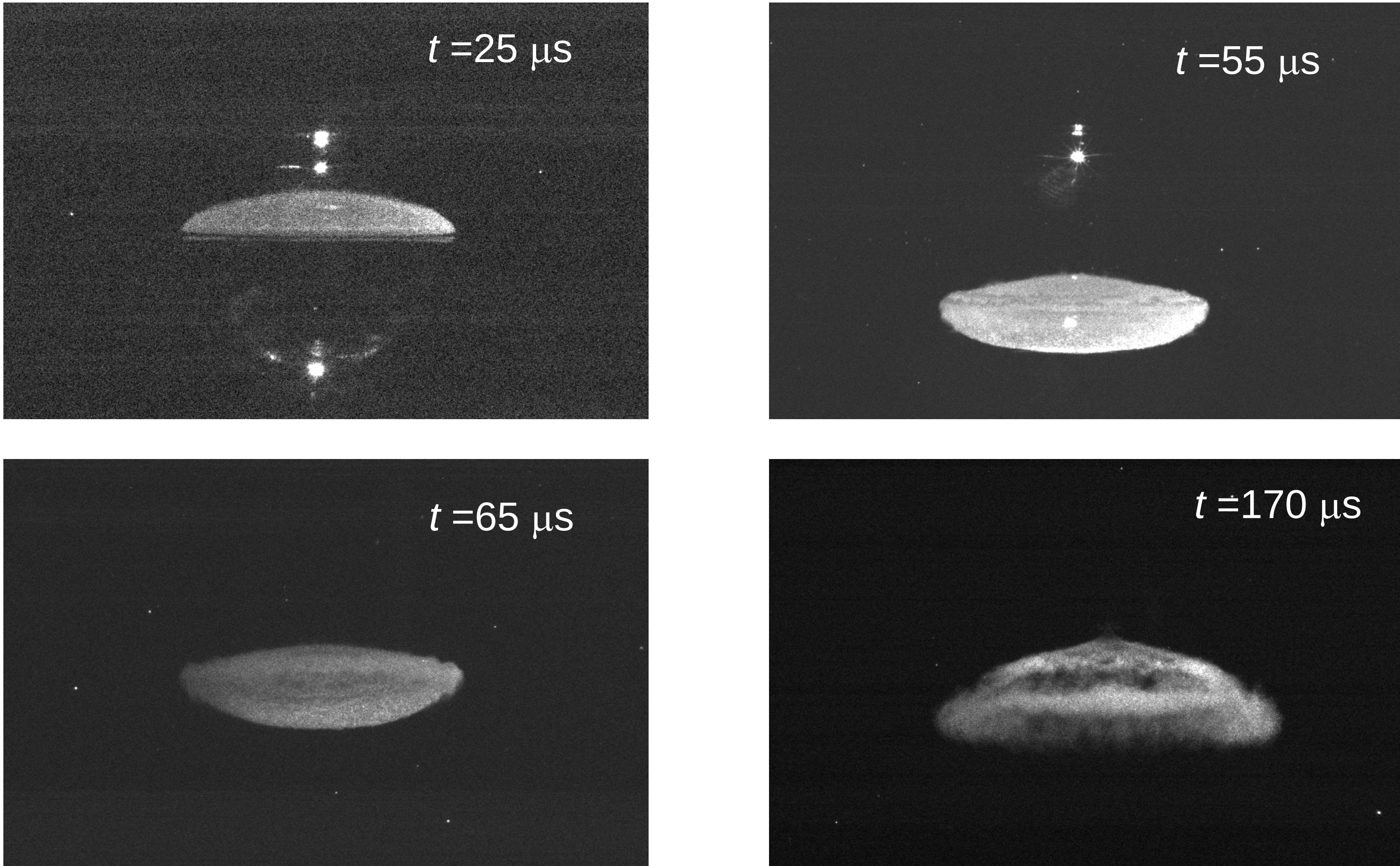


Formation of a ~5 cm diameter bubble and controlled release of bubble

Bubble free falls from injector stabilizing and a shock interacts with the bubble just out of view this view

Laser sheet intersects bubble in diametral plane after shock interaction

Shock Accelerated Bubble M#2.88



← 14.6 cm →

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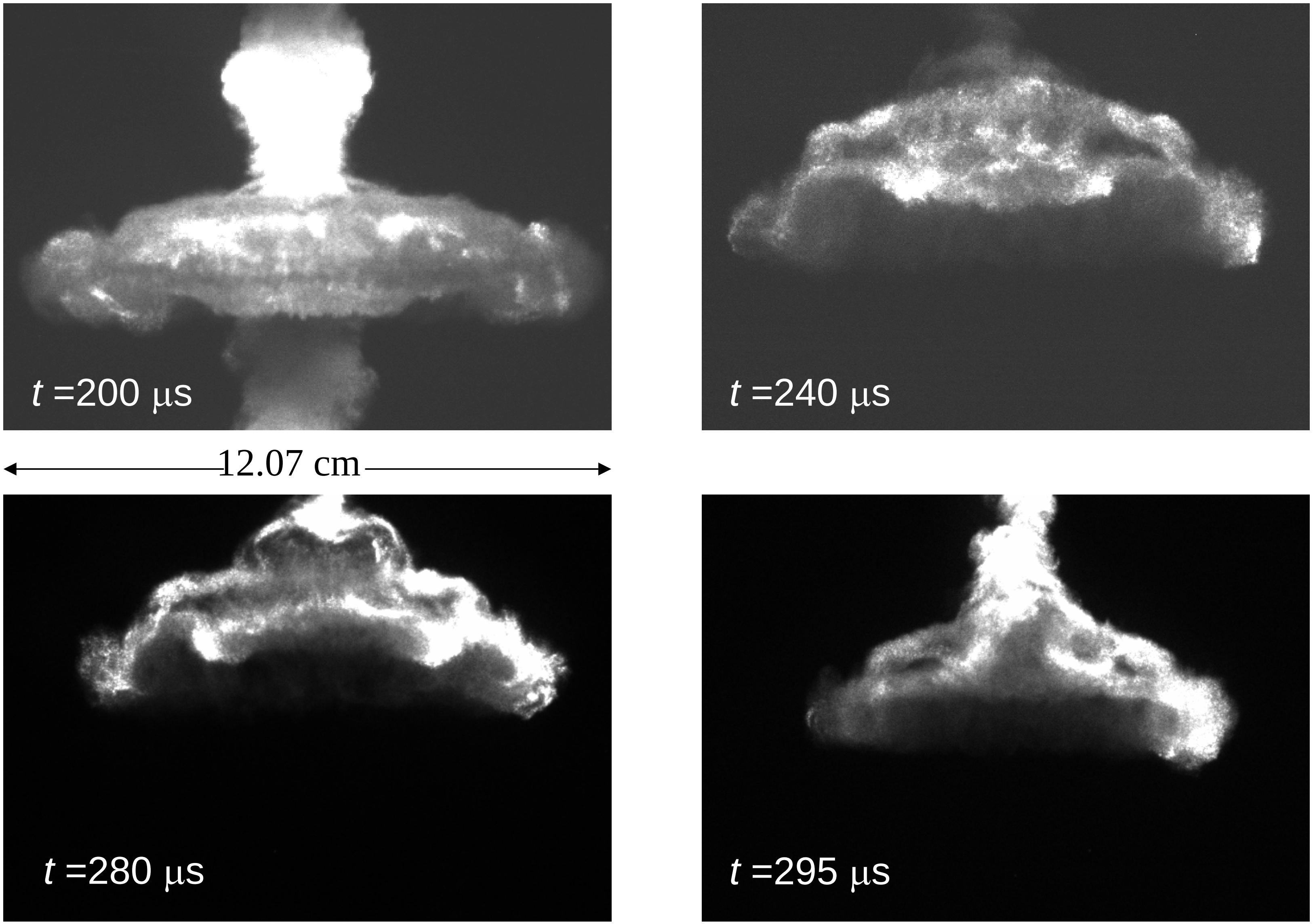
Shock Accelerated Bubble M#2.88



