Experimental Study of Shock-Induced Compression and Vortex Generation in the Shock-Bubble Interaction

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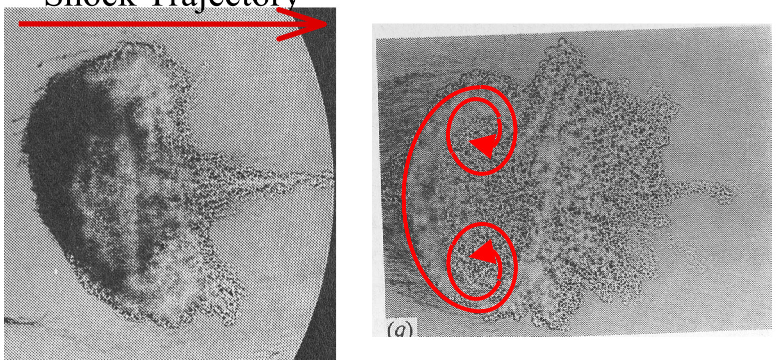
Literature Review: Experiments and Simulations

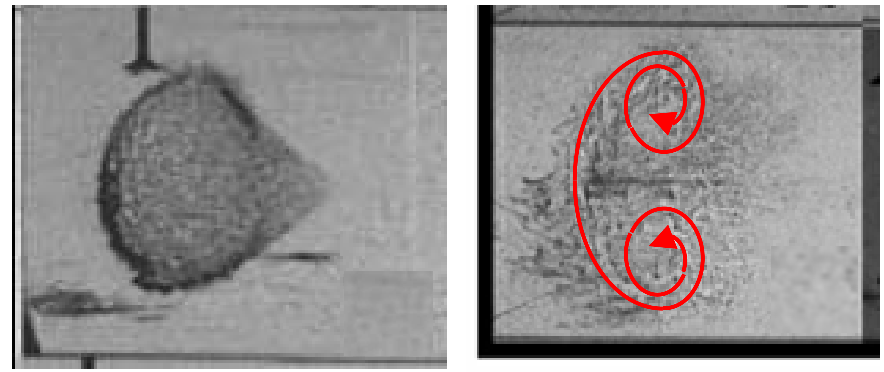
Haas & Sturtevant, JFM(1987)

Shock Trajectory



Freon-22 bubble in air, M =1.25

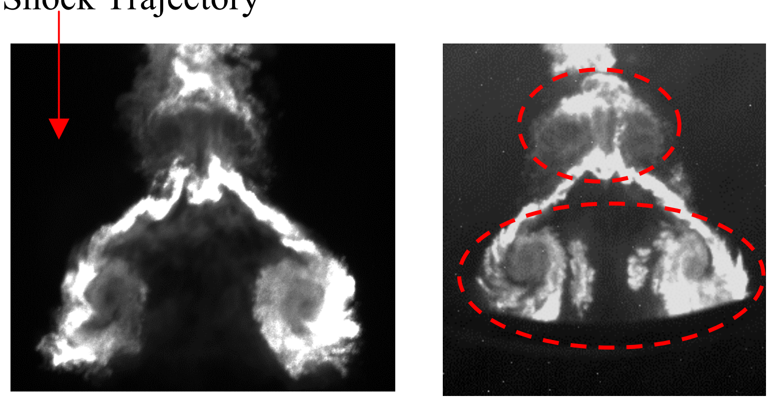
Layes, Jourdan & Houas, PRL(2003)



Krypton bubble in air, M=1.1

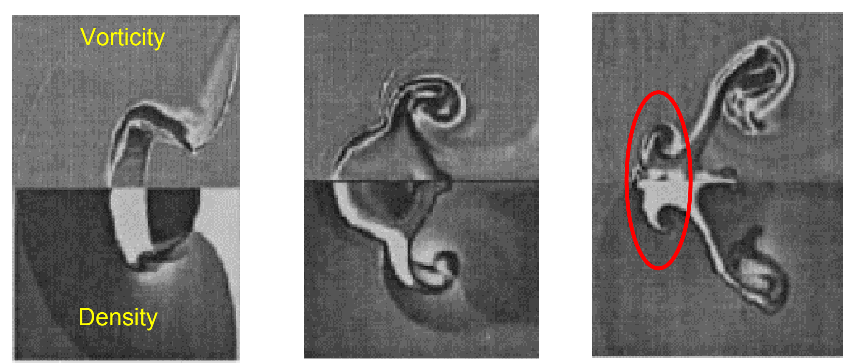
Ranjan *et al.*, PRL(2005)

Shock Trajectory



Argon bubble in nitrogen, M = 2.88

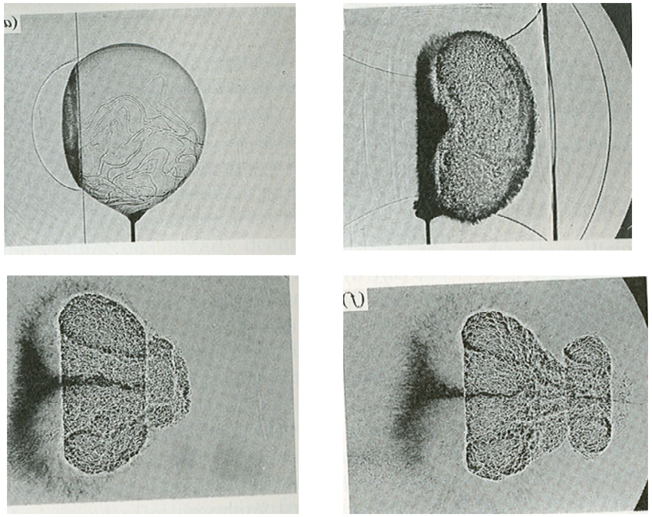
Zabusky and Zeng, JFM(1998)



Freon-12 bubble in air, M = 2.5

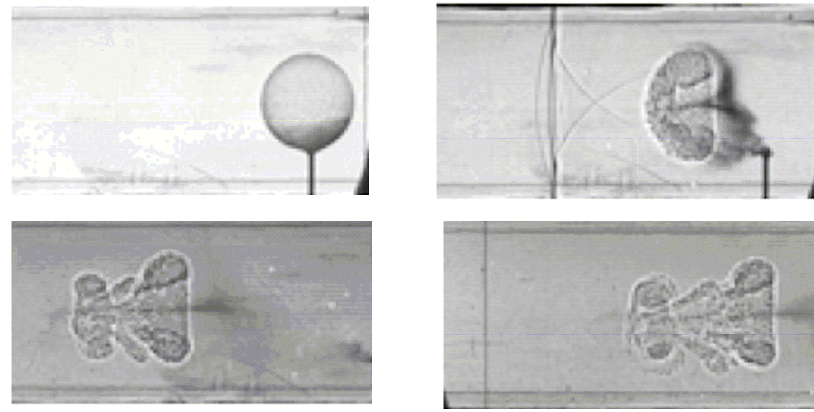
Literature Review: Experiments and Simulations

