IWPCTM Dec 2001 Pasadena, CA, USA

The Dependence of the Shock Induced Richtmyer-Meshkov Instability on Dimensionality and Density Ratio

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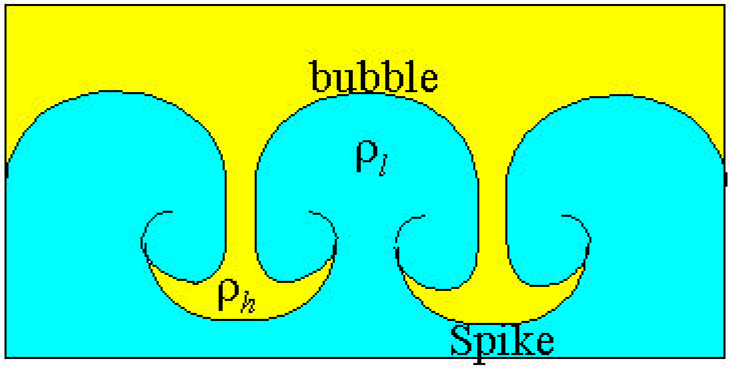
Buoyancy - Drag Consideration for the Single Mode Case

Newton s second law (for the bubble):

$$(\rho_l \cdot V + C_a \cdot V \cdot \rho_h) \cdot \frac{dU}{dt} = (\rho_h - \rho_l)V \cdot g \quad - \quad C_d \cdot \rho_h \cdot S \cdot U^2$$

For the bubble:

$$(\rho_l + C_a \rho_h)\dot{U} = (\rho_h - \rho_l) \cdot g - \frac{C_d}{\lambda} \rho_h \cdot U^2$$



For the spike: $(\rho_h \Leftrightarrow \rho_l)$

$$(\rho_h + C_a \rho_l)\dot{U} = (\rho_l - \rho_h) \cdot g - \frac{C_d}{\lambda} \rho_l \cdot U^2$$

Linear Stage Single Mode Velocity

Atwood Number: $A = \frac{r_H - r_L}{r_H + r_L}$

Using: $g(t) = U_0 \delta(t)$ and $U^2 << \frac{(\rho_h - \rho_l)\lambda \cdot g}{\rho_h \cdot C_d}$

$$U_{linear} = U_0 \cdot k \cdot h_0 \cdot A$$ Constant velocity $\left(k = \frac{2\pi}{\lambda}\right)$

Asymptotic Single Mode Velocities:

$$(\rho_l + C_a\rho_h)\dot{U} = (\rho_h - \rho_l)\cdot g - \frac{C_d}{\lambda}\rho_h \cdot U^2$$

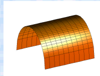
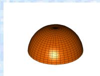
g=0

Using *:

2D :	C_d=6π	C_a=2
3D :	C_d=2π	C_a=1

For the bubble:

$$U_B = \left(\frac{\frac{1-A}{1+A} + C_a}{C_d} \right) \cdot \frac{l}{t}$$

	A≈0	A≈1
2D: 	$\frac{1}{2p}\cdot\frac{l}{t}$	$\frac{1}{3p}\cdot\frac{l}{t}$
3D: 	$\frac{1}{p}\cdot\frac{l}{t}$	$\frac{1}{2p}\cdot\frac{l}{t}$

For the spike: $\rho_h \Leftrightarrow \rho_l$

$$U_S = \begin{cases} (A+1)/(A-1)\cdot(3-A)/(3+A)\cdot U_B & \text{for 2D} \\ (A+1)/(A-1)\cdot U_B & \text{for 3D} \end{cases}$$

