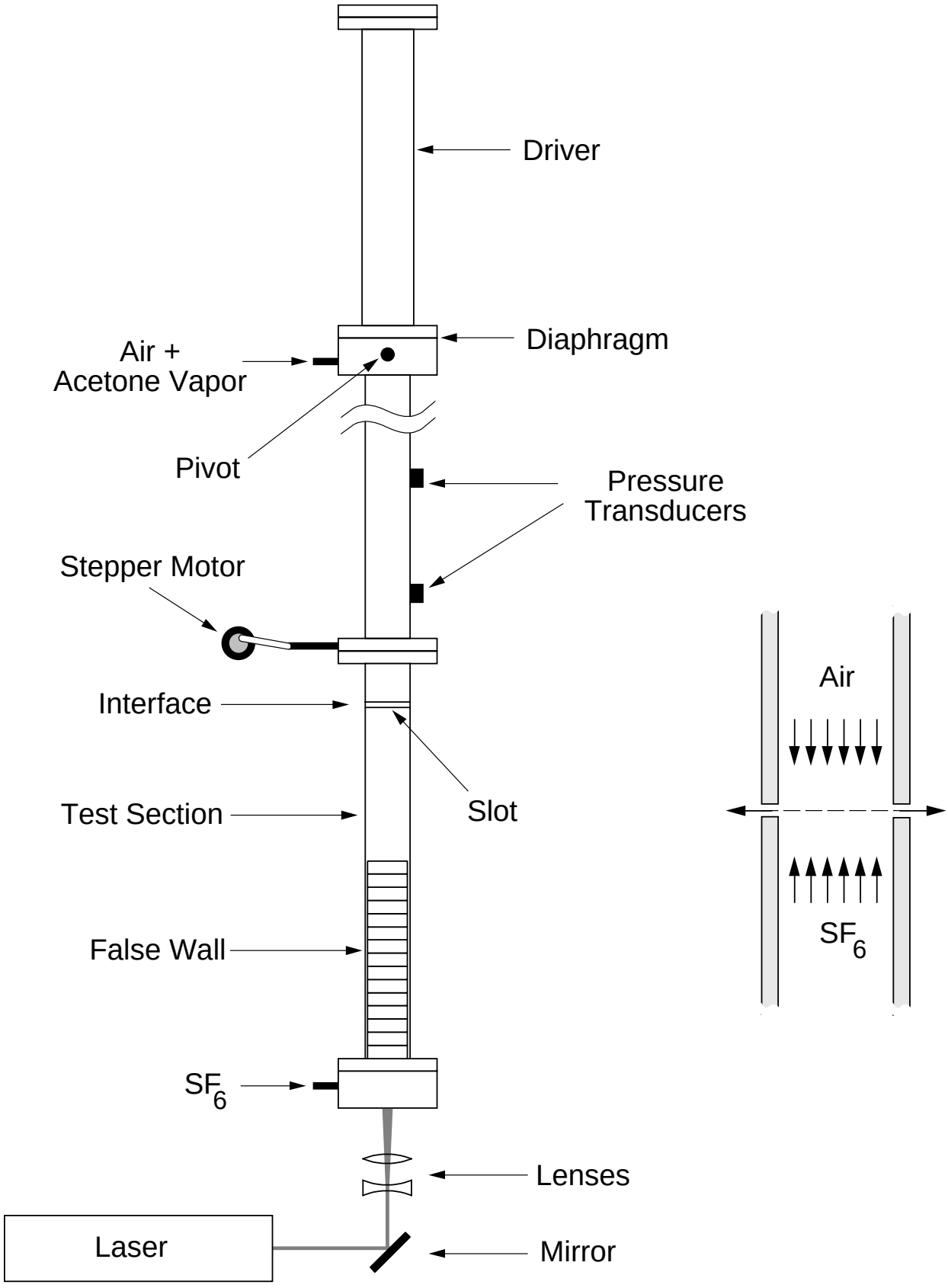
Experimental Investigation of Richtmyer-Meshkov Instability after a Second Interaction with a Reflected Shock Wave

