Path and wake of a deformable bubble rising close to a vertical wall

Pengyu Shi[1], Jie Zhang[2], Jacques Magnaudet[1]

1: Institut de Mécanique des Fluides de Toulouse (IMFT), Toulouse, France
2: Xi'an Jiaotong University, Xi'an, PR China

Motivation

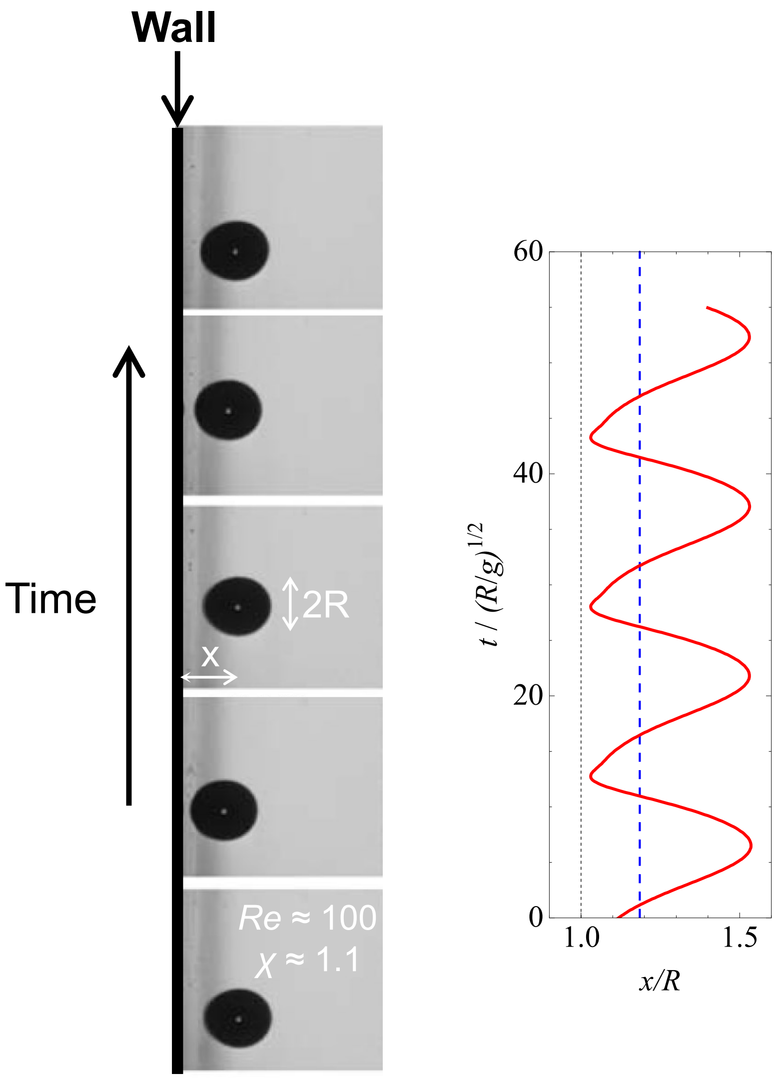
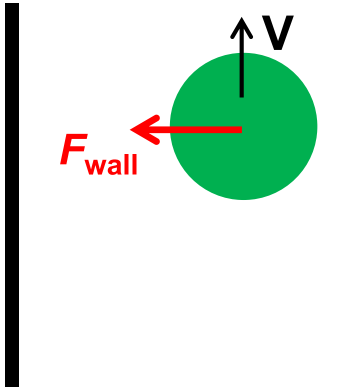
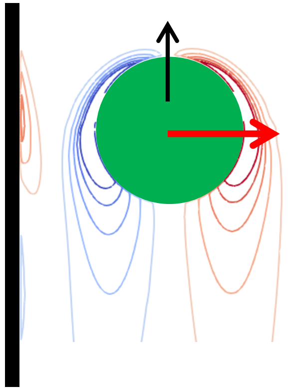