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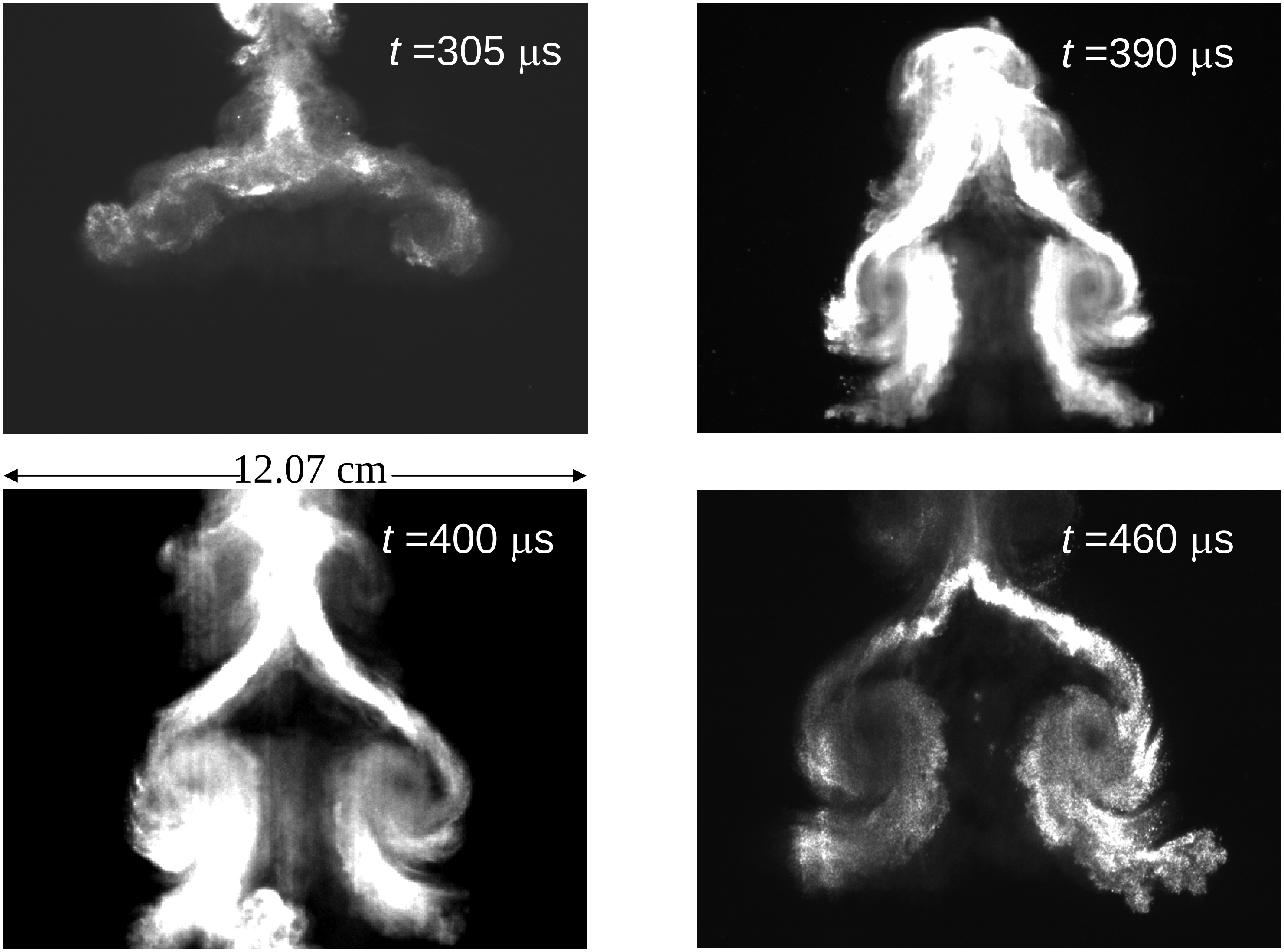

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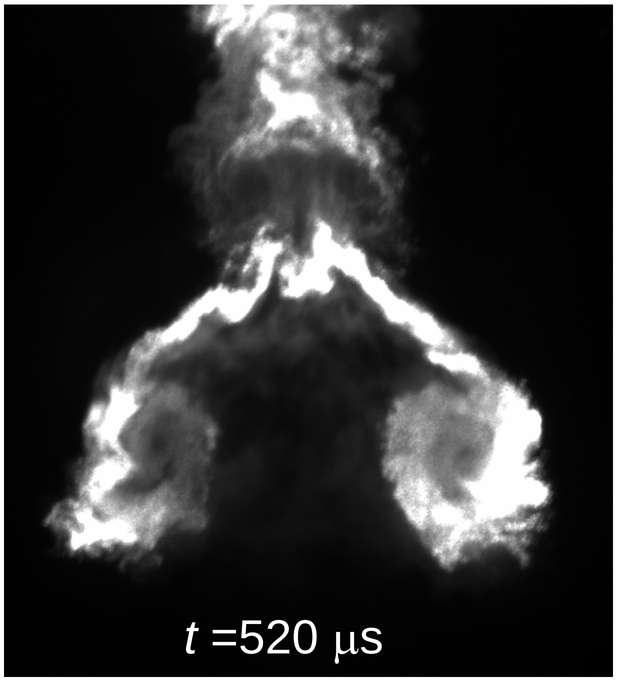
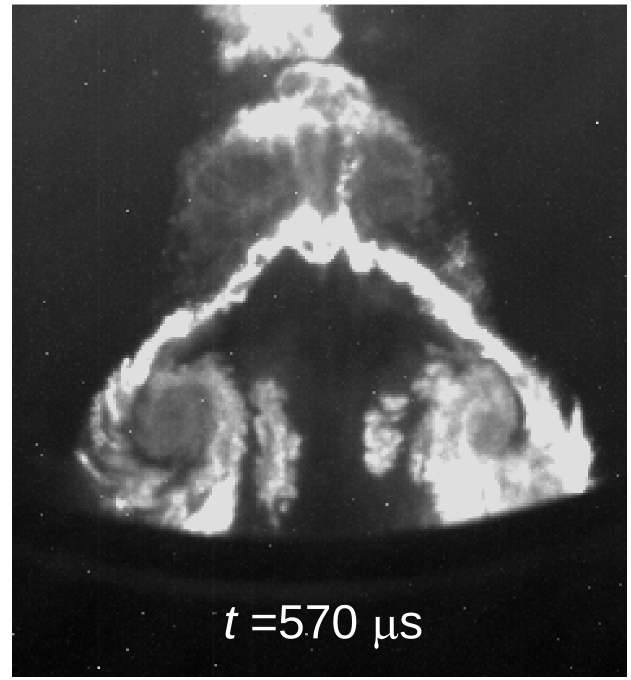
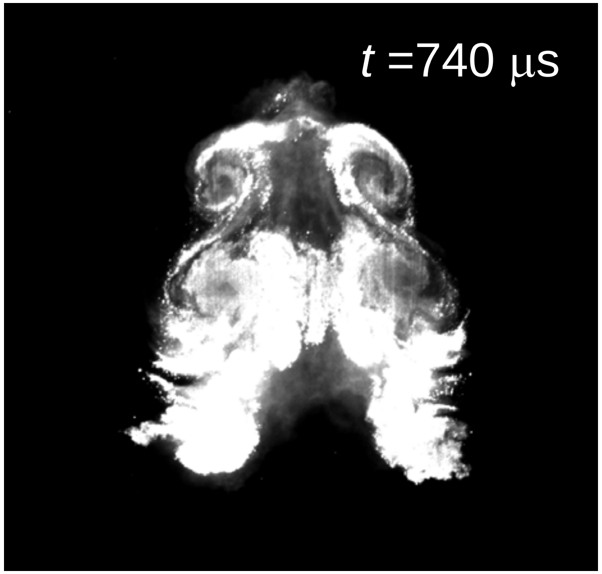
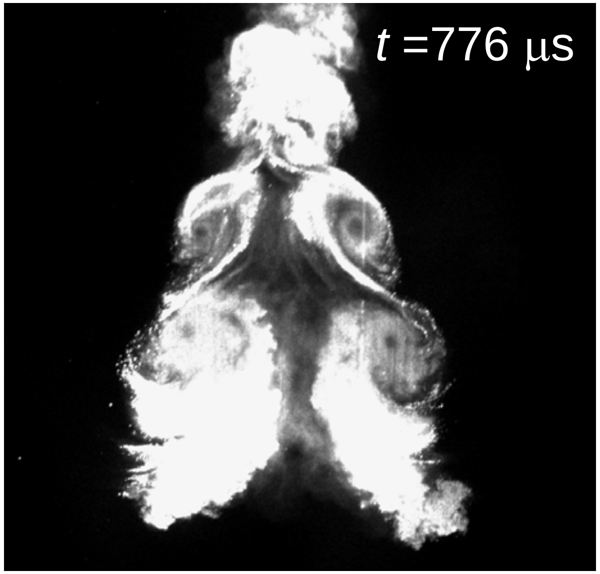