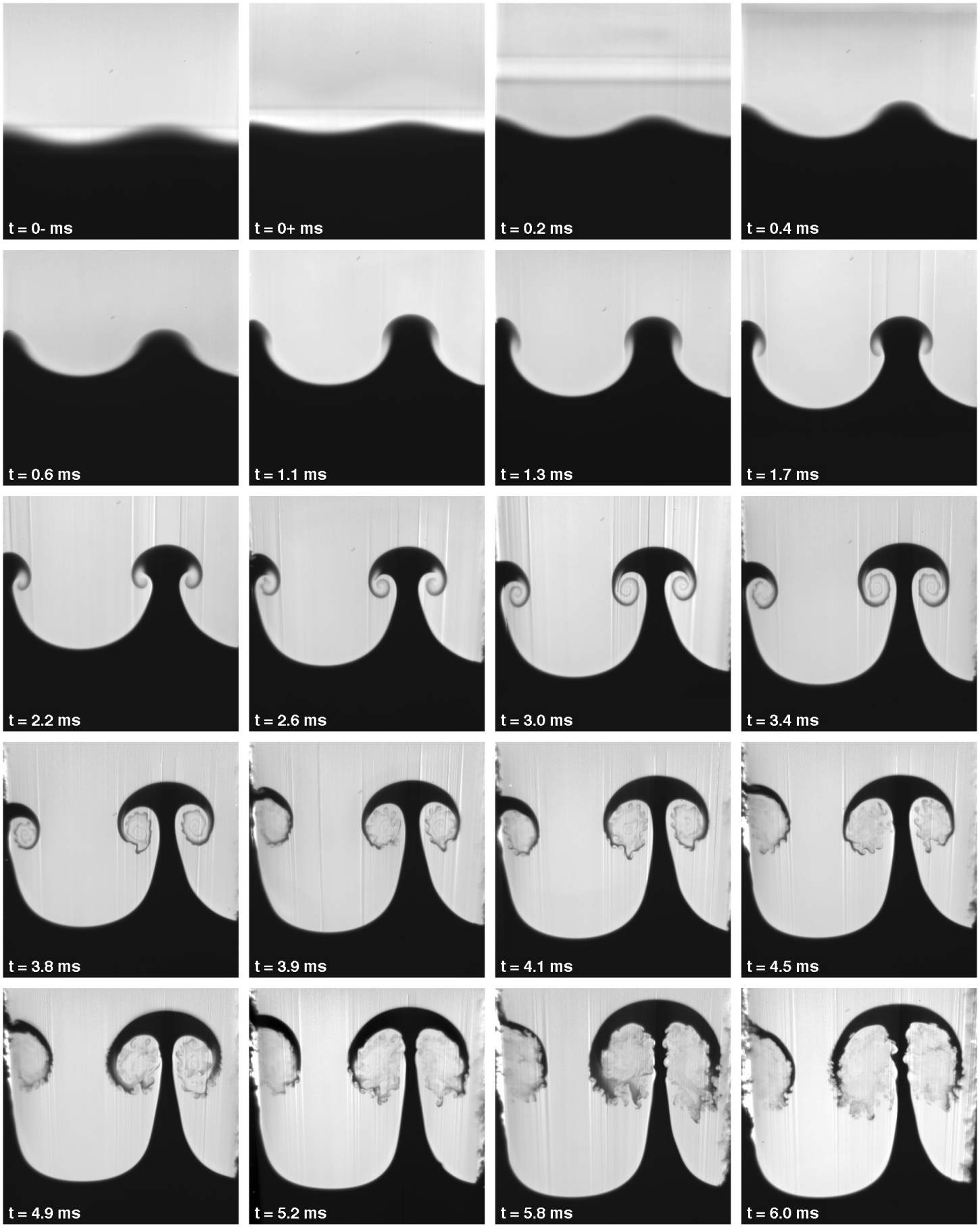
J.W. Jacobs and V.V. Krivets

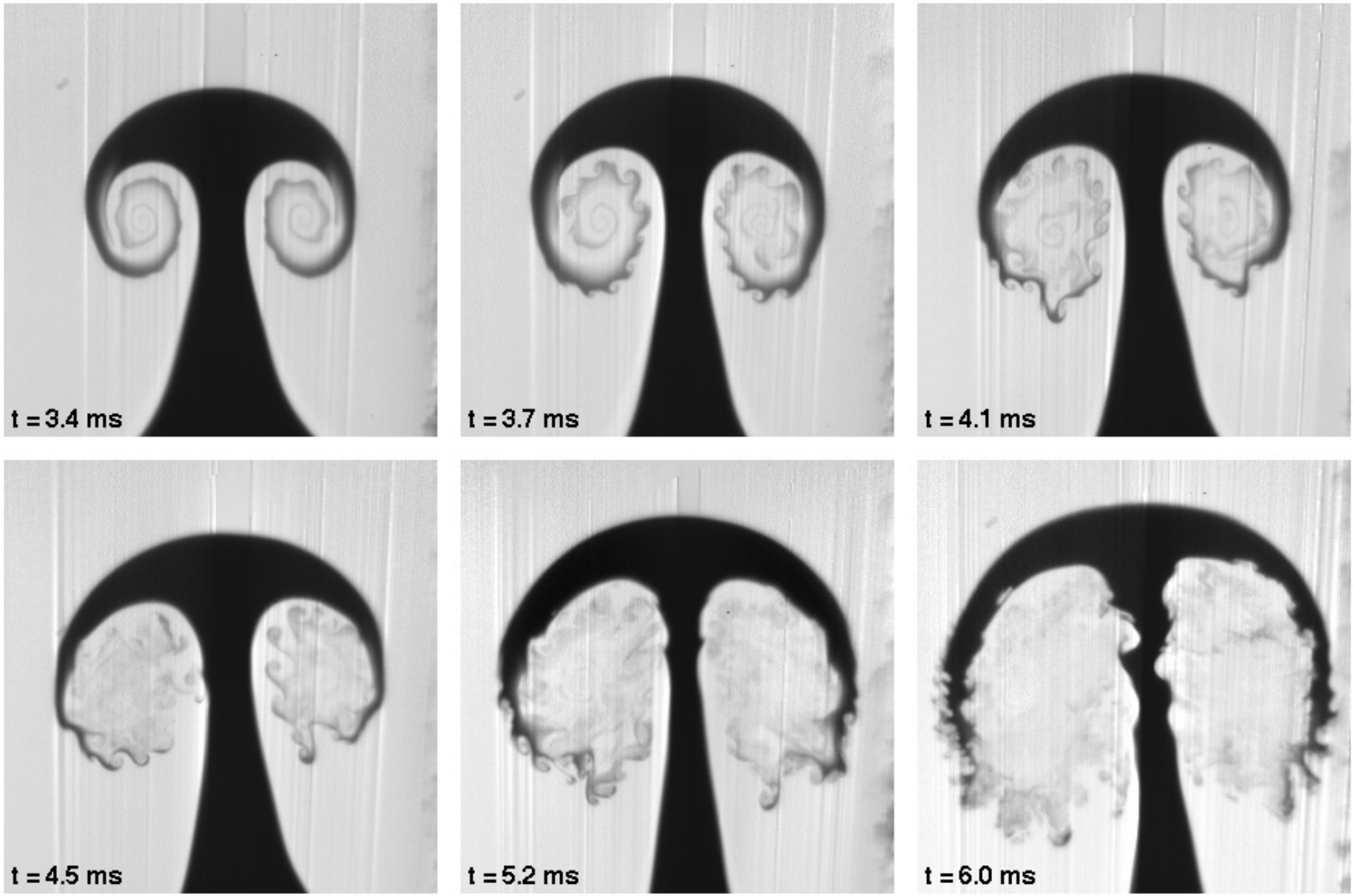
Department of Aerospace and Mechanical Engineering
University of Arizona

Supported by:

Lawrence Livermore National Laboratory


Driver
Diaphragm
Air +
Acetone Vapor
Pivot
Pressure
Transducers
Stepper Motor
Interface
Slot
Test Section
False Wall
SF6
Lenses
Laser
Mirror
Air
SF6


t = 0- ms
t = 0+ ms
t = 0.2 ms
t = 0.4 ms
t = 0.6 ms
t = 1.1 ms
t = 1.3 ms
t = 1.7 ms
t = 2.2 ms
t = 2.6 ms
t = 3.0 ms
t = 3.4 ms
t = 3.8 ms
t = 3.9 ms
t = 4.1 ms
t = 4.5 ms
t = 4.9 ms
t = 5.2 ms
t = 5.8 ms
t = 6.0 ms