Haas & Sturtevant, JFM(1987)



Helium bubble in air, M=1.25

Layes, Jourdan & Houas, PRL(2003)

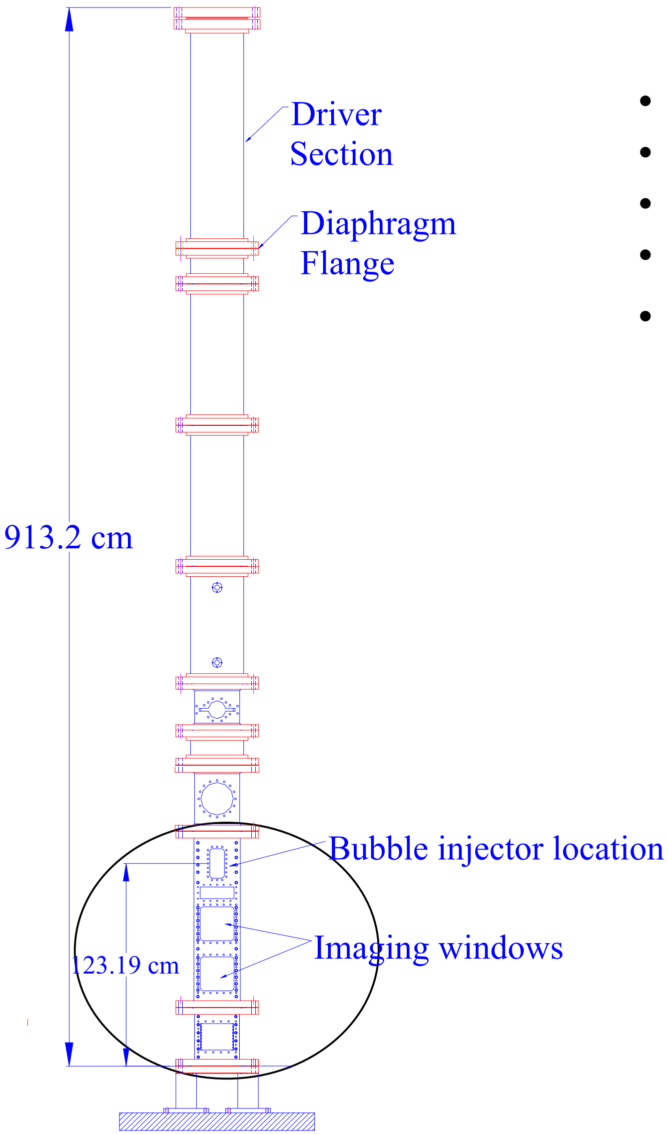


Helium bubble in air, M=1.24

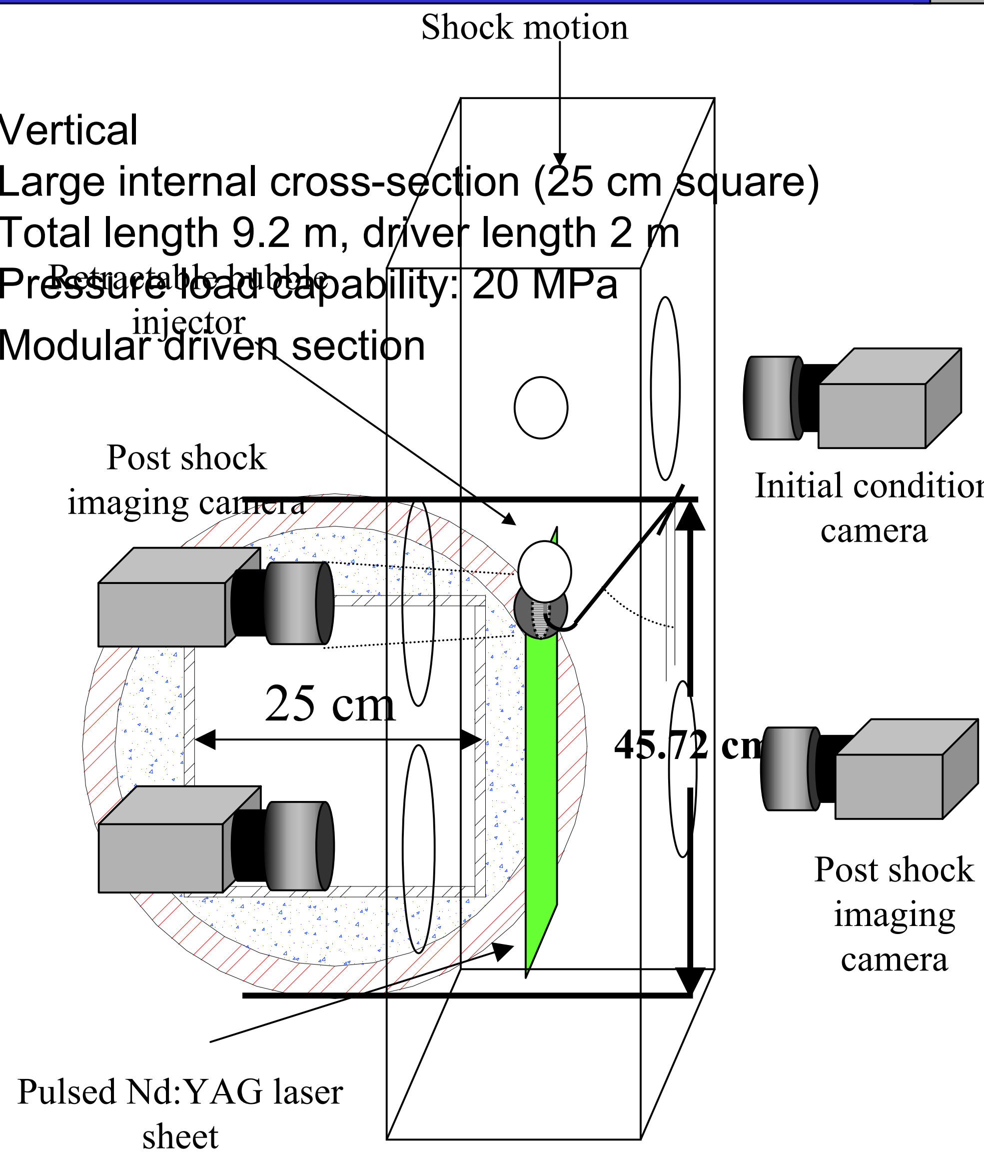
Current work

- Bubble is in free motion (**free-rising**)
- Visualization: **Planar laser imaging**
- Experiments are conducted for wide range of Mach numbers (**1.3<*M*<3.0**)
- Experiments have been conducted for **late times**.