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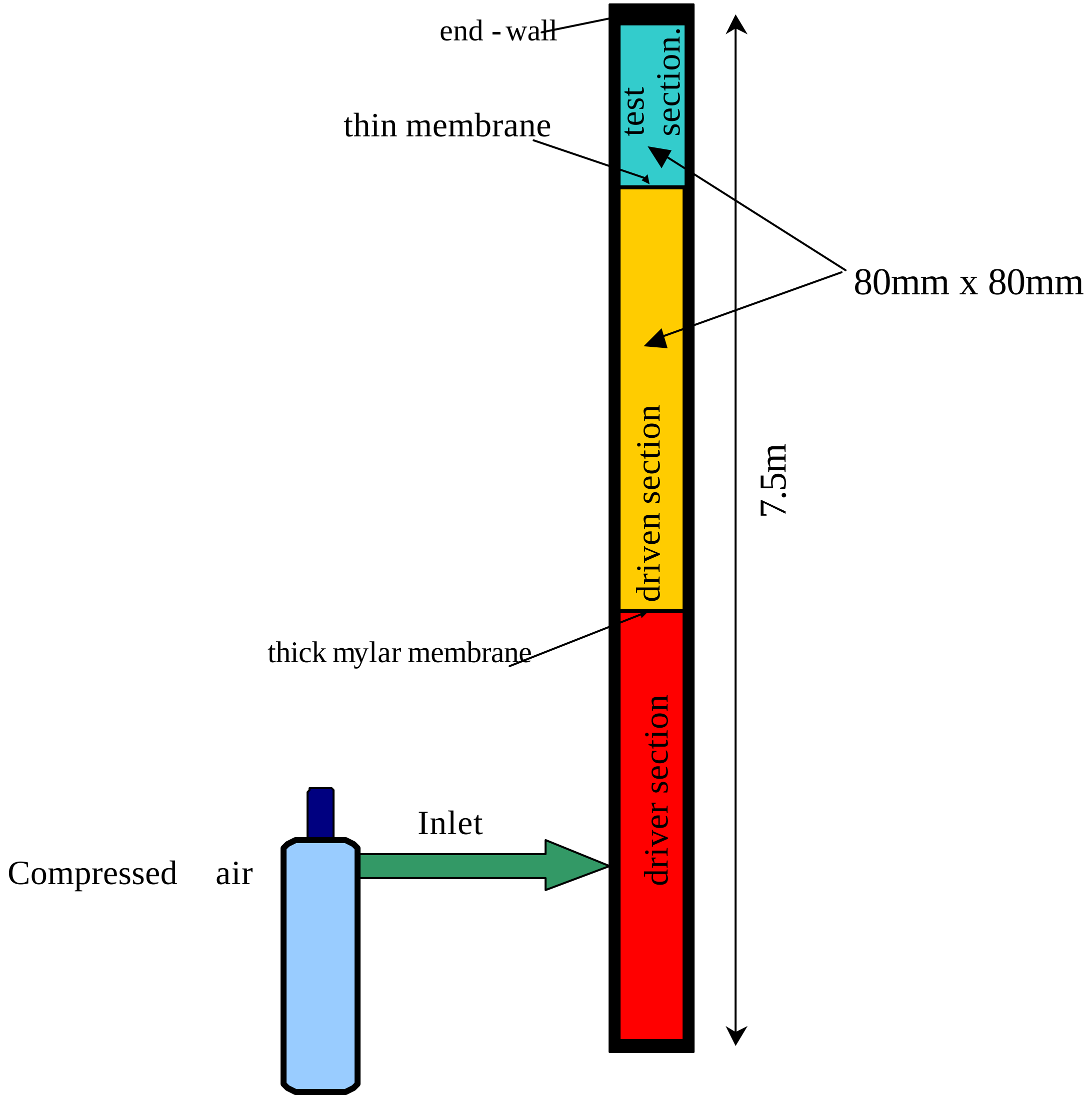
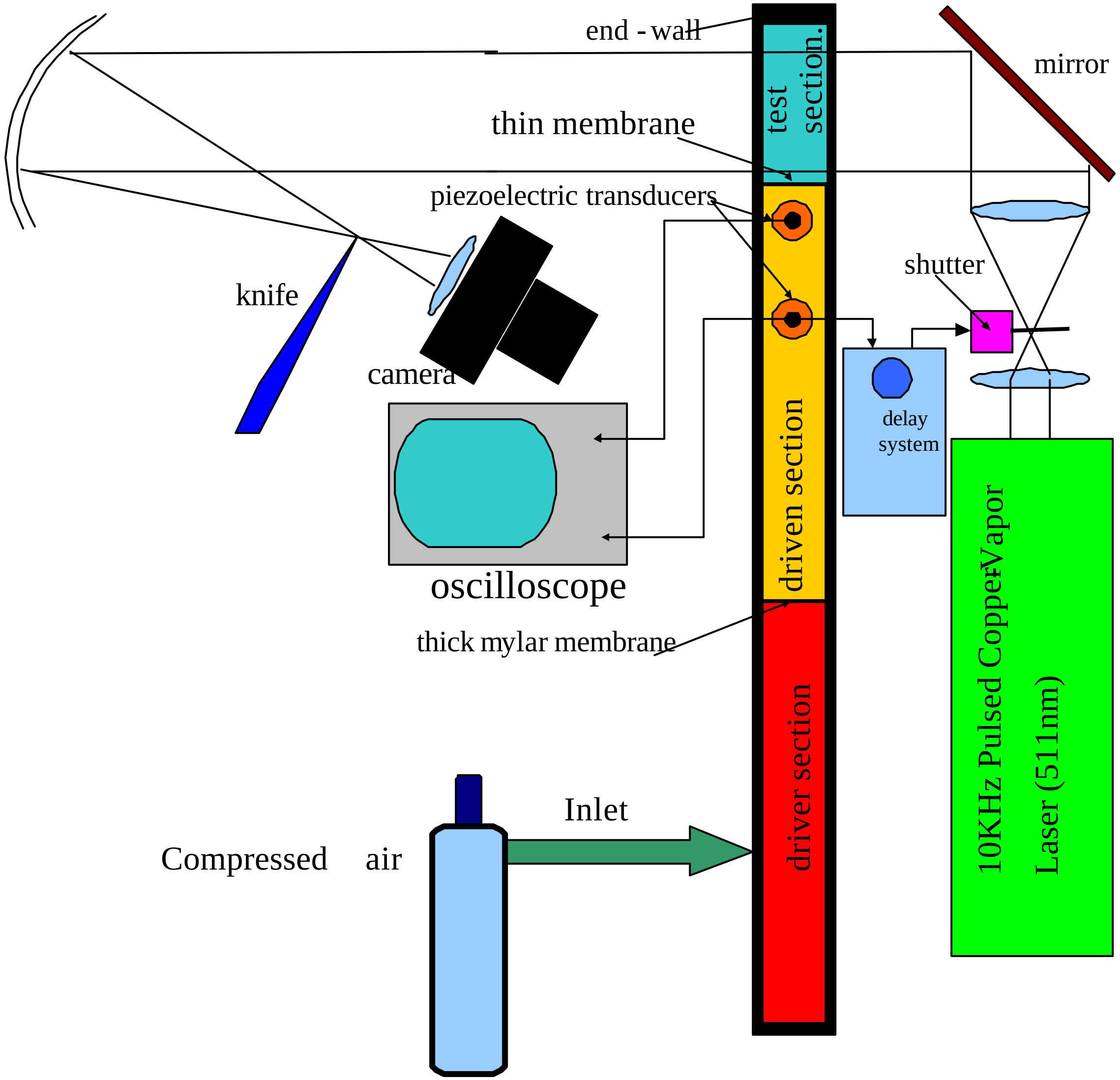
* Layzer (1955);
Hecht *et al.* (1994).