t = 3.4 ms
t = 3.7 ms
t = 4.1 ms
t = 4.5 ms
t = 5.2 ms
t = 6.0 ms

Reynolds Number

$$\mathrm{Re} = \frac{U\ell}{\nu}$$

Let, $\ell \sim h = 2a$, $U \sim \frac{dh}{dt}$, $\nu =$ average viscosity

At time of transition,

$$\mathrm{Re} \sim \frac{h\dot{h}}{\nu} \approx 50{,}000$$

Alternatively let, $\mathrm{Re} = \frac{\Gamma}{\nu}$

Linear stability theory gives, $\Gamma = \frac{2}{\pi}\lambda \dot{a}_0$

Then,

$$\mathrm{Re} = \frac{2}{\pi}\frac{\lambda \dot{a}_0}{\nu} \approx 42{,}000$$

Nonlinear Models

Zhang & Sohn (1997)

$$v_{b/s} = \frac{v_0}{1 + v_0 a_0 k^2 t + \max\left[0,\ a_0^2 k^2 - A^2 + \frac{1}{2}\right] v_0^2 k^2 t^2} \mp \frac{A v_0^2 k t}{1 + 2k^2 a_0 v_0 t + 4k^2 v_0^2 \left[a_0^2 k^2 + \frac{1}{3}(1 - A^2)\right] t^2}$$

when $A^2 \le \frac{1}{2} + a_0^2 k^2$

$$v = \tfrac{1}{2}(v_b + v_s) \to \frac{v_0}{\left[a_0^2 k^2 - A^2 + \frac{1}{2}\right] v_0^2 k^2 t^2} \quad \frac{1}{t^2} \quad \text{as} \quad t \to \infty$$

Sadot el al. (1998)

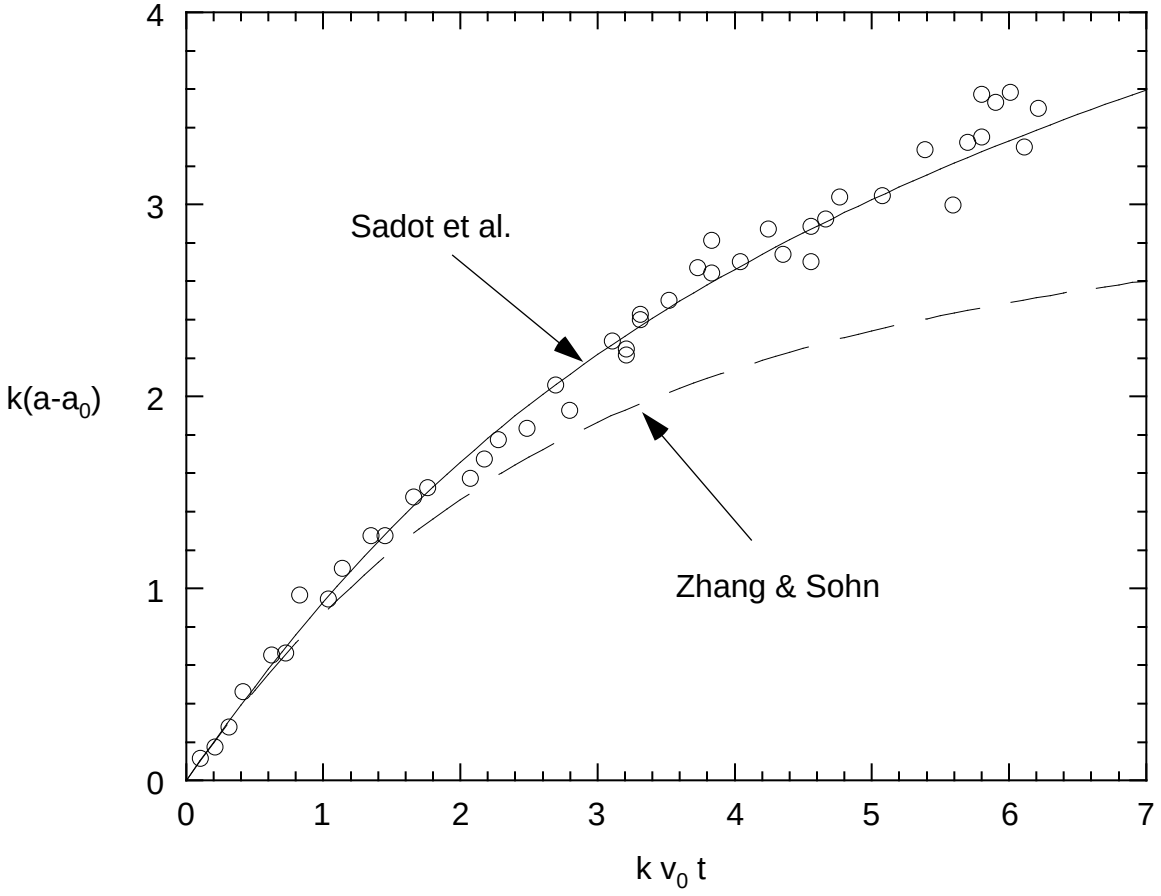
$$v_{b/s} = \frac{v_0 (1 + v_0 k t)}{1 + (1 \pm A) v_0 k t + \left[\frac{1 \pm A}{1 + A}\right] \frac{1}{2\pi C} v_0^2 k^2 t^2}$$