Experimental Setup: Initial Condition



- 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

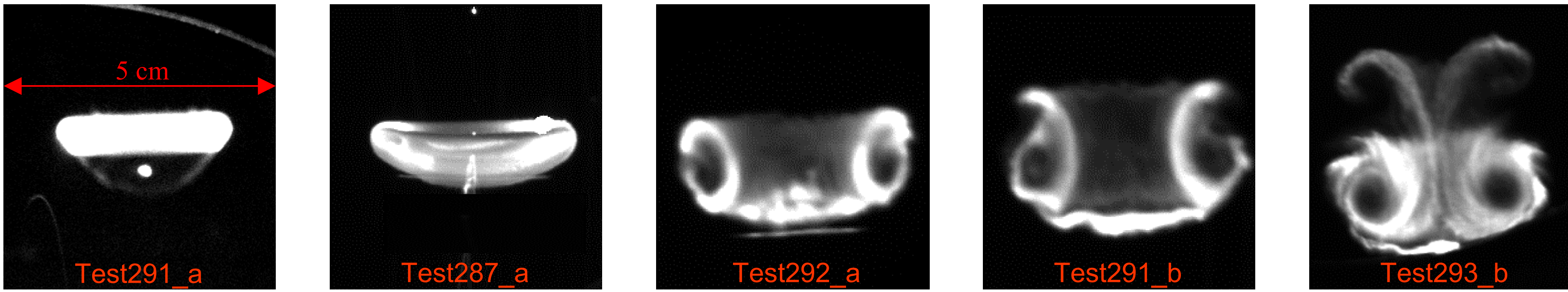


3-D Simulations: RAPTOR

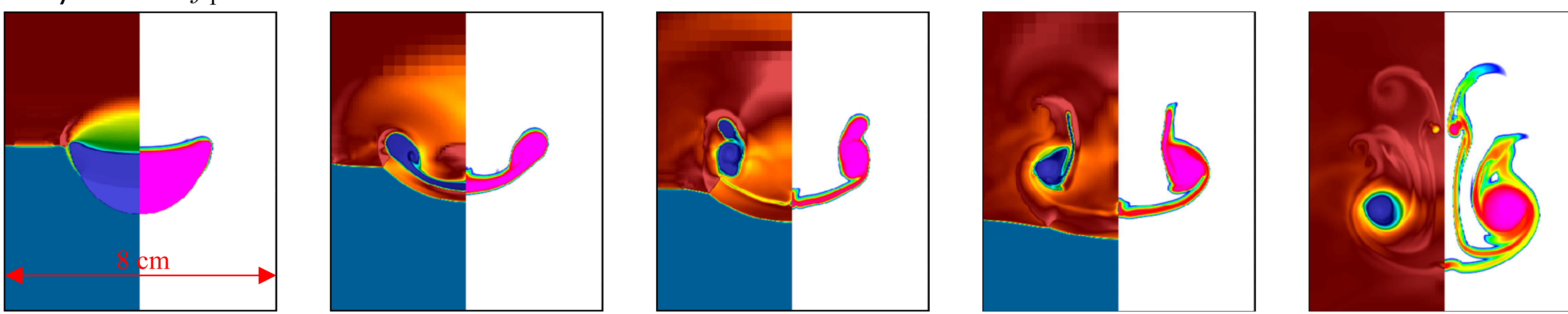
RAPTOR (LLNL)

- Compressible Euler equations
- 3-D rectangular grid
- Eulerian Godunov-based shock-capturing scheme
- Block-structured adaptive mesh refinement (AMR)
  - Finest-level grid spacing: 195 μm, or R_{130}
- Gamma law EOS
- Multifluid method using effective mixture properties

Flow Visualization: High Mach Number , M=2.95



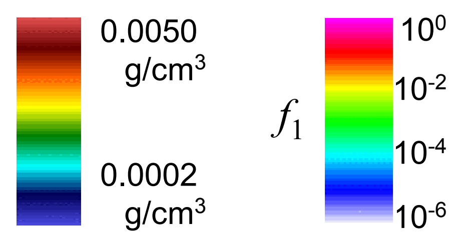
t = 13 μs	t = 35 μs	t = 70μs	t = 113 μs	t = 230 μs
τ = 1.3	τ = 4.0	τ = 7.7	τ = 11.6	τ = 23.8



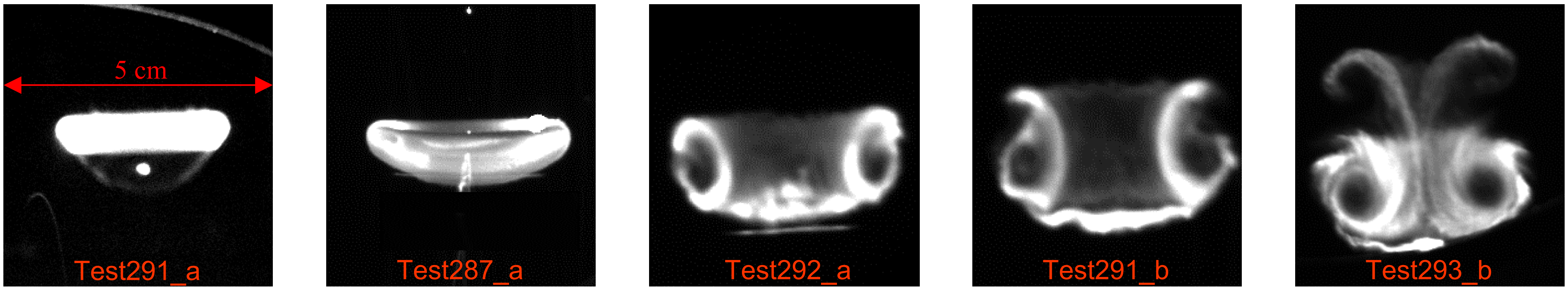
t = 12.7 μs	t = 40.5 μs	t = 75.3 μs	t = 112.2 μs	t = 230.7 μs
τ = 1.3	τ = 4.1	τ = 7.7	τ = 11.5	τ = 23.6