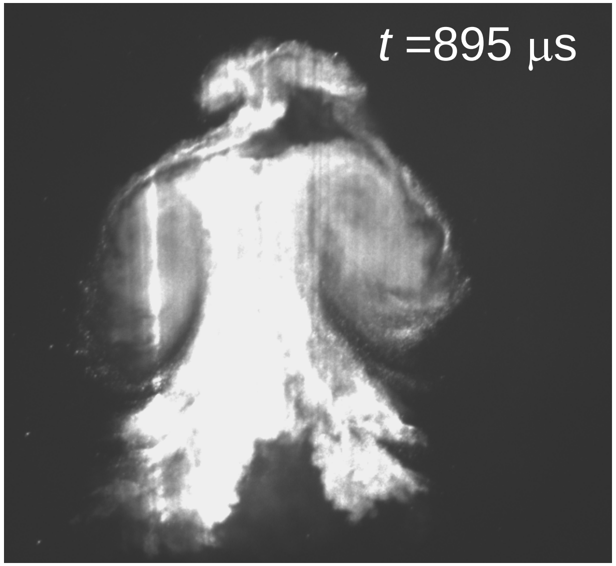
← 9.52 cm →

Shock Accelerated Bubble M#2.88





15.24 cm



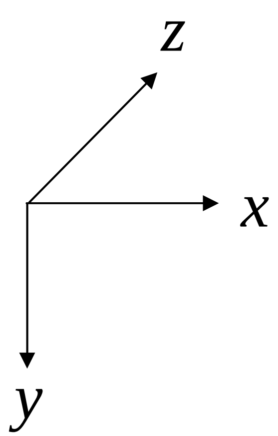
Computational experiments

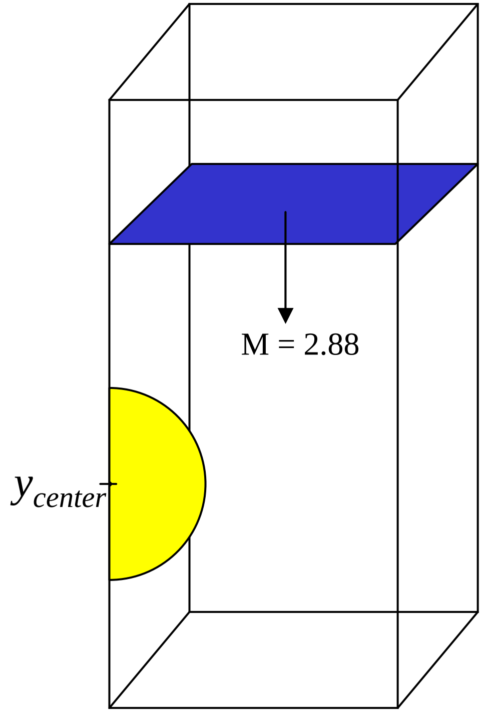
- Raptor code (LLNL)
- Godunov-based PLM, with AMR
- 2-D axial symmetry; 3-D cartesian
- Grid:
  - 2-D: 3 AMR levels (4,4,2), $\Delta x_{min} = 0.078$ mm
  - 3-D: 2 AMR levels (4,4), $\Delta x_{min} = 0.195$ mm
  - M = 2.88, 3.38