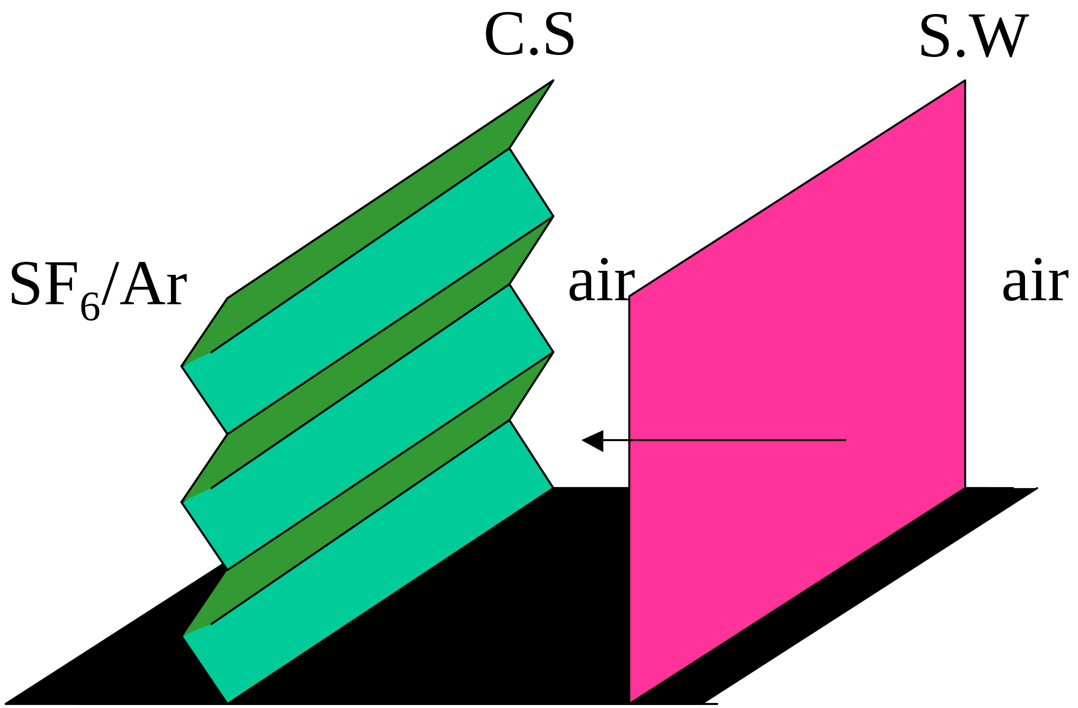
Experimental Apparatus



Experimental Apparatus

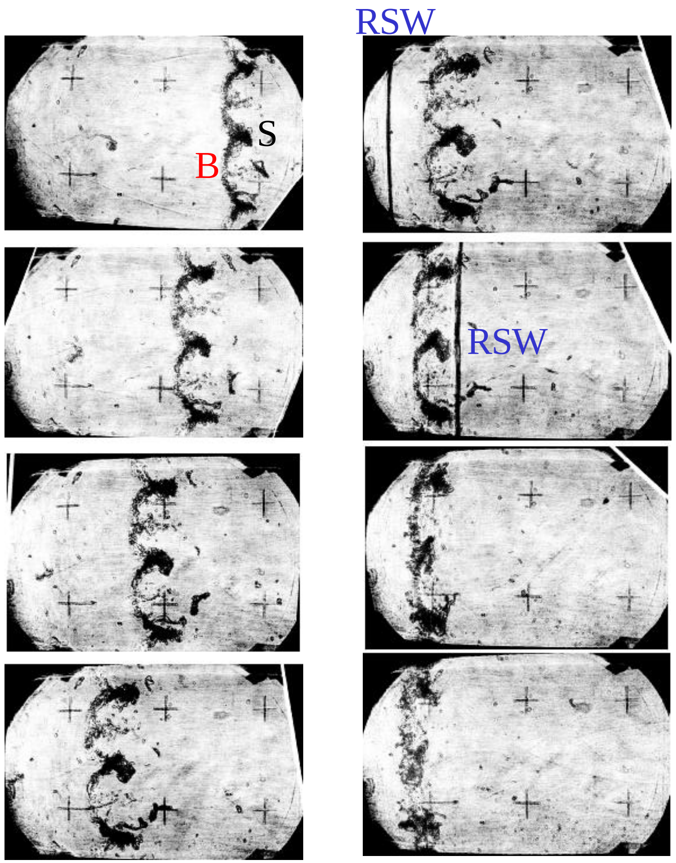


Experimental Setup - The Membrane

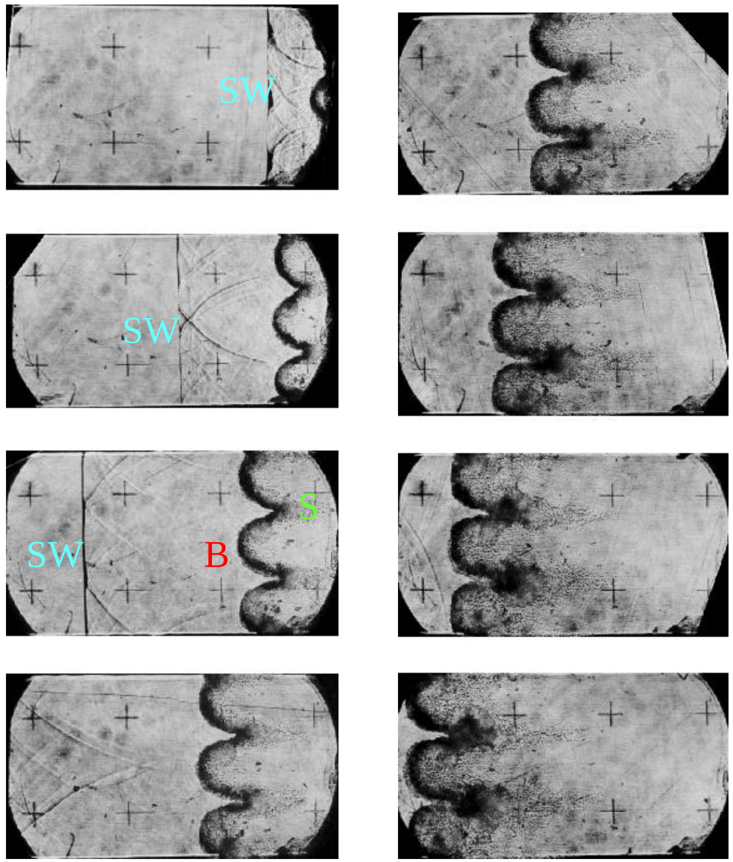


2D - Low and High Atwood number Experiments

A=0.2 (Air to Ar) λ=26mm



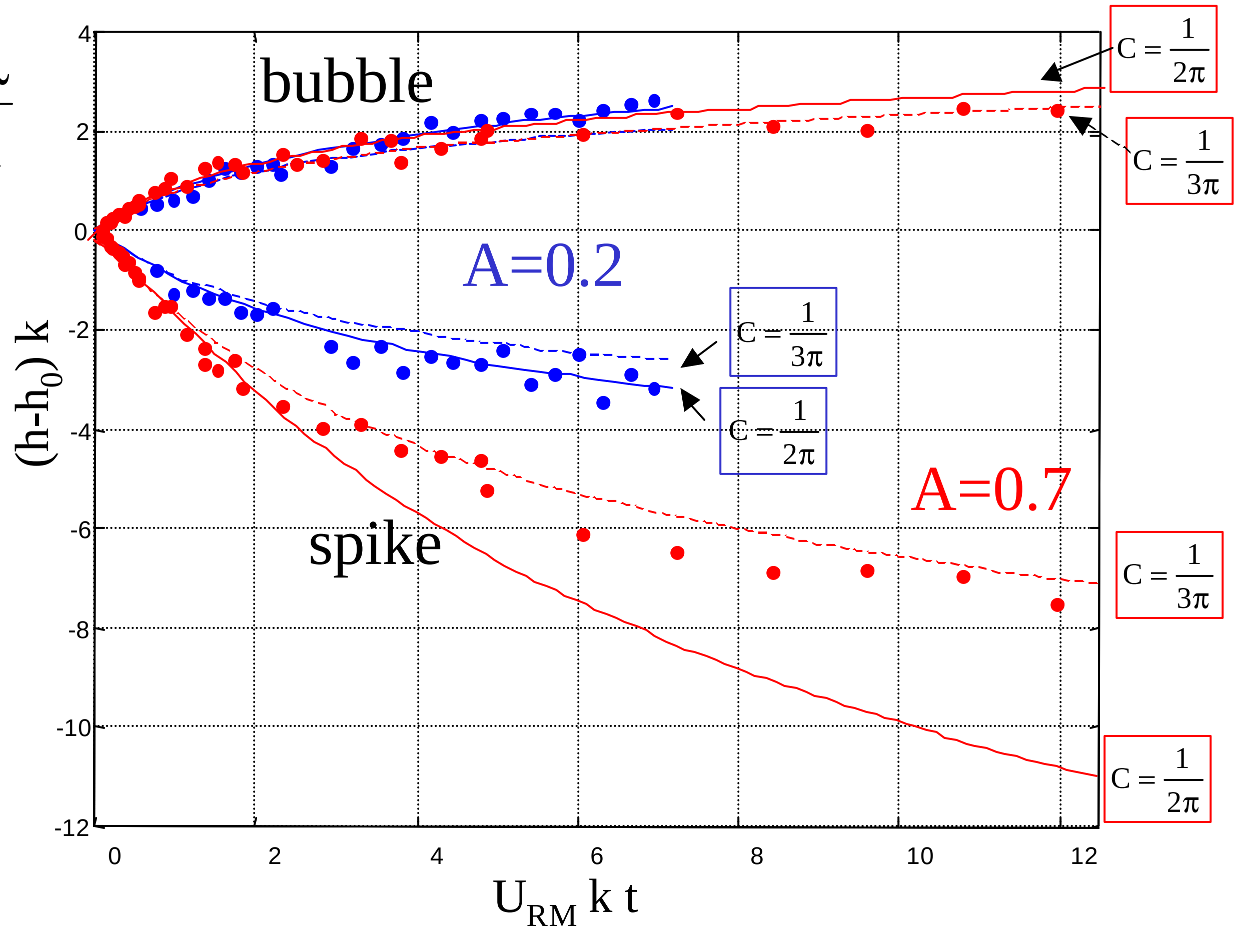
A=0.7 (Air to SF_6) λ=26mm



Experiment vs. Model for the Atwood Number Dependence

$$U_{asy} = C \cdot \frac{\lambda}{t}$$

	A=0.2	A=0.7
1/C	2π	3π
U_b/U_s	0.77	0.28



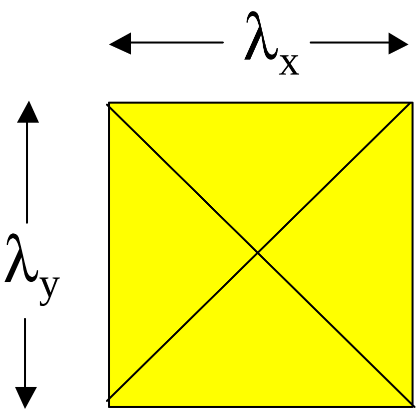