Bubble gas: He
Ambient gas: N_2
At = - 0.75

$$\tau = \frac{t}{t'} \qquad t' = \frac{D}{2\,W_t}$$



Flow Visualization: High Mach Number , M=2.95



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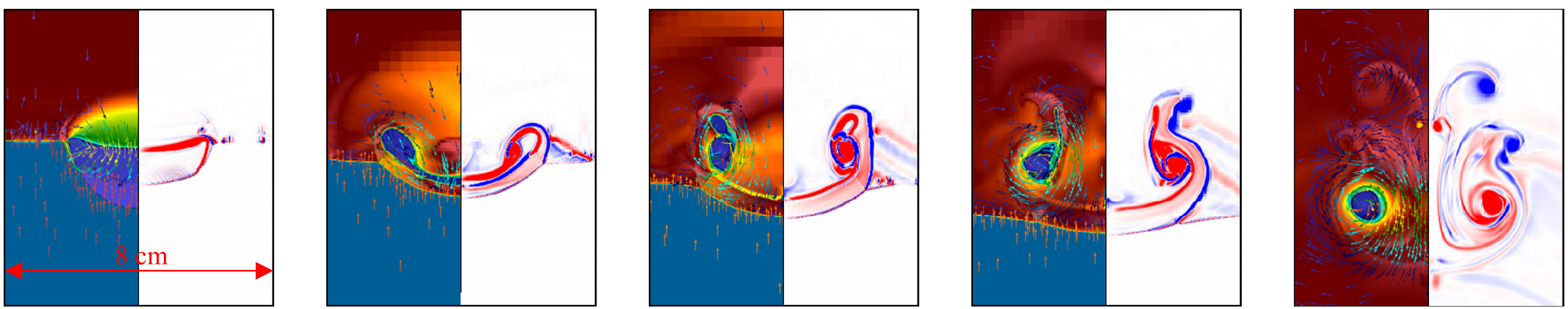
$\vec{U}'$ ω



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Bubble gas: He
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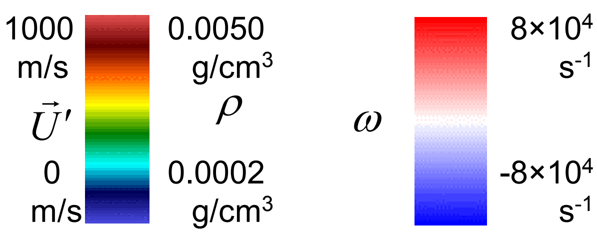
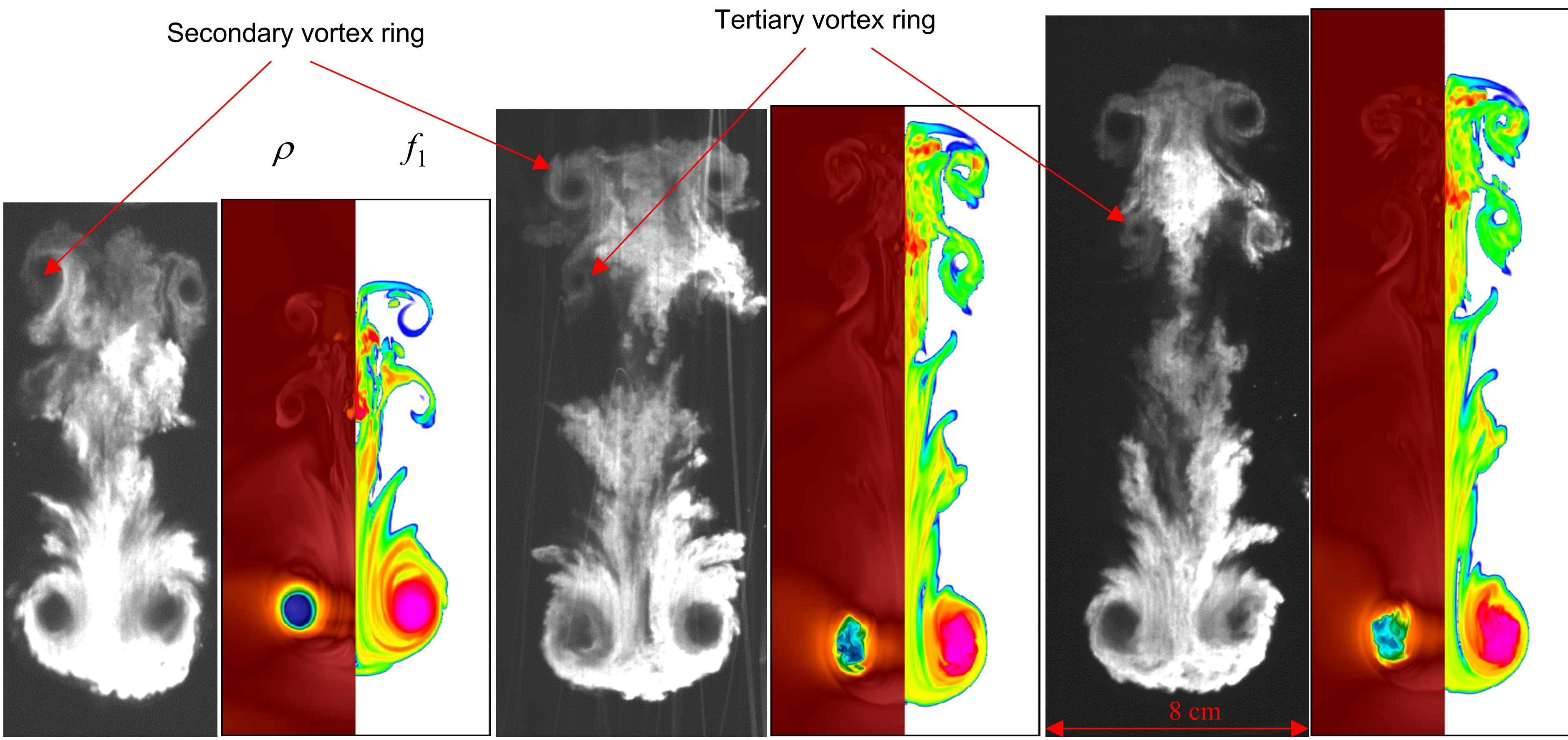
$$\vec{U}' \equiv \vec{U}(x,y,z) - u_2\hat{y}$$