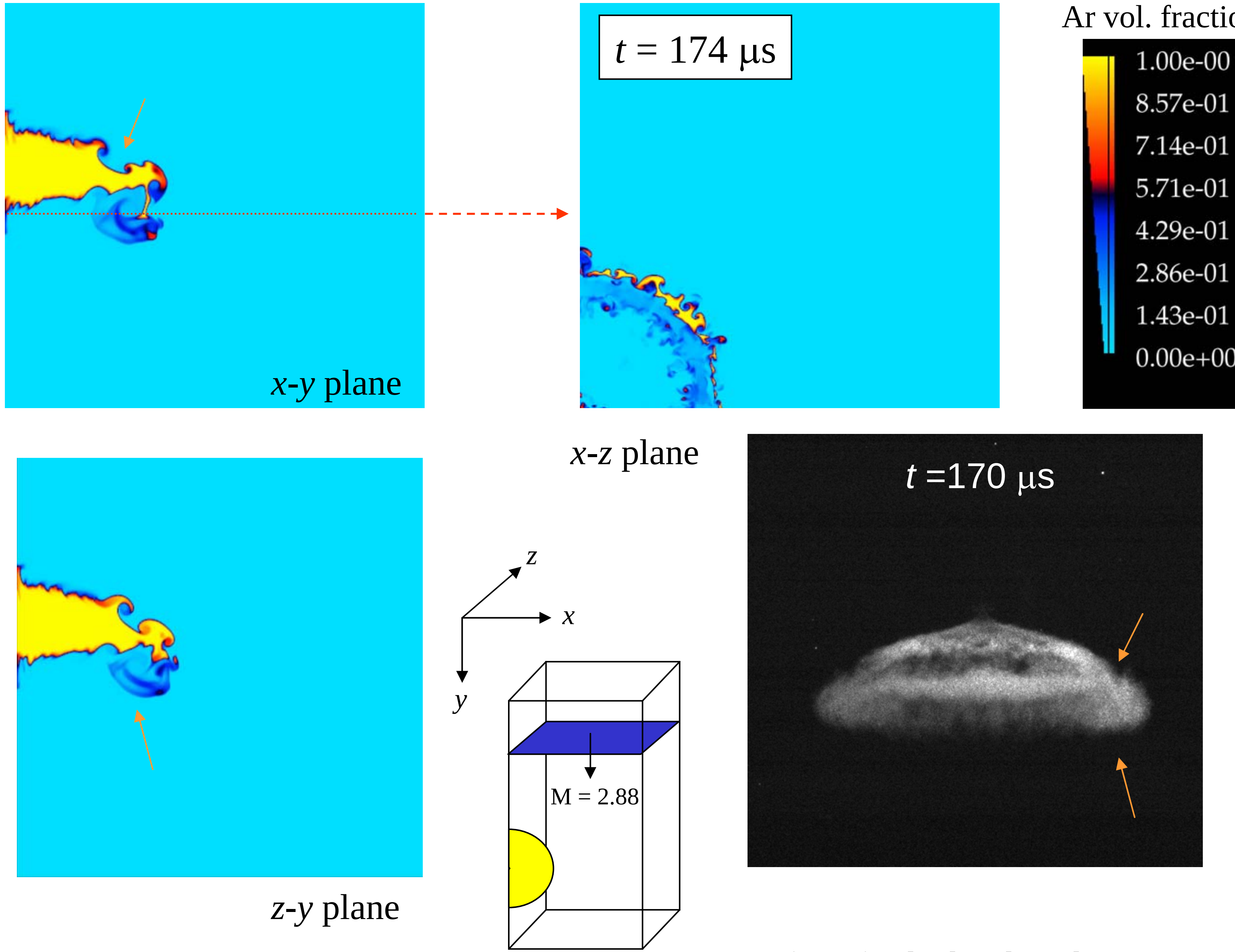
- ~5 cm dia. Ar bubble in N_2 initially at 98.274 kPa
- Film model: match film mass

Setup of 3-D problems and visualization:

- Shock propagates along the *y*-axis
- Bubble is centered at $(0, y_{center}, 0)$
- Results are viewed using 3 planar slices: one perpendicular to each axis, at a selected location on that axis.
- *x*-*y* and *z*-*y* plots are shown at $z = 0$ and $x = 0$ locations, respectively.
- *x*-*z* plots are shown at a *y* location selected to be near the main vortex ring (indicated by red line).







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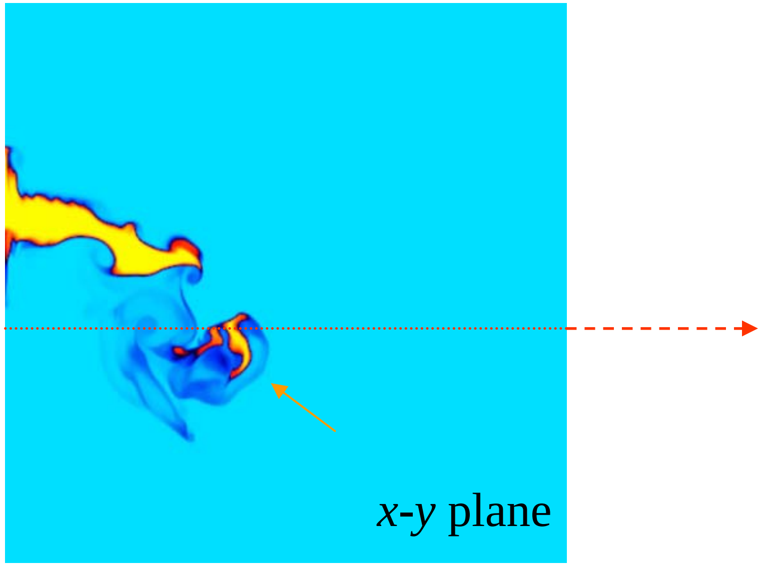