Figure reproduced from Takemura & Magnaudet (2003, JFM)

Large wall distance:
(Van Wijngaarden 1976, JFM)



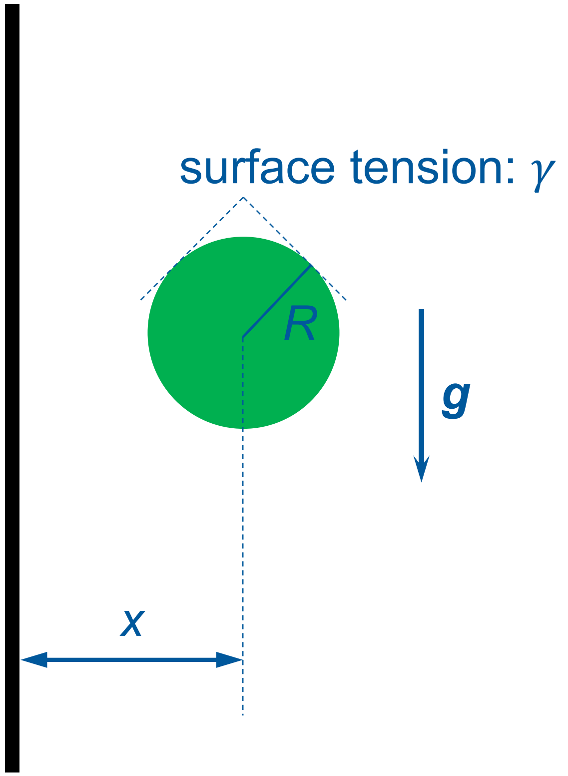
Small wall distance:
(Magnaudet et al. 2003, JFM)



This suggests the existence of an *equilibrium wall-normal distance*,
But in real life bubble keeps bouncing…

Aim of our work:
to understand the mechanism responsible for near-wall bouncing, based CFD results of 3D fully-resolved simulations