Flow Visualization: High Mach Number , M=2.95



t = 430 μs, τ = 46.3

t = 445.6 μs, τ = 45.6

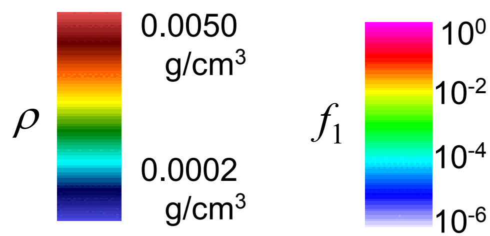
t = 721 μs, τ = 63.5

t = 620.9 μs, τ = 63.5

t = 725 μs, τ = 69.5

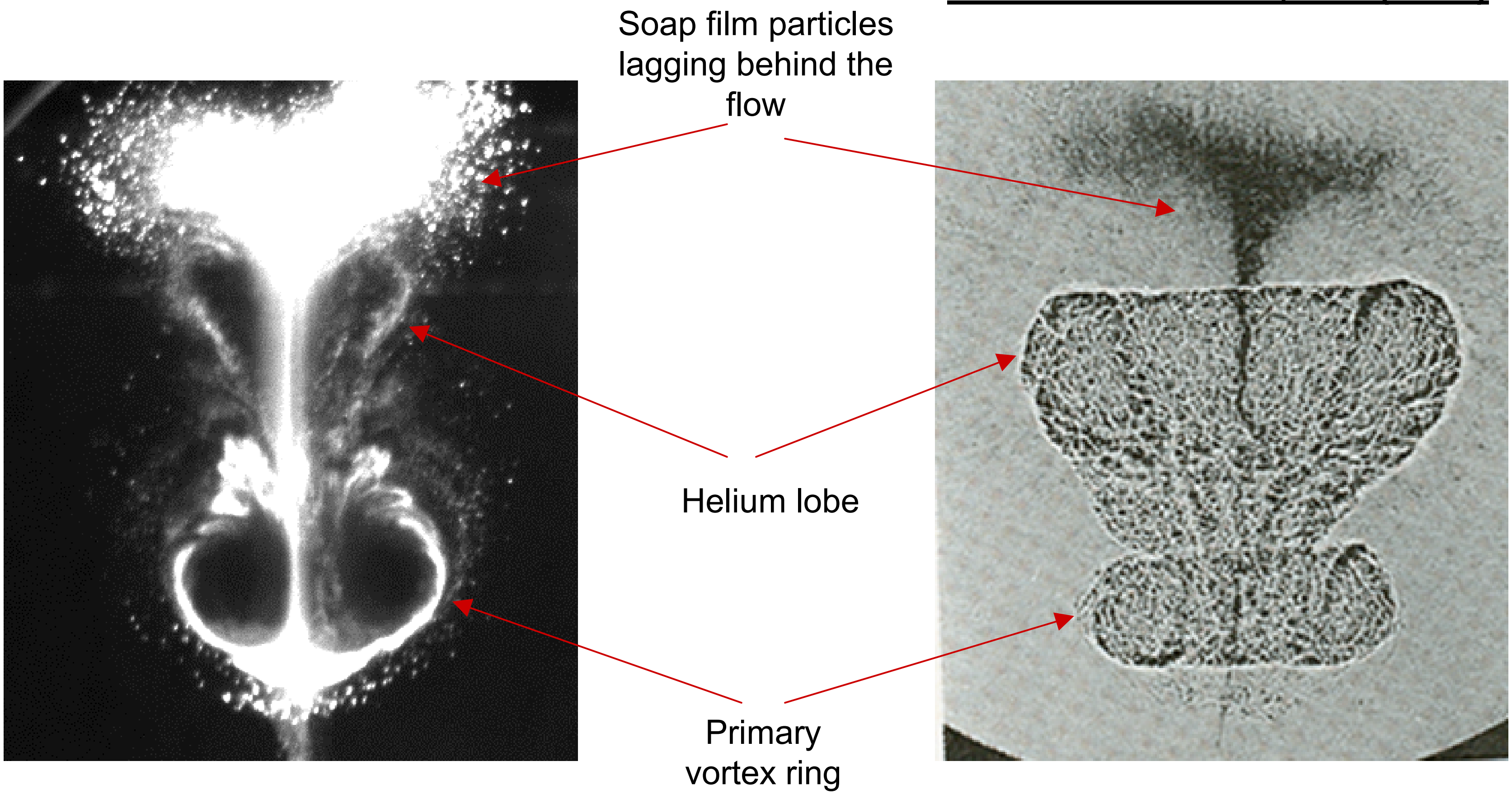
t = 699.7 μs, τ = 71.6

$$\tau = \frac{t}{t'} \qquad t' = \frac{D}{2\,W_t}$$



Comparison: Helium Bubble

Haas & Sturtevant, JFM(1987)