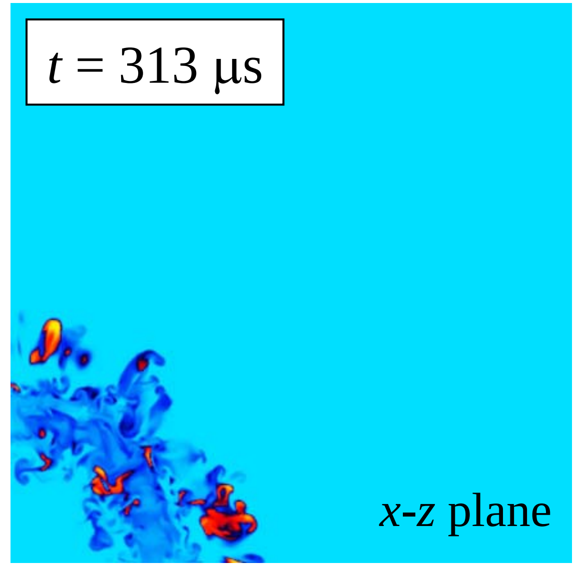

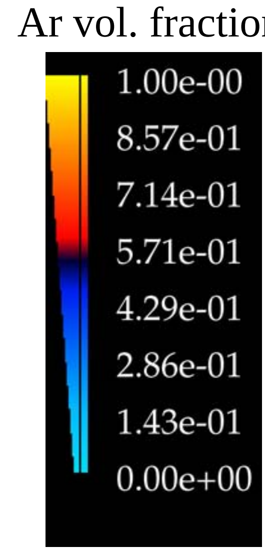

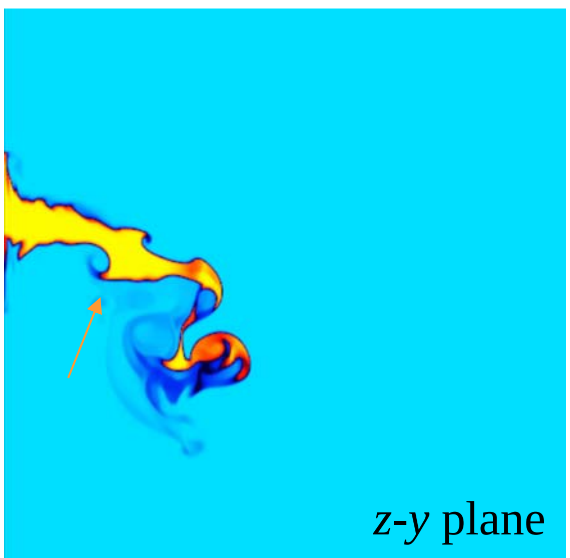

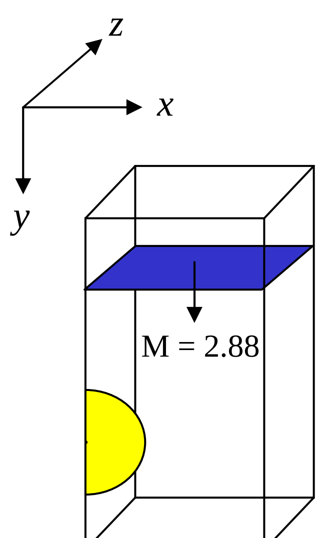

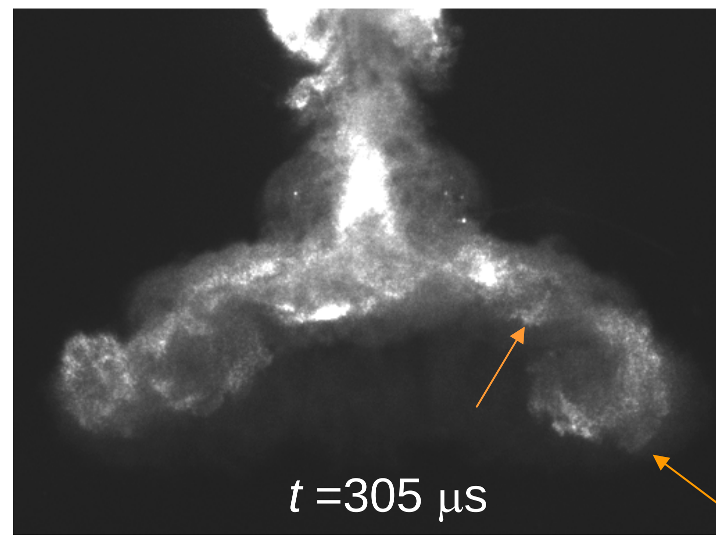

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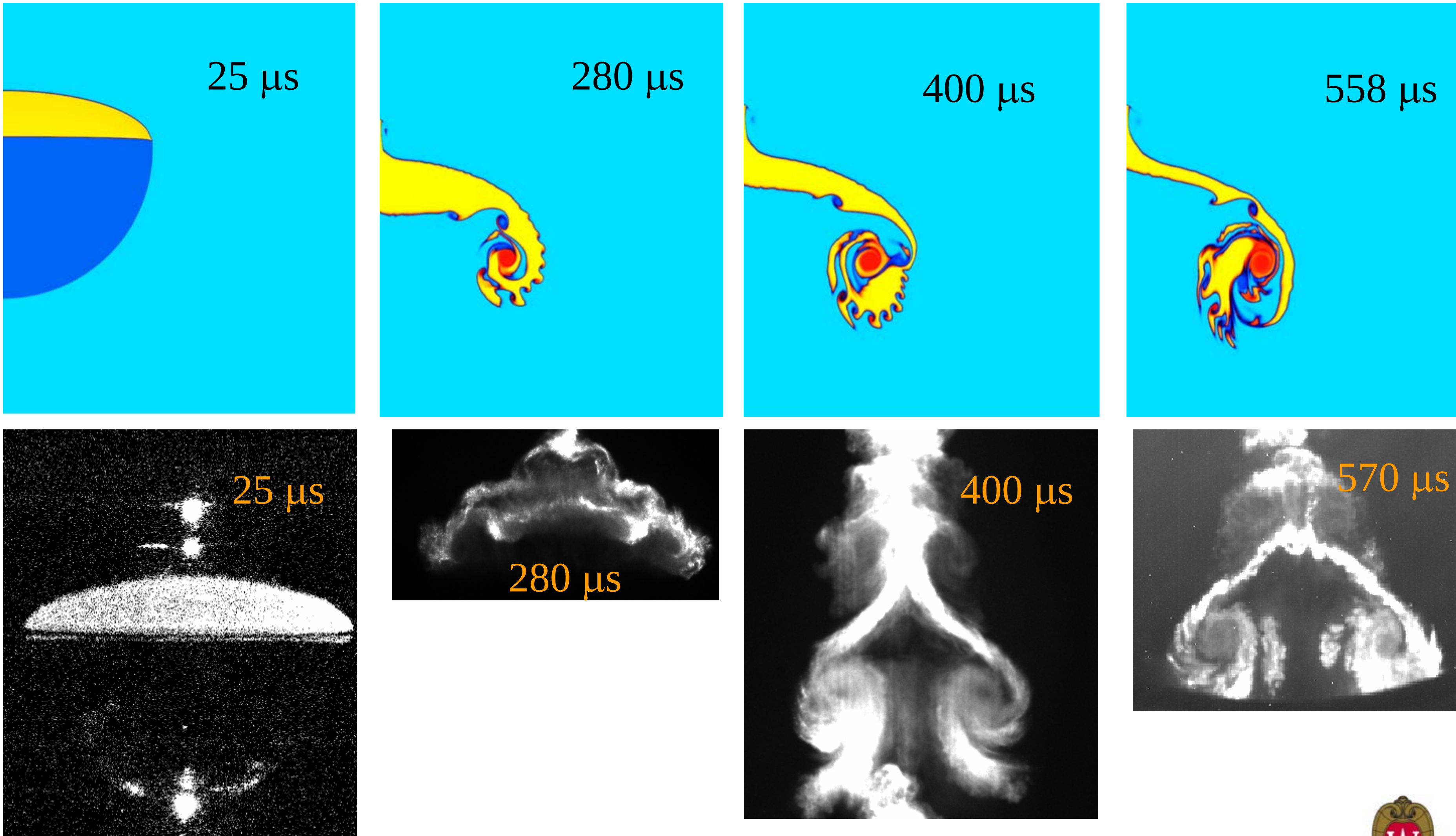
Qualitative laboratory/computational comparison M#2.88



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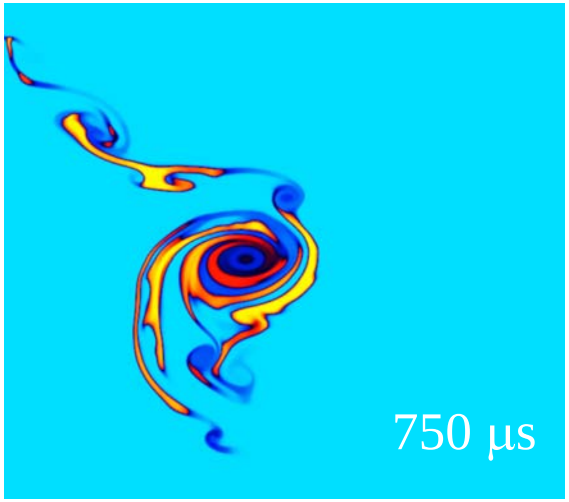