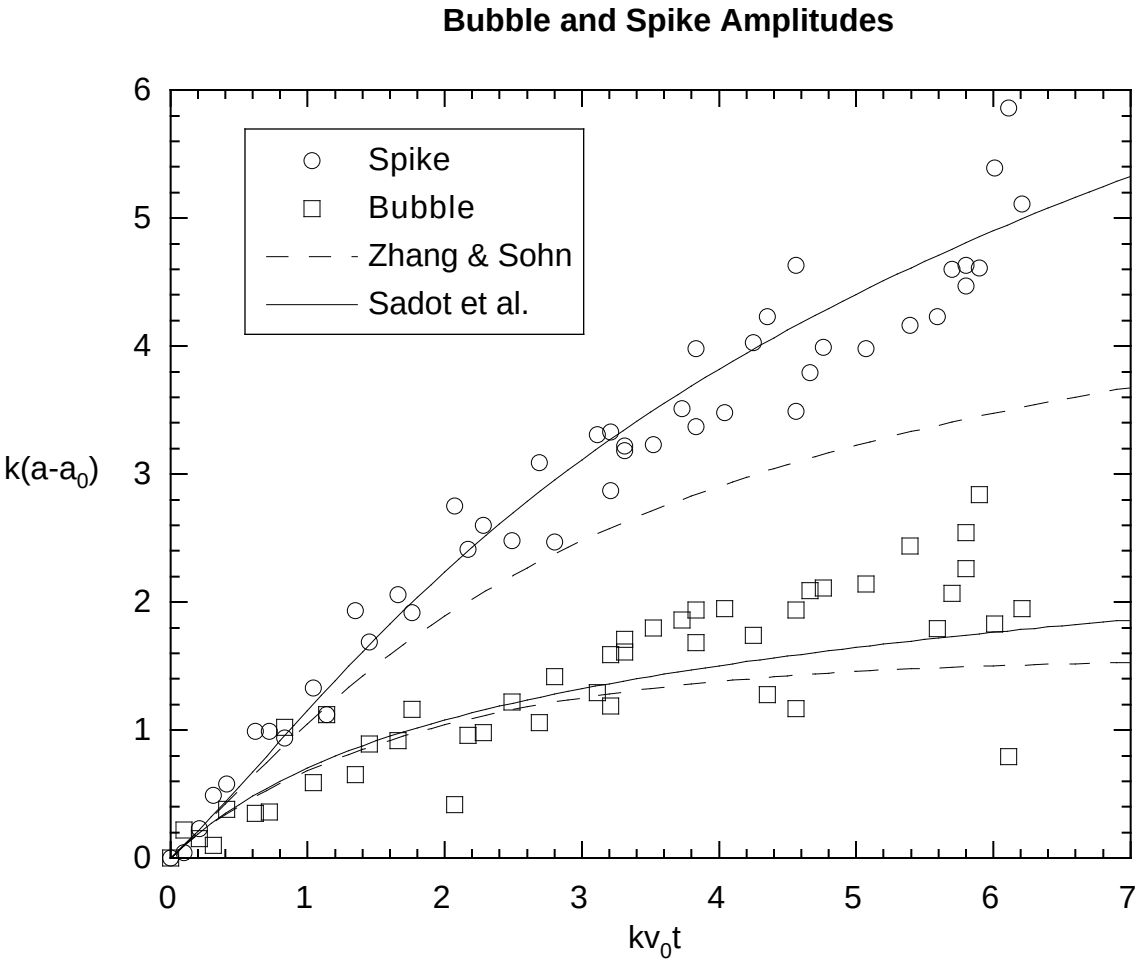
where

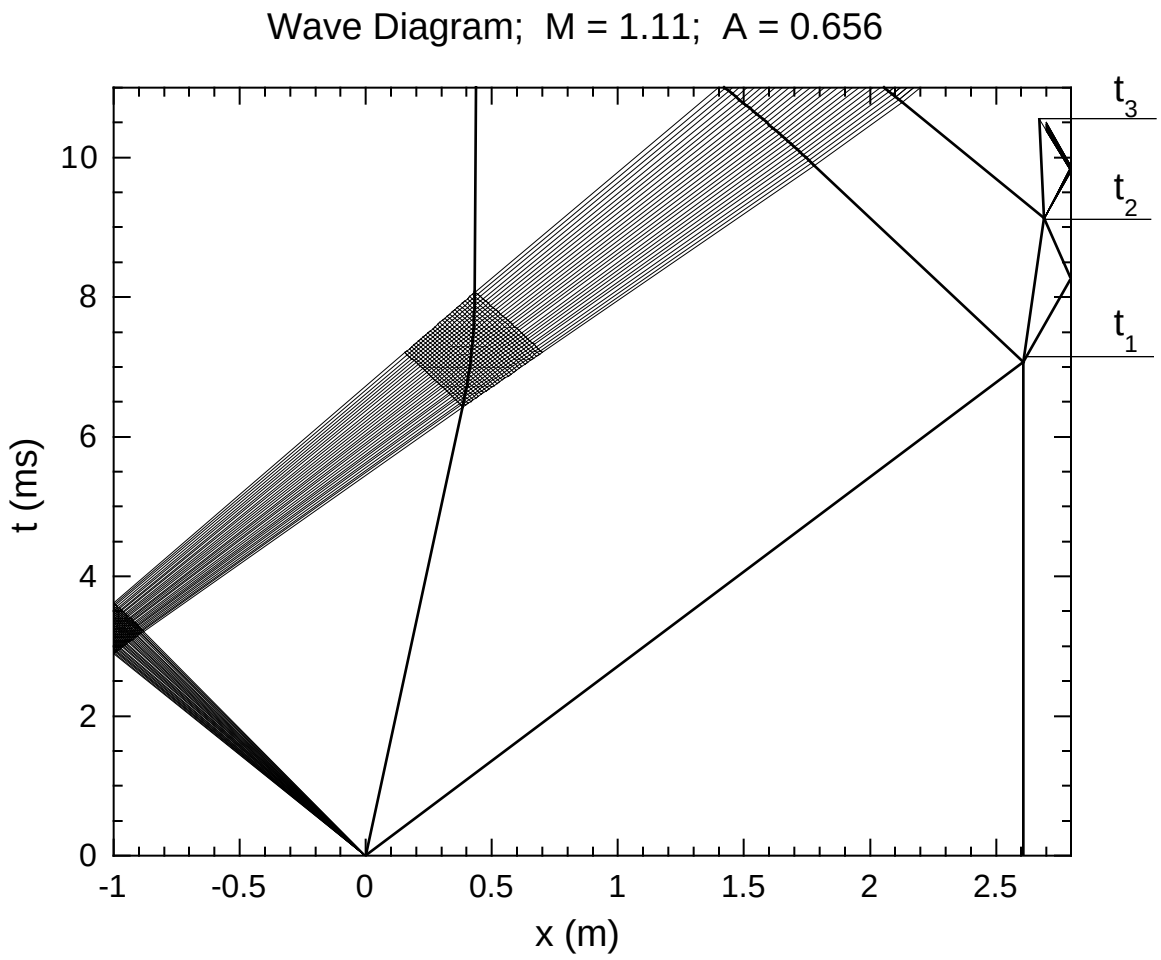
$$C = \begin{cases} 1/3\pi & A \ge 0.5 \\ 1/2\pi & A \to 0 \end{cases}$$