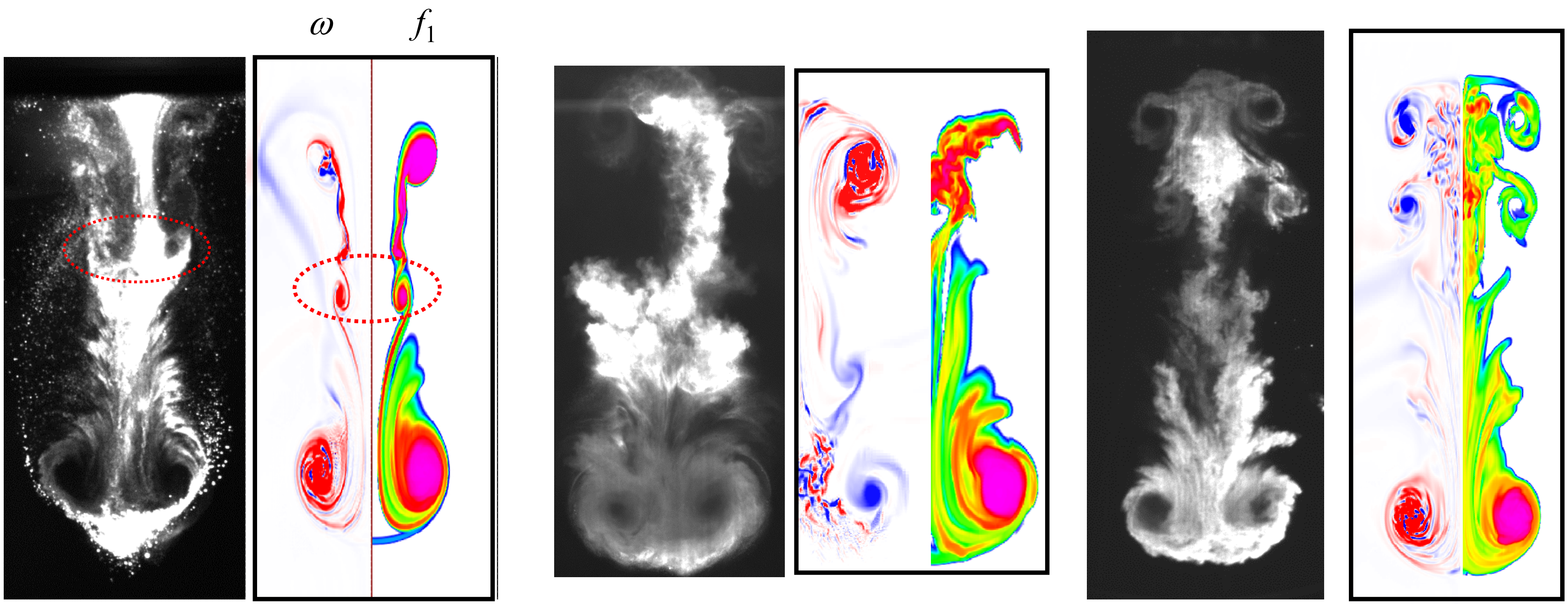
$t = 968\ \mu s,\ \tau = 57.9$

Helium bubble in nitrogen, M =1.4

$t = 600\ \mu s$

Helium bubble in air, M =1.25

Flow Visualization: Helium Bubble at Late Times



$t = 1768$ μs
$\tau = 105.75$

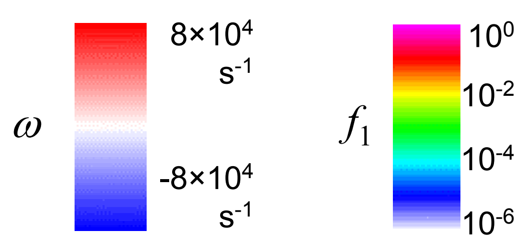
M = 1.4

$t = 737$ μs
$\tau = 63.43$

M = 2.08

$t = 725$ μs
$\tau = 69.5$

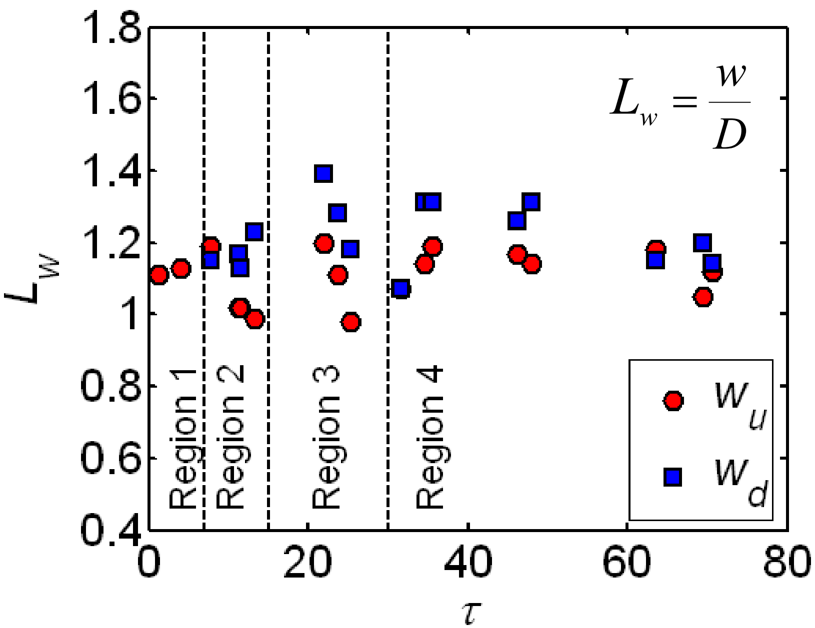
M = 2.95

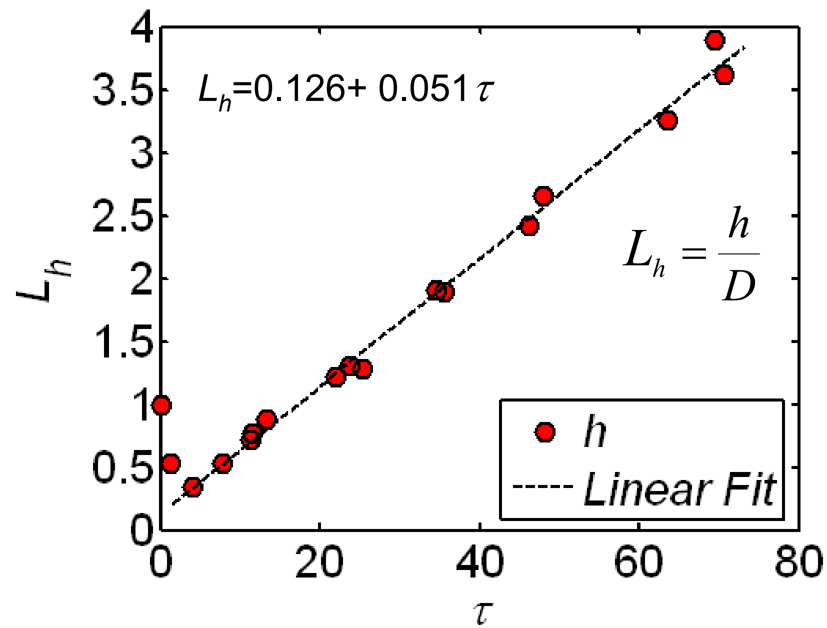


Results: Helium Bubble in Nitrogen, M =2.95

Region 1: Compression phase   Region 2: Mass transfer phase

Region 3: Shock reflection from the shock tube side walls Region 4: Turbulent mixing zone