Dimensionality Investigation:

$$U_{B_{A\approx 1}}^{(asy.)} =$$

2D:	$\frac{1}{3p}\cdot\frac{l}{t}$
3D:	$\frac{1}{2p}\cdot\frac{l}{t}$

The Effective Wavelength

3D



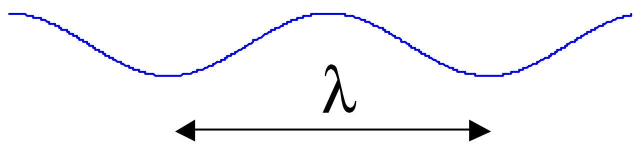
$$k_i = \frac{2\pi}{\lambda_i}$$

$$i = x, y$$

$$|k| = \sqrt{k_x^2 + k_y^2}$$

$$\bar{\lambda} = \frac{2\pi}{|k|}$$

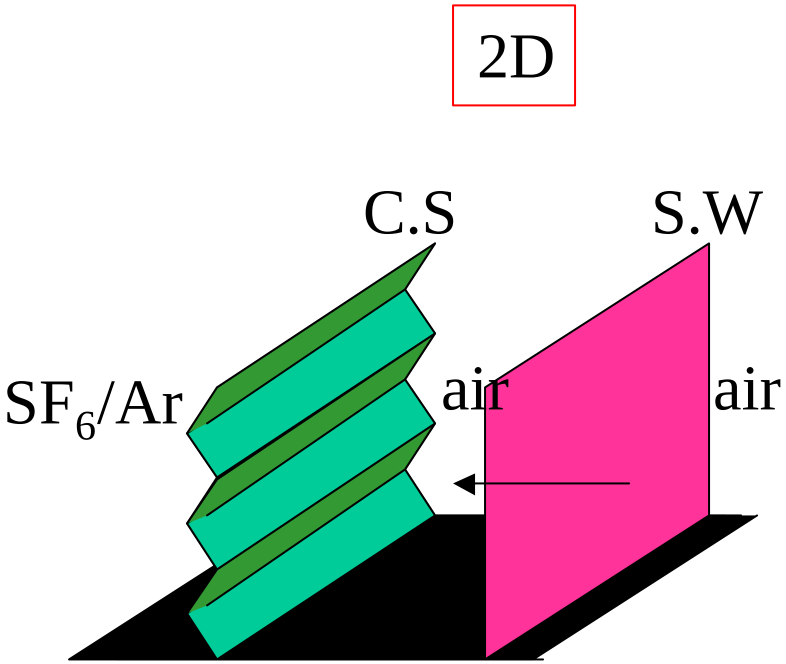
2D

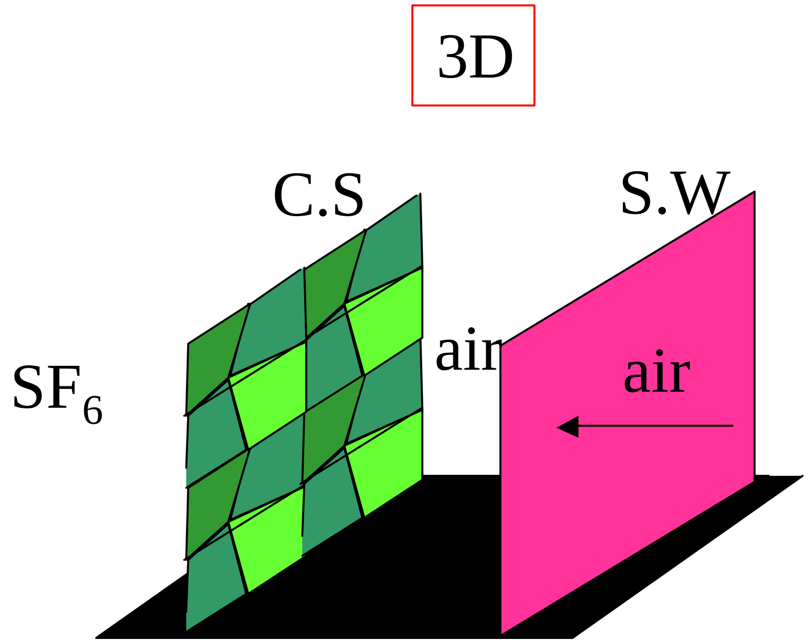


$$k = \frac{2\pi}{\lambda}$$

Experimental Setup - The Membrane - 2D/3D case

Periodic Initial Conditions:

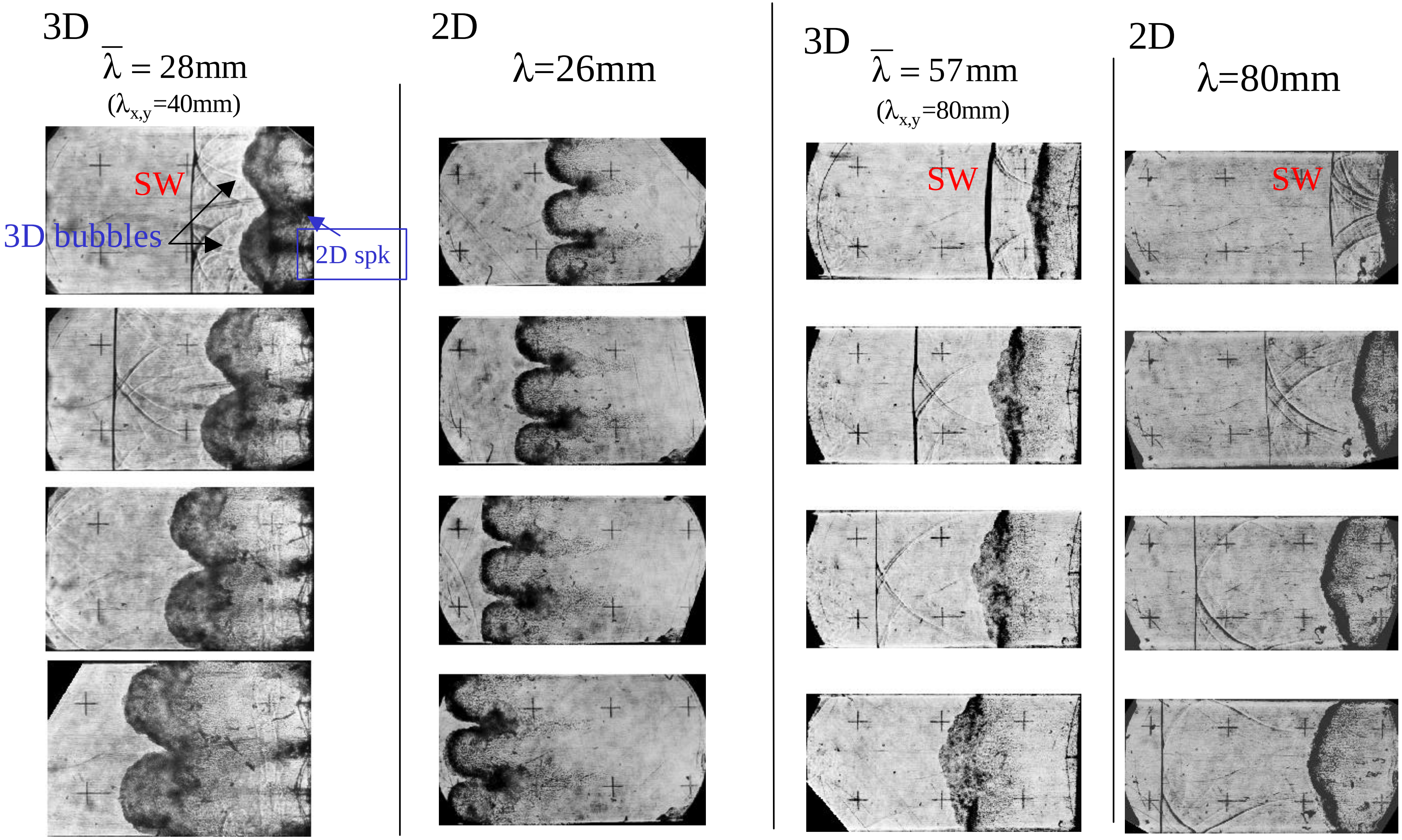




(Bubble-3D Spike-2D)

Results of 2D vs. 3D Experiments

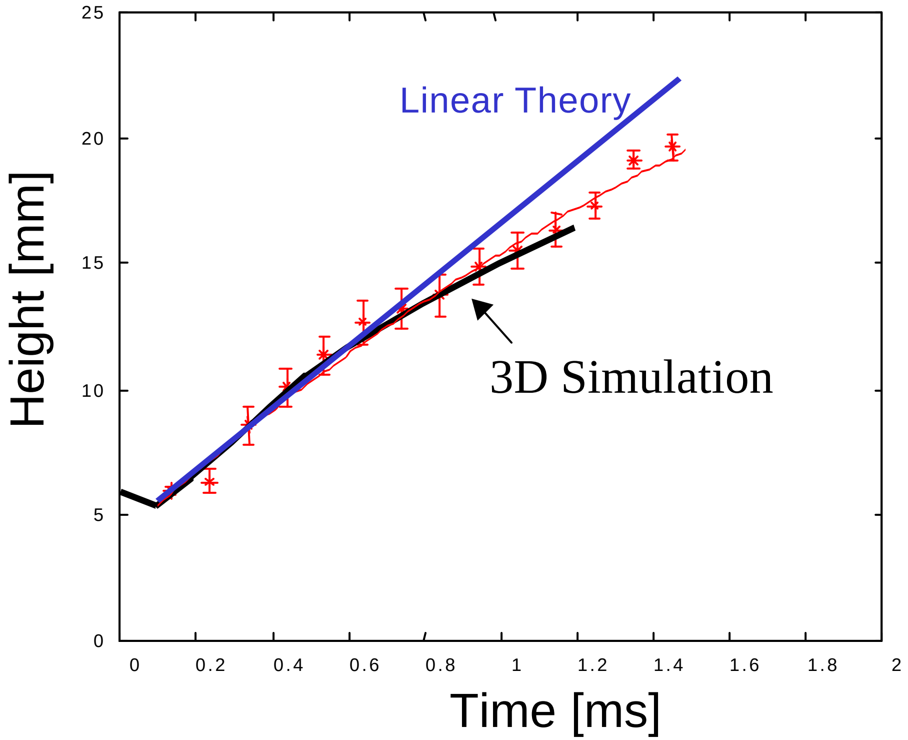
(M=1.20 Air to SF_6)



Dimensionality Dependence Results - Bubbles

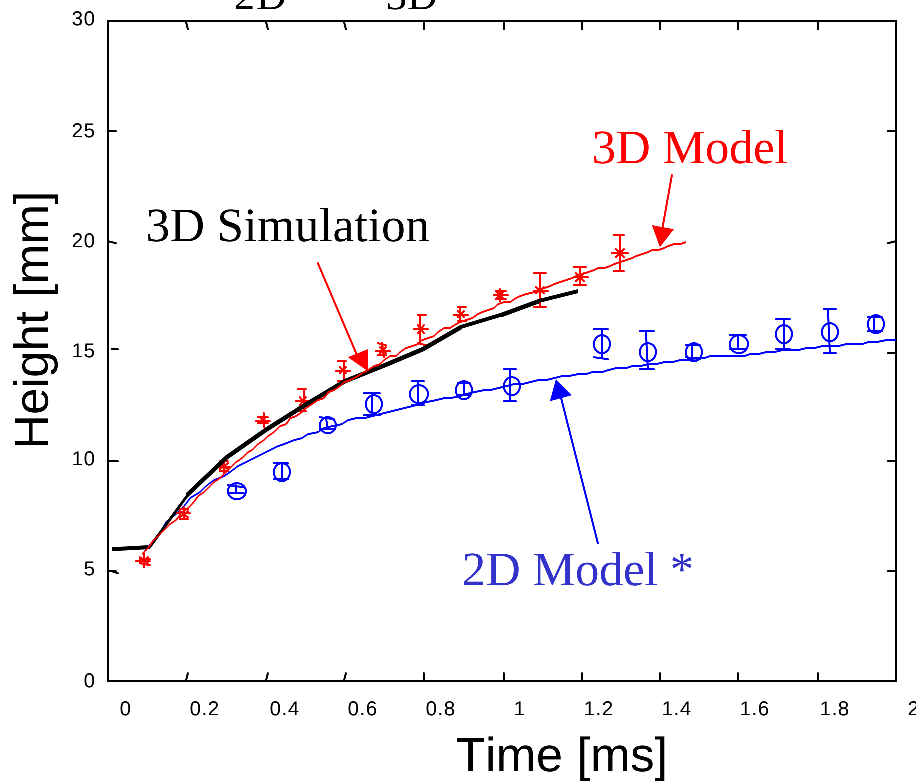
Linear stage

$k_{3D} \approx 0.1 mm^{-1}$



Nonlinear stage

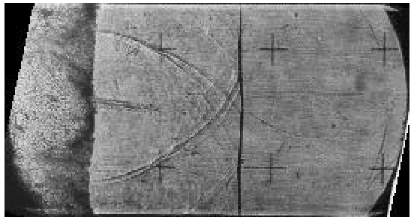
$k_{2D} \approx k_{3D} \approx 0.2 mm^{-1}$