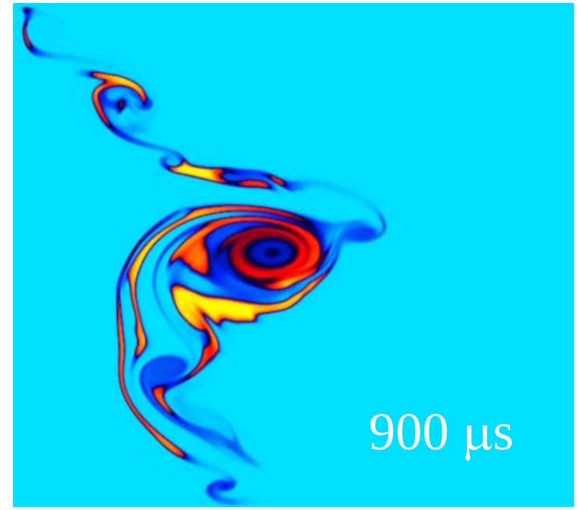

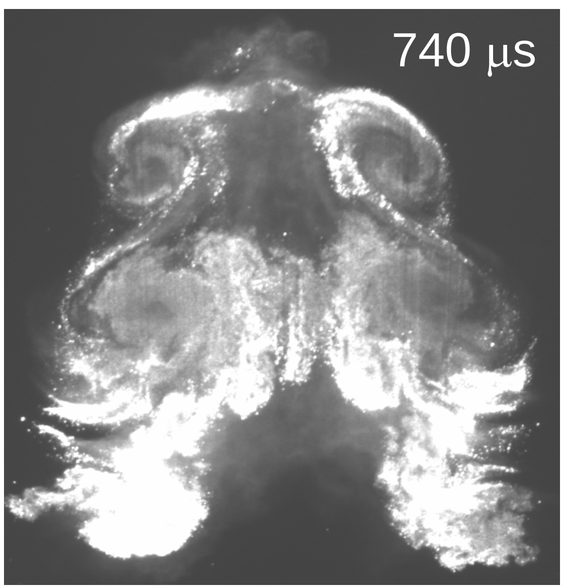

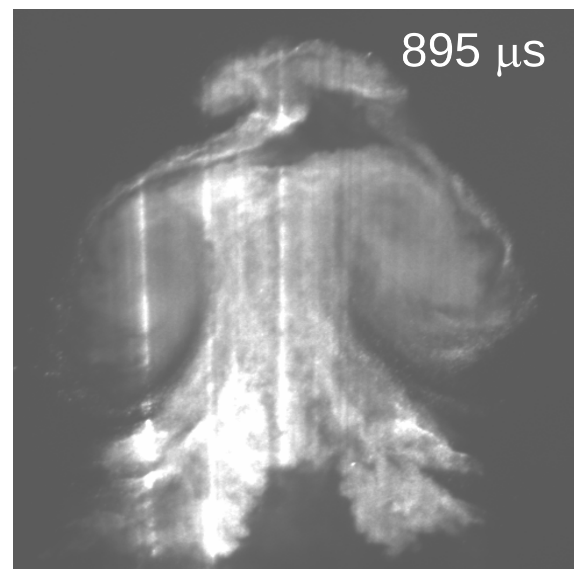

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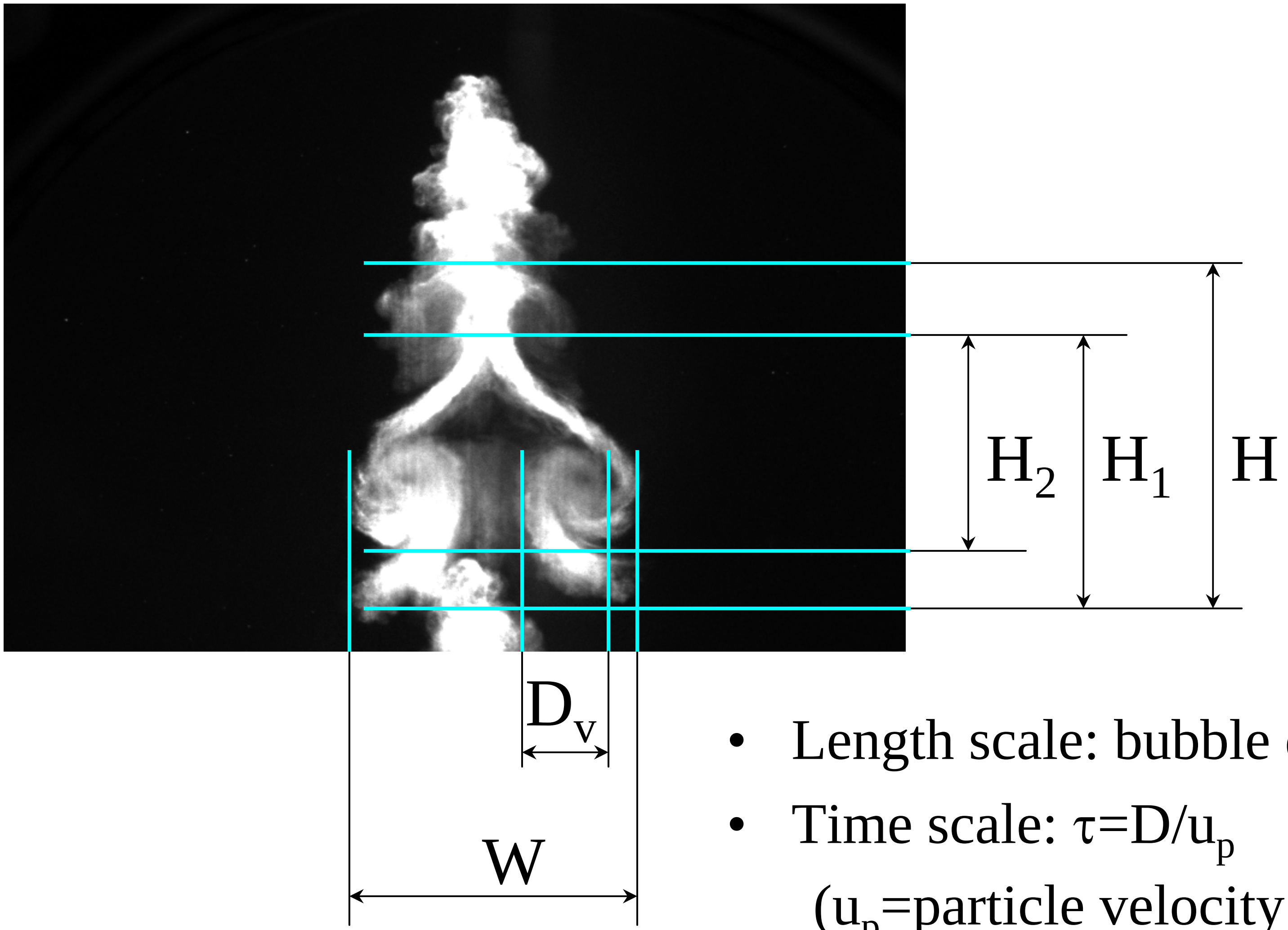
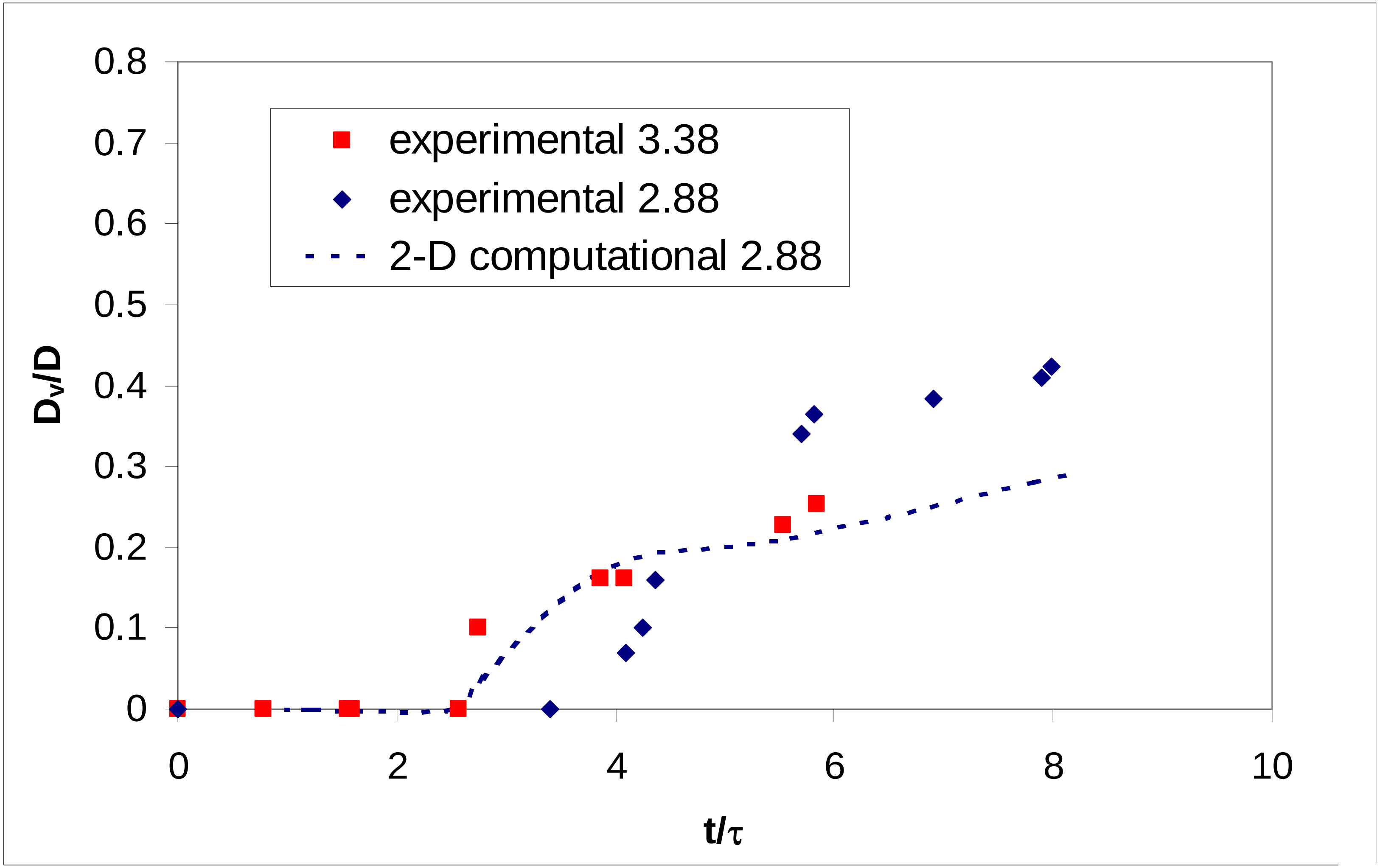
Geometrical features