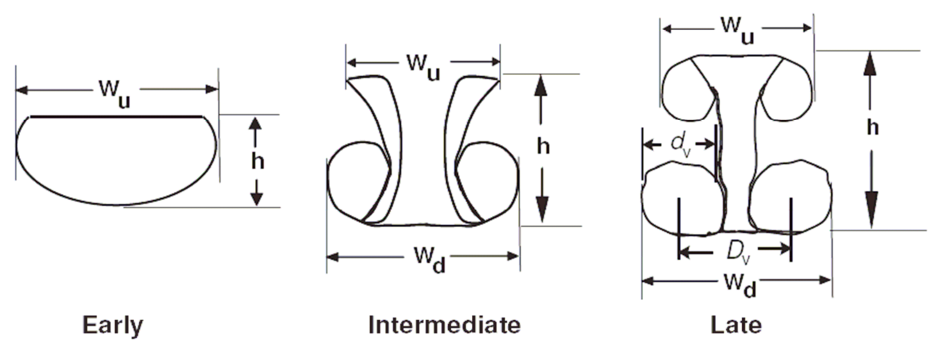
Rate of axial elongation($\alpha = \frac{dL_h}{d\tau}$)

$\alpha = 0.051$ (M=2.95)

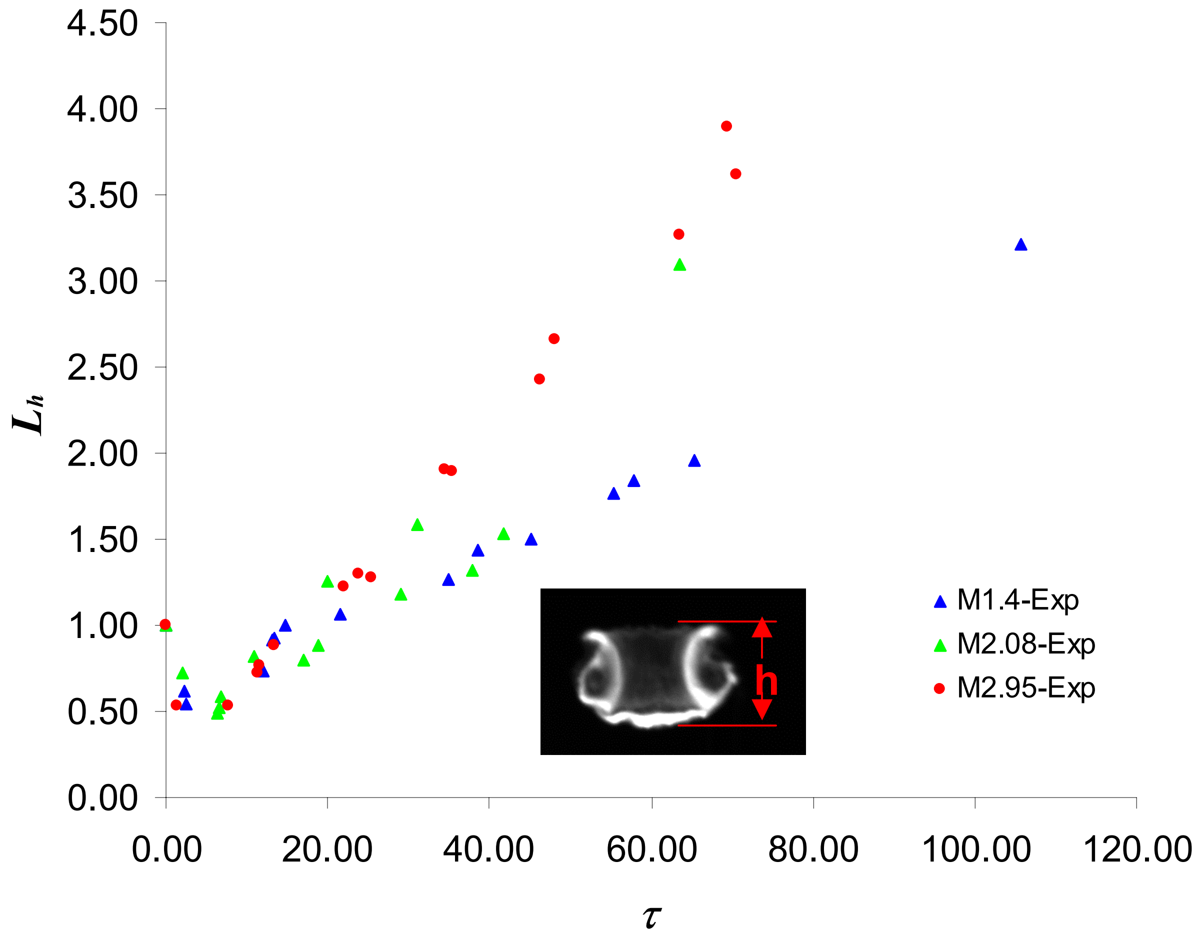
$\alpha = 0.024$ (Layes *et al.*,M=1.24 *PoF 2005*)

(M=1.40)