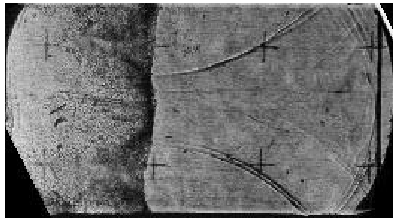
* [Sadot *et al.* (1998)]

Completing the picture   3D Spikes

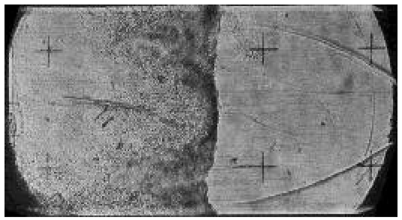
t=0.8mS



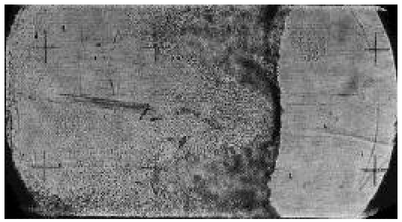
t=1.1mS



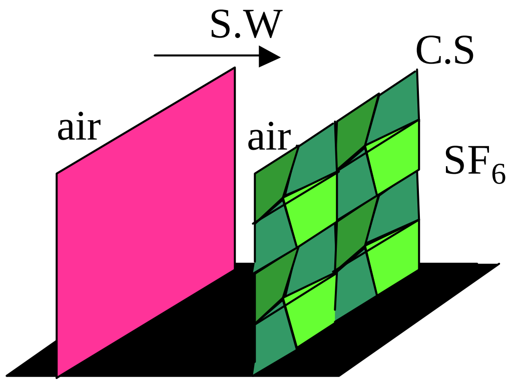
t=1.4mS