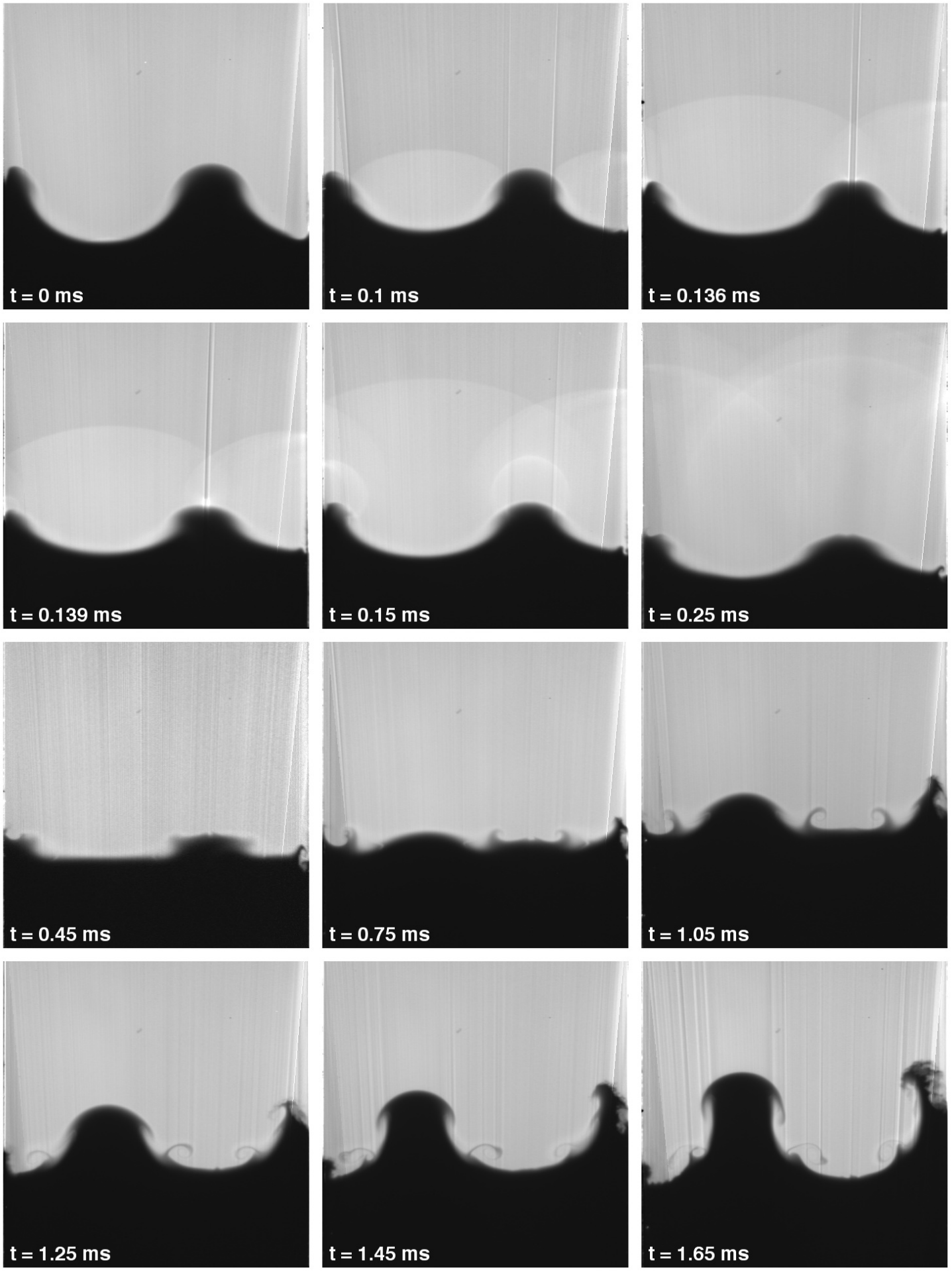
$$v \to \left(\frac{1}{1 - A}\right) \frac{C\lambda}{t} \quad \frac{1}{t} \quad \text{as} \quad t \to \infty$$