$$\tau = \frac{t}{t'} \qquad t' = \frac{D}{2W_t}$$

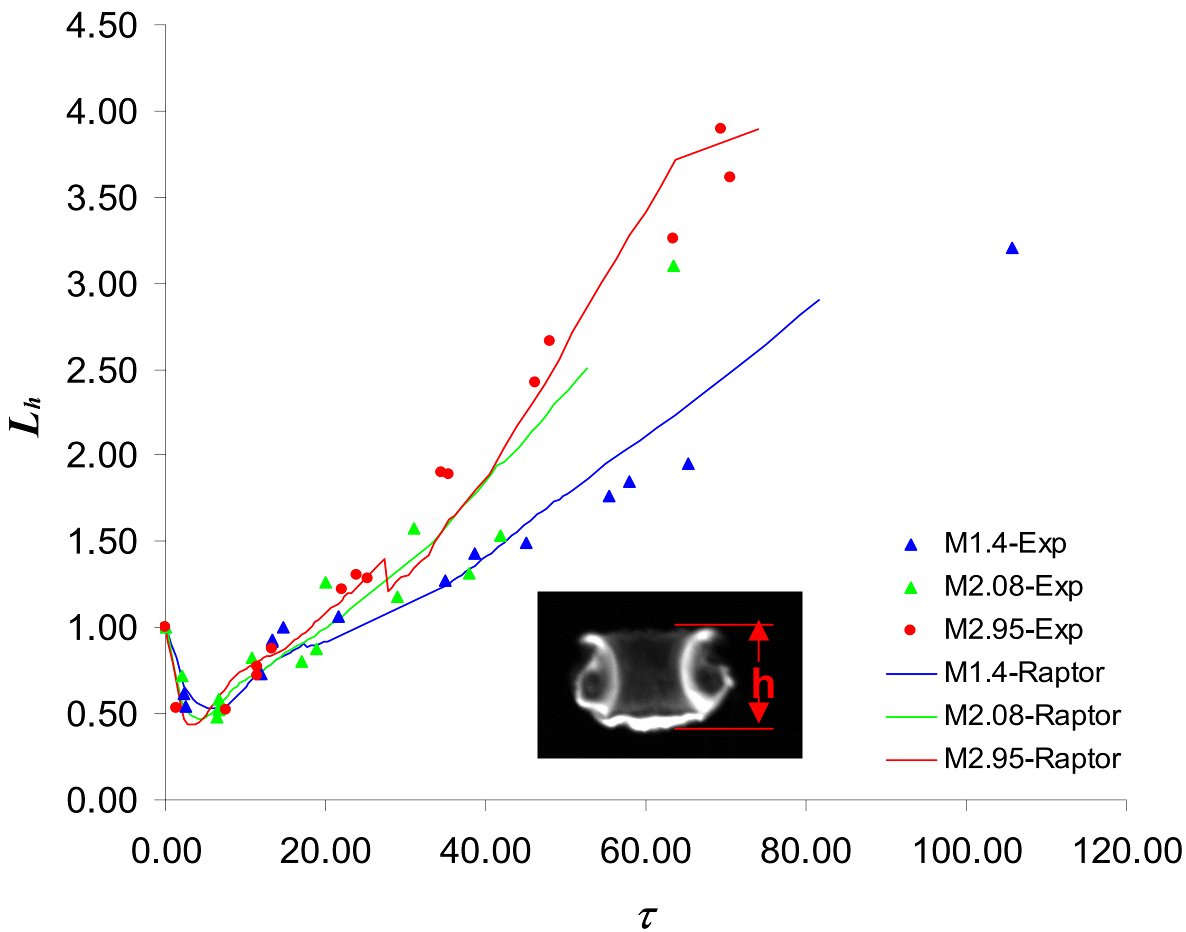


Comparison: Height



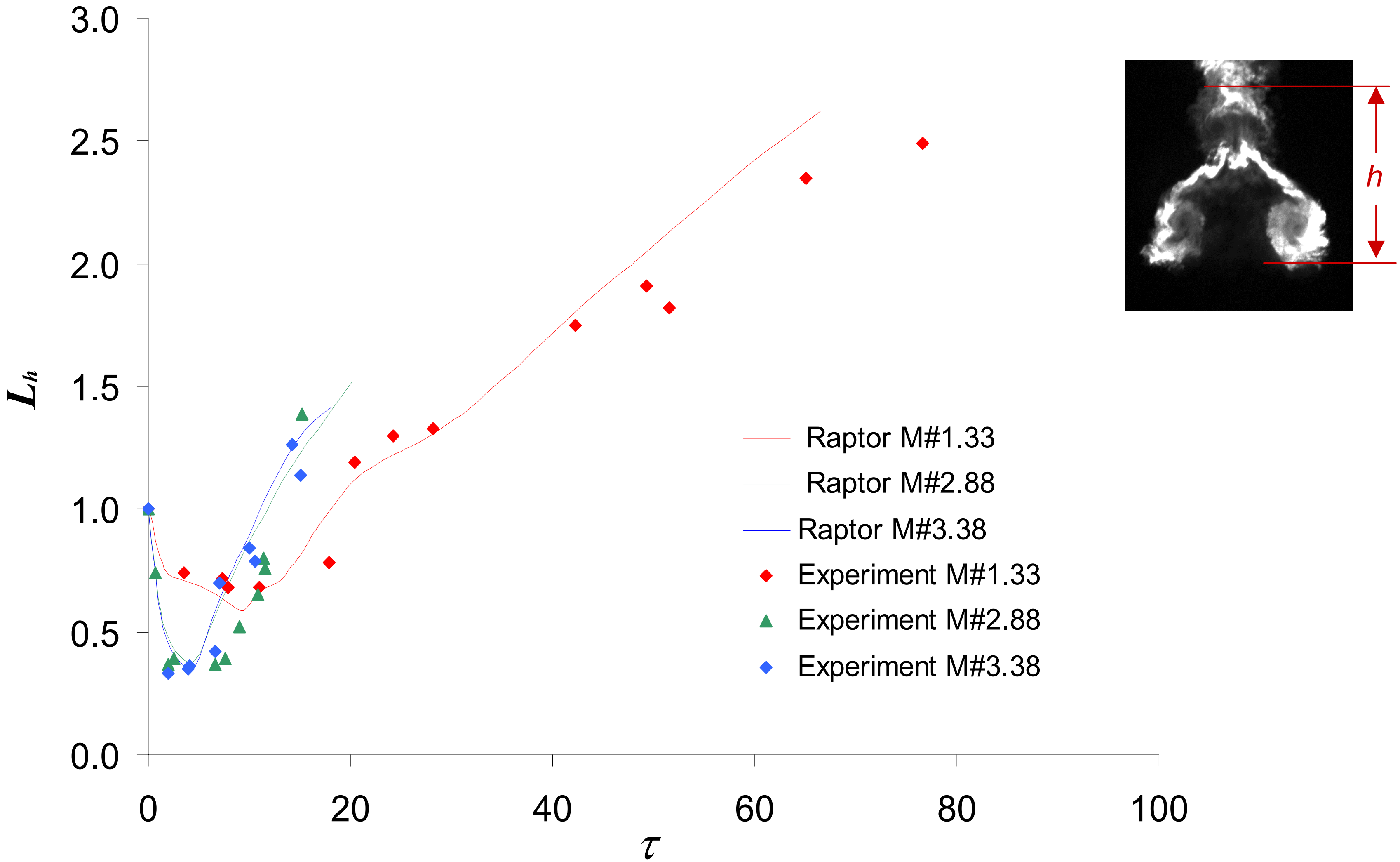
Helium bubble

Comparison: Height



Helium bubble

Comparison: Height



Argon bubble in nitrogen

Conclusions

- Experimental technique : Successful high Mach number experiments with planar imaging and free flow bubble are performed for late times.

- Comparison to simulations : Salient flow features are captured in both experiments and simulations.

- Bulk properties of bubble growth : Spatial extent, circulation & vortex ring velocity are predicted with mixed success by simulation and various models.

- Secondary features : Strong counter-rotating secondary and tertiary vortex rings are observed at $M > 2$.

- Mach number effects : Transition in bubble growth trends is observed at $M \sim 2$.