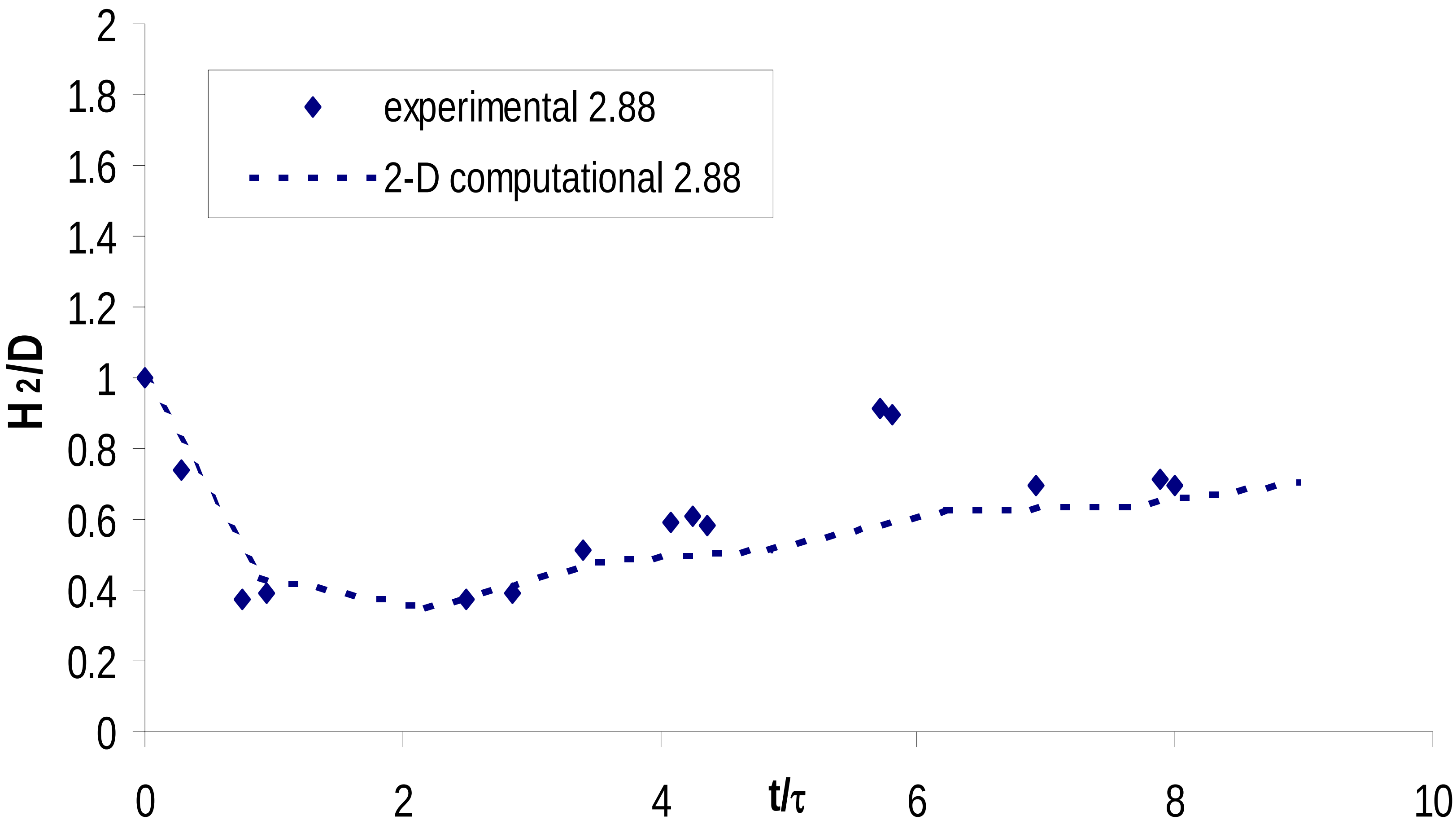


- Length scale: bubble diameter D
- Time scale: $\tau = D/u_p$
  (u_p=particle velocity behind shock)

Vortex diameter growth rate



Experiments vs. computations (H_2; M=2.88)