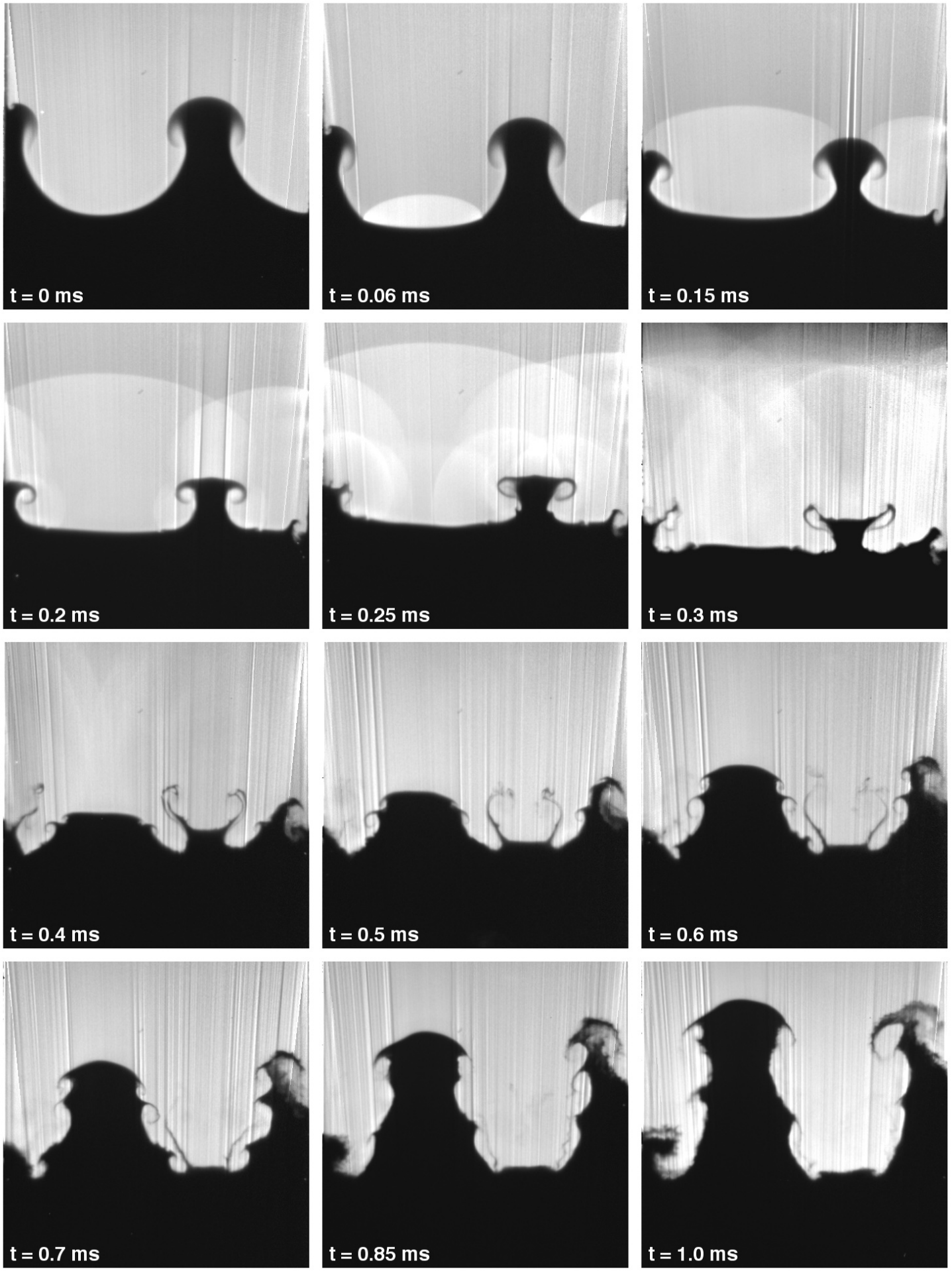
Late Time Growth

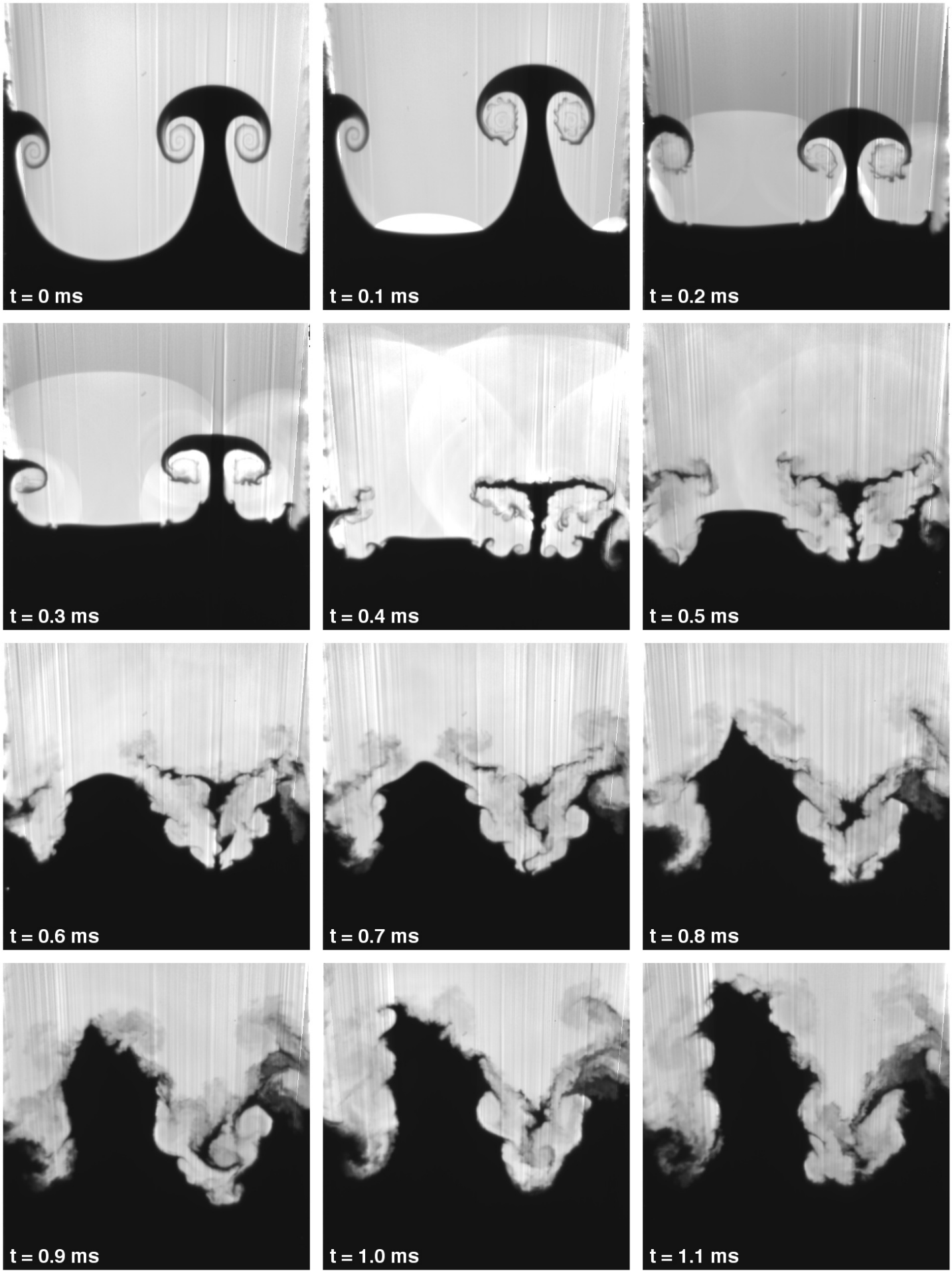


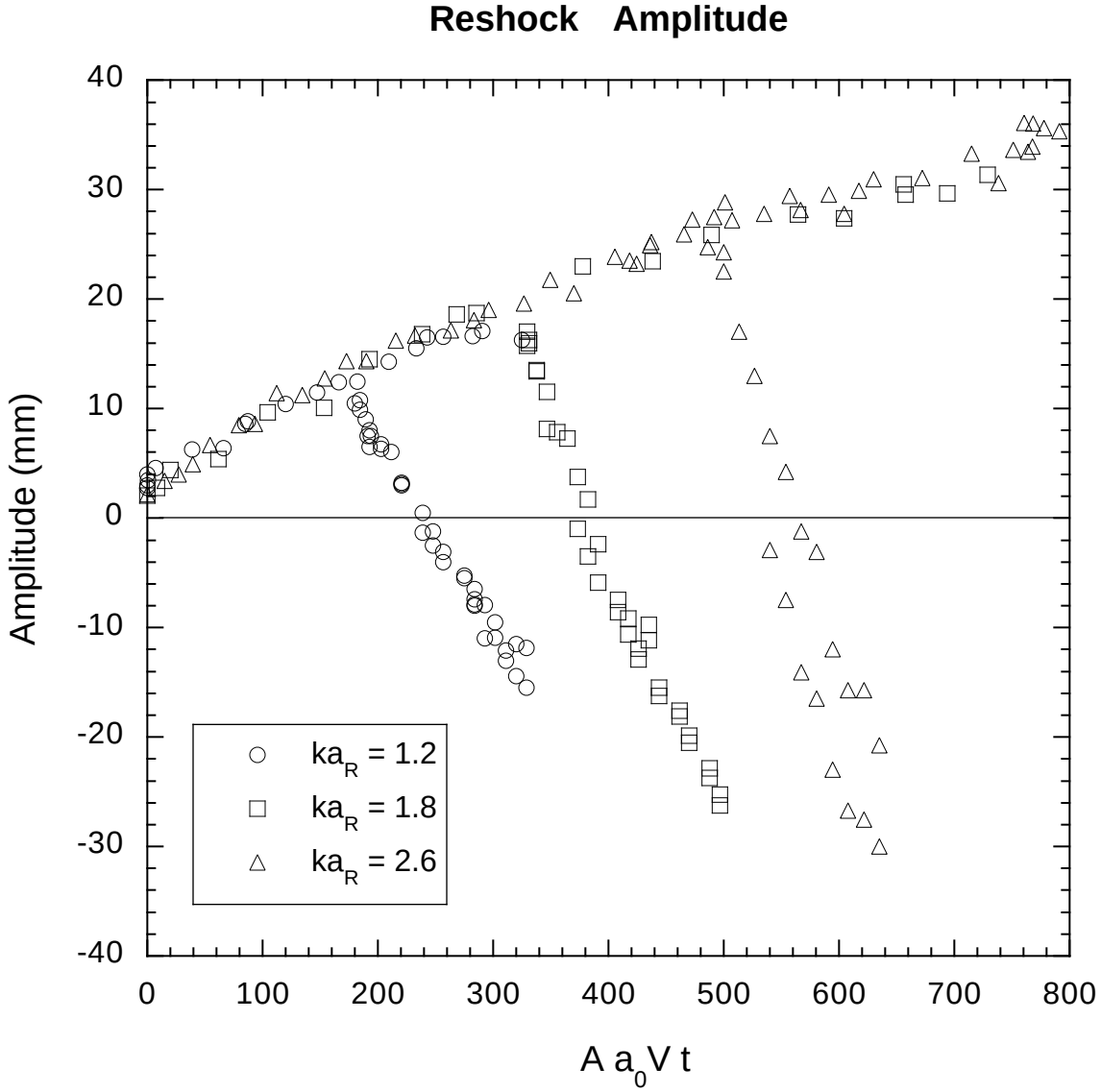

Bubble and Spike Amplitudes
Spike
Bubble