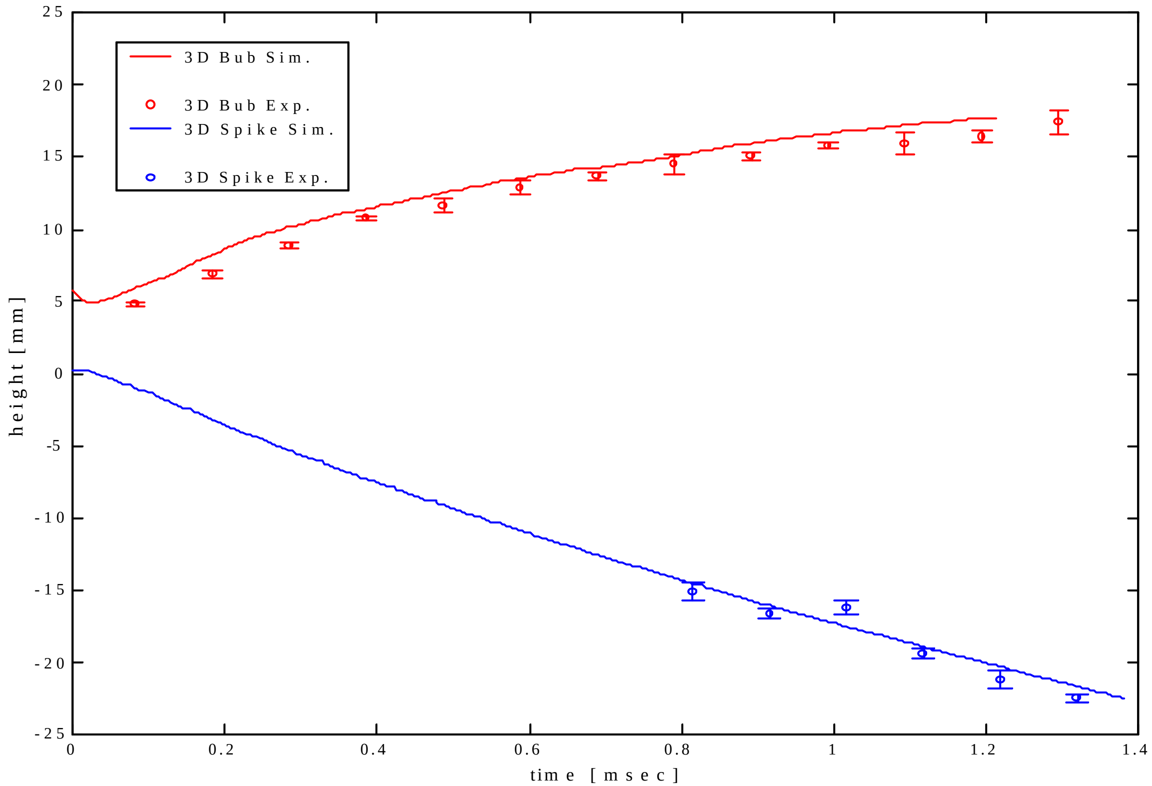


t=1.7mS

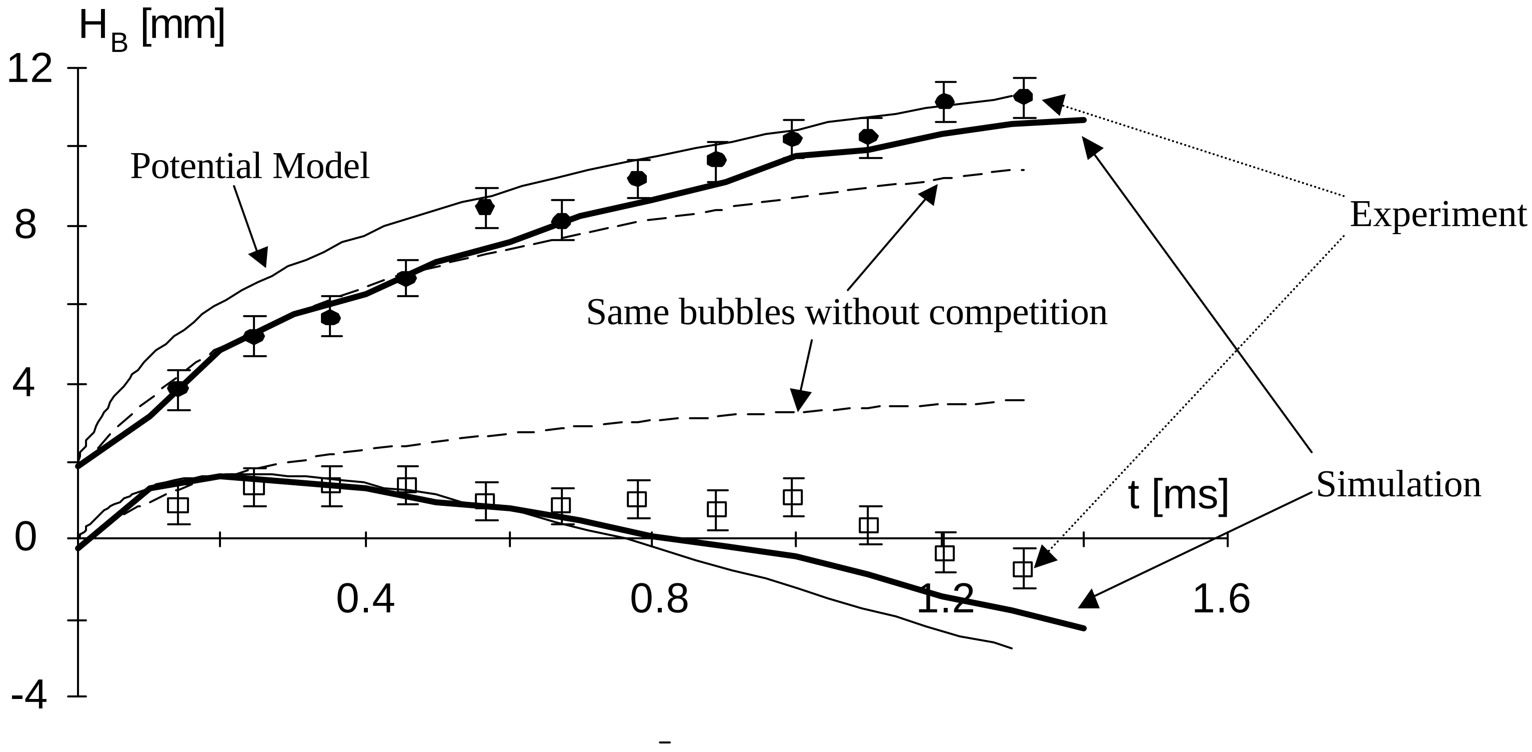


3D Spike , 2D Bubble





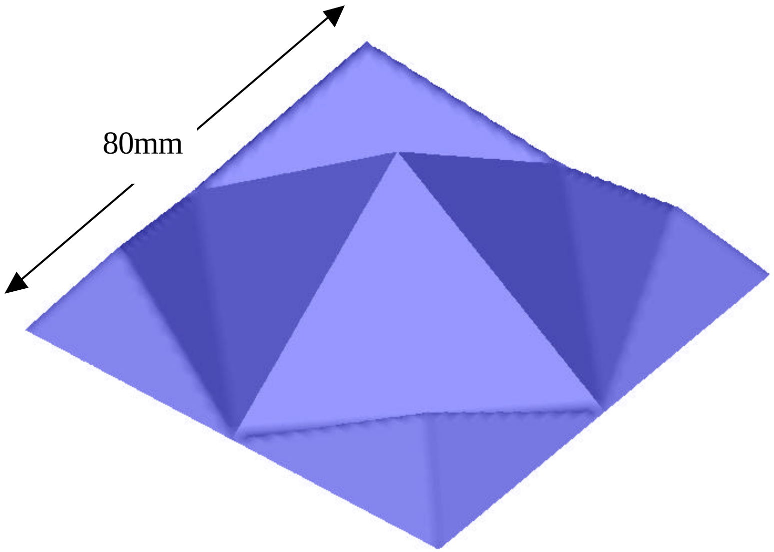
Bubble Competition 2D



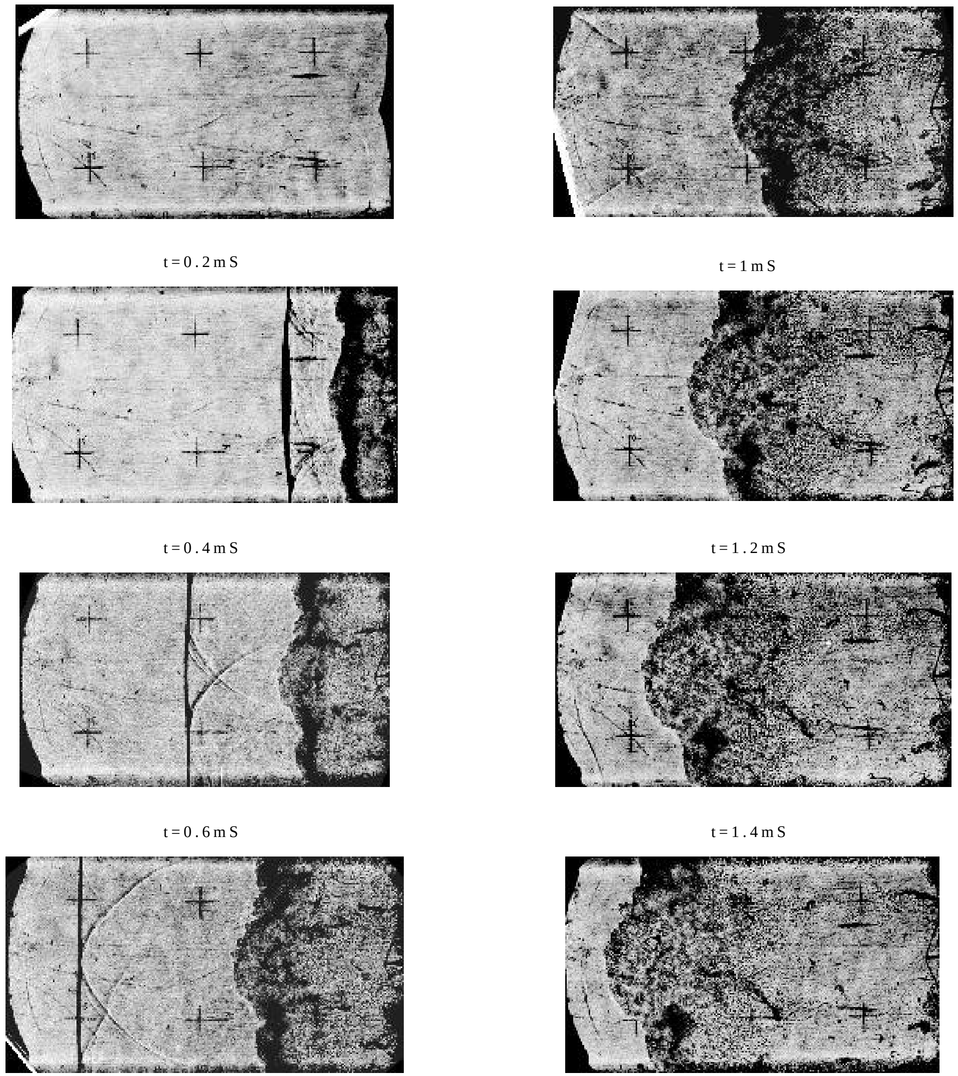
M=1.2 A=0.67 λ_1=10mm λ_2=25mm

[Sadot *et al.* (1998)]