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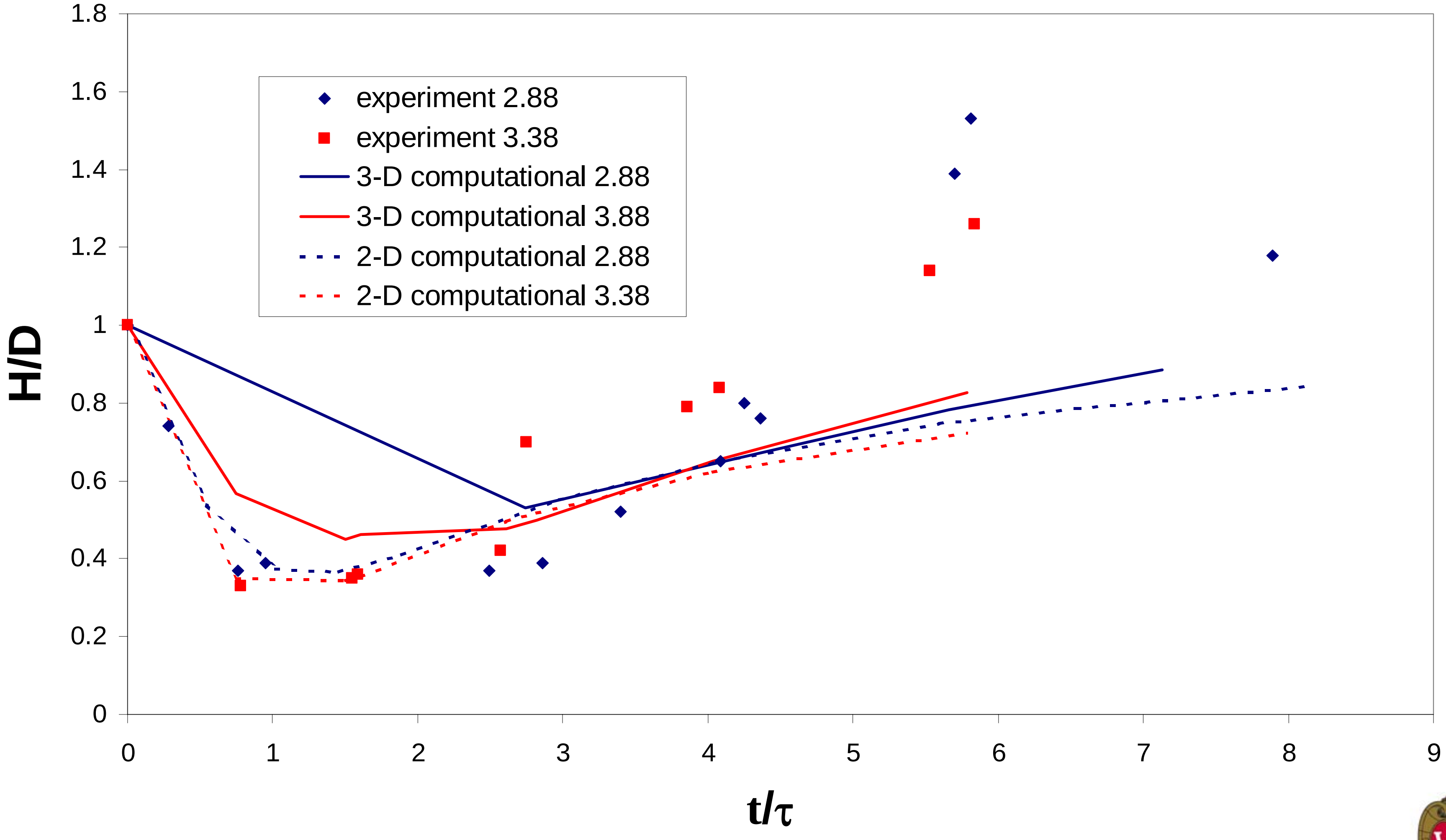
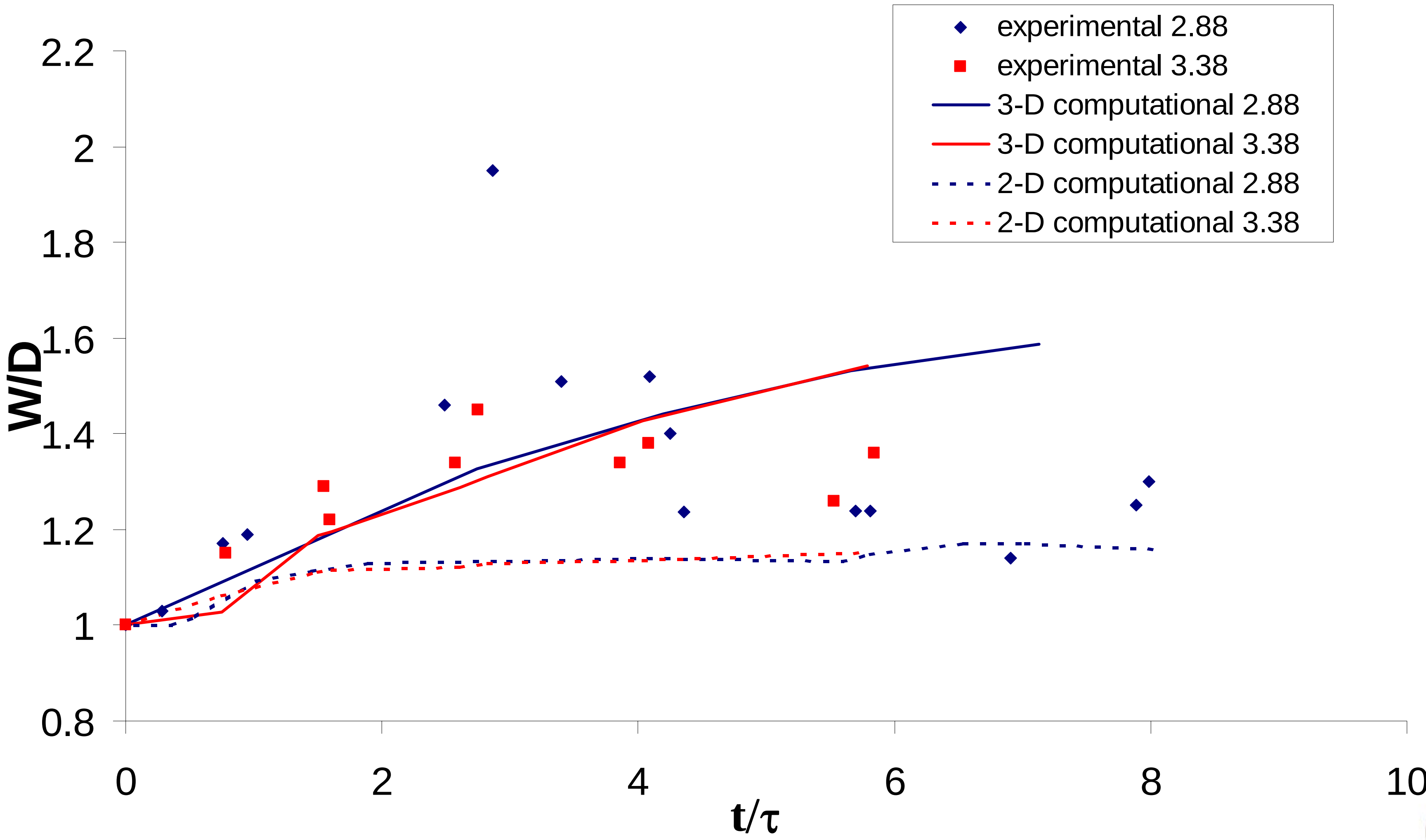
Height growth rate



Width growth rate



Conclusions

- Developed new bubble-release technique
- Used strong (M>2.5) shocks
- Observed bubble distortion, formation of vortex ring
- Measured growth rates of relevant large scale features
- $\tau=D/u_p$ appears to be appropriate time scale
- 3D simulation with film improved agreement to intermediate times
  - Improve 3-D model and computational diagnostics

- Develop "tomography" experiment
- Develop experiment to measure species concentration