Zhang & Sohn
Sadot et al.
k(a-a0)
kv0t
0
1
2
3
4
5
6
7

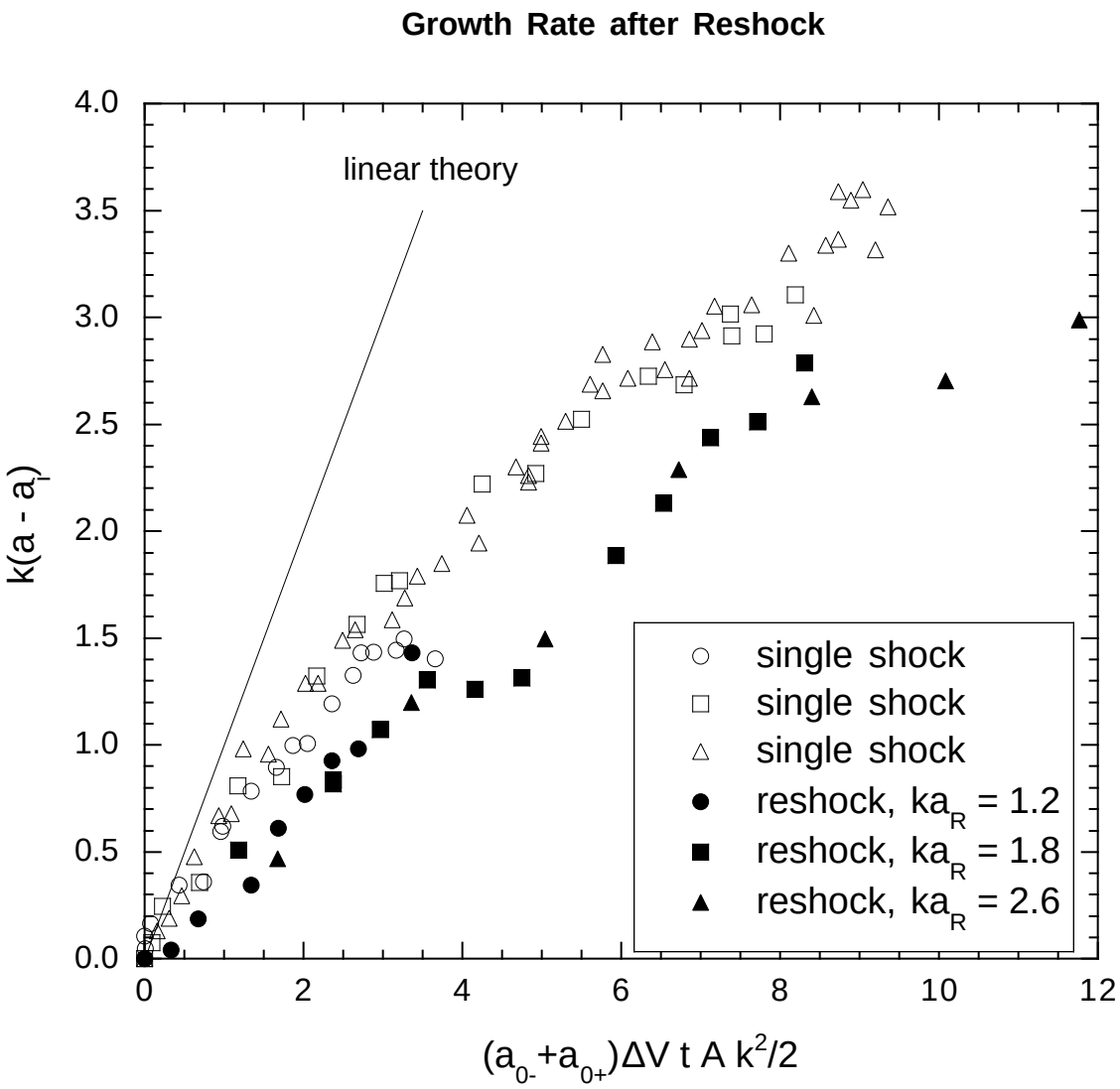

Wave Diagram; M = 1.11; A = 0.656
t (ms)
x (m)
0
2
4
6
8
10
-1
-0.5
0
0.5
1
1.5
2
2.5
t3
t2
t1