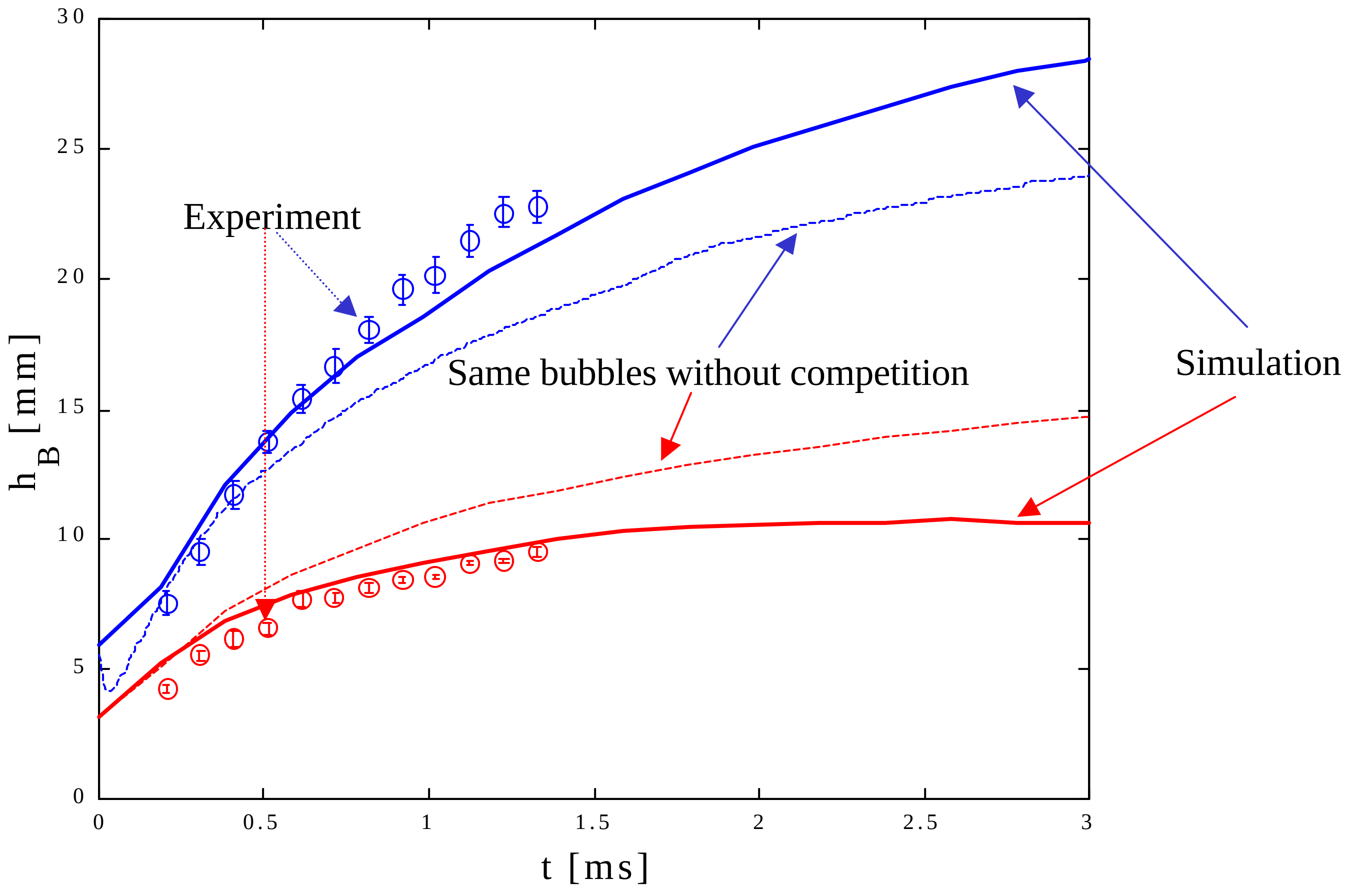
Bubble Competition in 3D - Experiment



(M=1.20 Air to SF_6)



Bubble Competition in 3D



Summary

Experiments were performed to investigate the dependence of the RM instability (Bubbles and Spikes) on the dimensionality and the Atwood number.

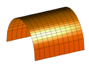
Good agreement was found between the results of the experiments and the prediction of the model as well as with the results of full simulations.

Bubble Competition was shown to exists also in the 3D case.

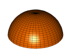
Inertia of the bubble

$U_B =$

	A≈0	A≈1
2D:	$\frac{1}{2p}\cdot\frac{l}{t}$	$\frac{1}{3p}\cdot\frac{l}{t}$
3D:	$\frac{1}{p}\cdot\frac{l}{t}$	$\frac{1}{2p}\cdot\frac{l}{t}$



Dimensional effect



Summary: Implications for Multimode Theory for the RM Instability

Alon *et. al*. (1994, 1995), D. Oron *et. al*. (1998), Shvarts *et. al*. (2000)

Two key elements govern the multimode bubble front evolution :

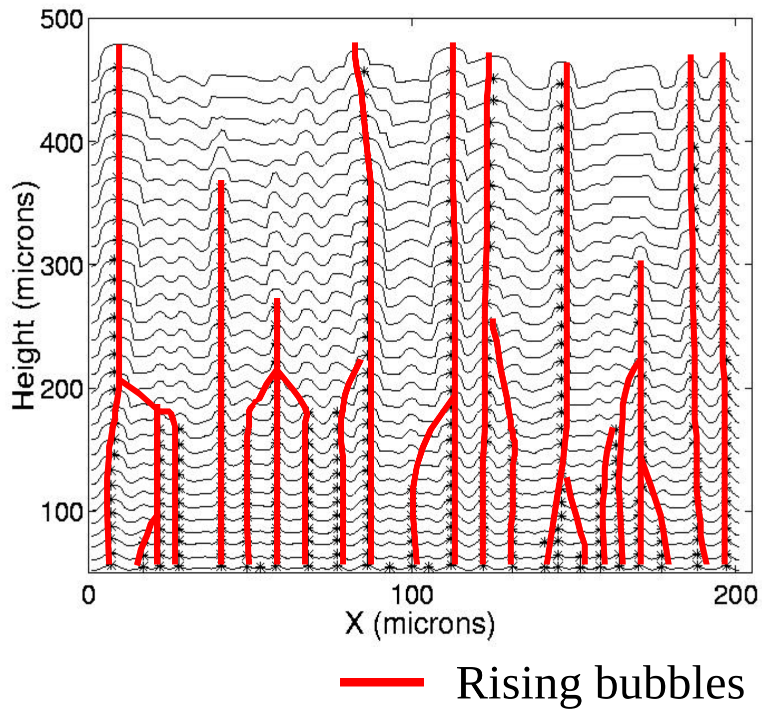
1) The asymptotic velocity of a single bubble. <= Shown as depended on **Dimensionality** and **Atwood**.
2) The merger rate between two neighboring bubbles. <= Merging was observed in **3D** as well.

$$h_B = a_0 \cdot t^{\theta_B (2D/3D, A)}$$

$$h_S = b_0 \cdot t^{\theta_s (2D/3D, A)}$$

Present work verifies the: 2D/3D and Atwood Number Dependence of Single-Mode Bubble/Spike

Bubble Envelope (Simulation)



$$q_{2D} \cong 0.4 \neq q_{3D} \cong 0.2$$