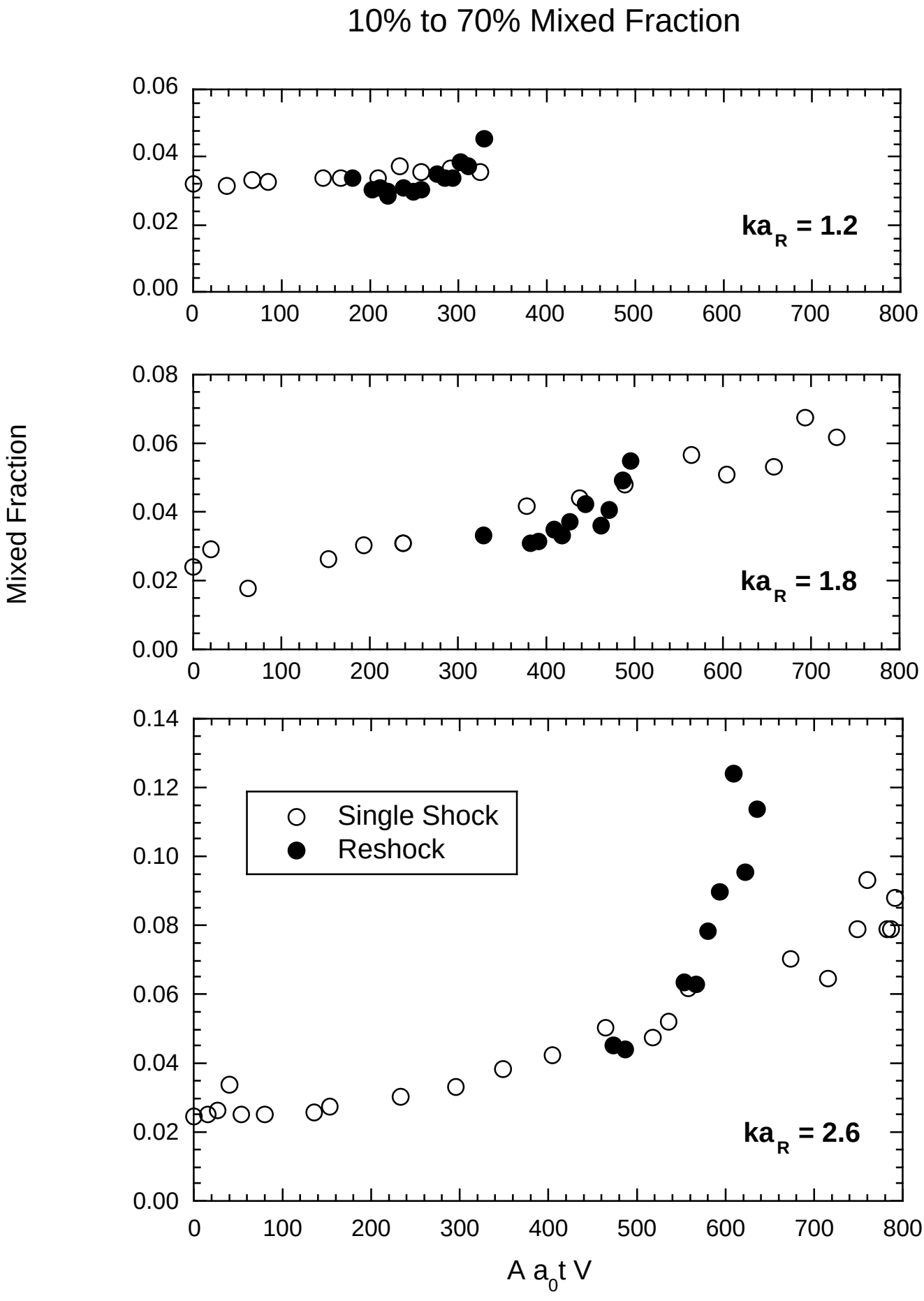

t = 0 ms
t = 0.1 ms
t = 0.136 ms
t = 0.139 ms
t = 0.15 ms
t = 0.25 ms
t = 0.45 ms
t = 0.75 ms
t = 1.05 ms
t = 1.25 ms
t = 1.45 ms
t = 1.65 ms


t = 0 ms
t = 0.06 ms
t = 0.15 ms
t = 0.2 ms
t = 0.25 ms
t = 0.3 ms
t = 0.4 ms
t = 0.5 ms
t = 0.6 ms
t = 0.7 ms
t = 0.85 ms
t = 1.0 ms


t = 0 ms
t = 0.1 ms
t = 0.2 ms
t = 0.3 ms
t = 0.4 ms
t = 0.5 ms
t = 0.6 ms
t = 0.7 ms
t = 0.8 ms
t = 0.9 ms
t = 1.0 ms
t = 1.1 ms


Reshock Amplitude
Amplitude (mm)
40
30
20
10
0
-10
-20
-30
-40
0
100
200
300
400
500
600
700
800
A a0 V t
kaR = 1.2
kaR = 1.8
kaR = 2.6


Growth Rate after Reshock
linear theory
single shock
single shock
single shock
reshock, ka$_R$ = 1.2
reshock, ka$_R$ = 1.8
reshock, ka$_R$ = 2.6
k(a - a$_i$)
(a$_{0-}$+a$_{0+}$)ΔV t A k^2/2
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
0
2
4
6
8
10
12


10% to 70% Mixed Fraction
Mixed Fraction
0.06
0.04
0.02
0.00
0
100
200
300
400
500
600
700
800
ka$_R$ = 1.2
0.08
0.06
0.04
0.02
0.00
ka$_R$ = 1.8
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
Single Shock
Reshock
ka$_R$ = 2.6
A a$_0$ t V

Conclusions

- Single-mode RM experiments show a transition to turbulence in the vortex cores at Re ≈ 50,000.
- Late-time amplitude measurements show excellent agreement with the model of Sadot et al. (1998).
- Penetration depth measurements for the three reshock conditions collapse when plotted in dimensionless form and have a growth rate approximately 1/3 that given by linear stability theory.
- Reshock at early stages of the instability show similar evolution to that of single interaction with little increase in the mixing rate.
- Reshock at late stages of the instability produces a complex interface pattern and a significant increase in the mixing rate.