Statement of the problem

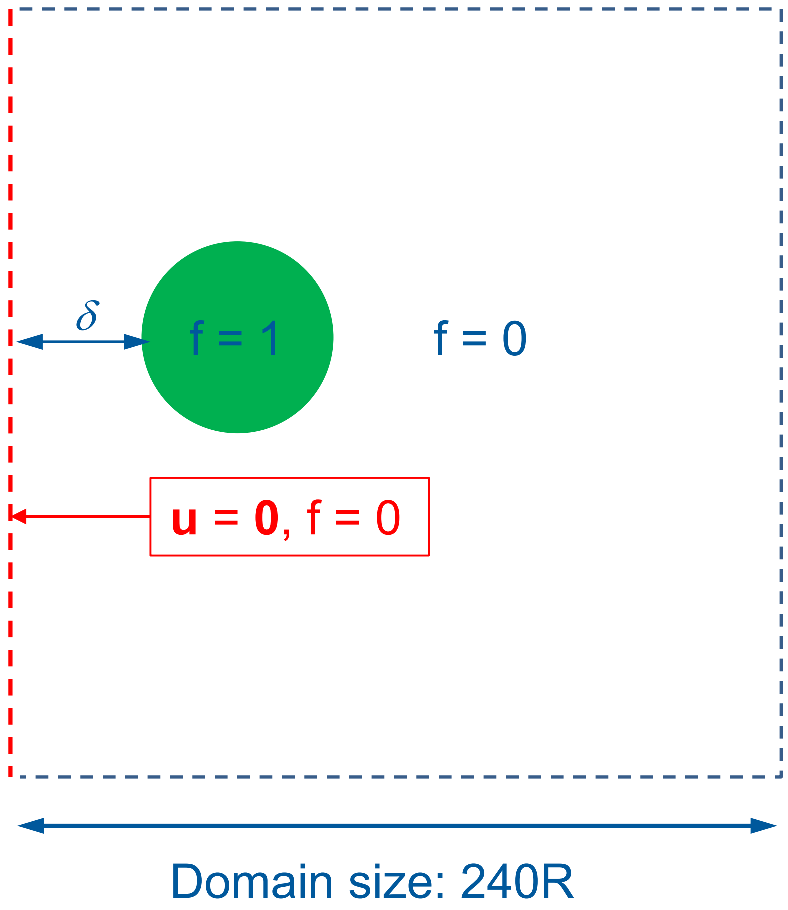


$$Ga = \frac{R\sqrt{Rg}}{\nu} \qquad Bo = \frac{\rho g R^2}{\gamma} \qquad \overline{x_0} = \frac{x_0}{R}$$

$$\rho_g/\rho = 10^{-3}, \qquad \mu_g/\mu = 10^{-2}$$

In the computations discussed later, $\overline{x_0} = 2$

Numerical approach



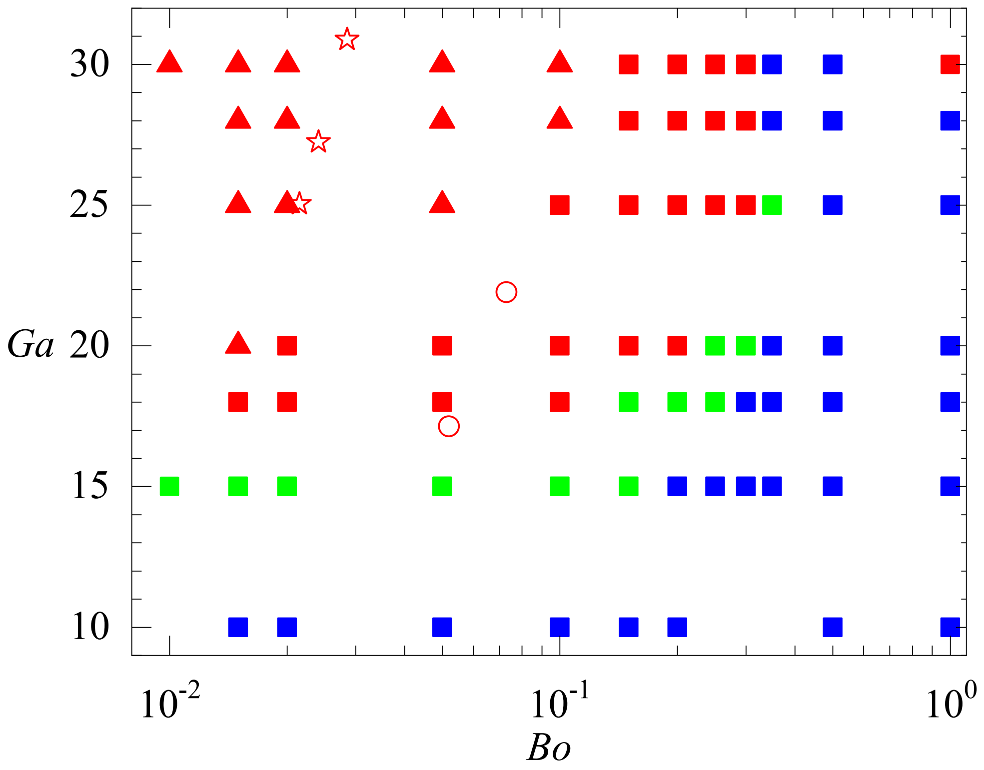
***Basilisk* code** (Popinet 2009, 2015)

- Gas-liquid interface tracked by VOF approach
- Adaptive mesh refinement:
  - Refinement based on f & **u**, $\xi_f = 10^{-3}$, $\xi_u = 10^{-2}$
  - Grid size: $\Delta_{max} \approx 2R$

    $\Delta_{min} = 1/68R$ if $\delta > 0.1R$

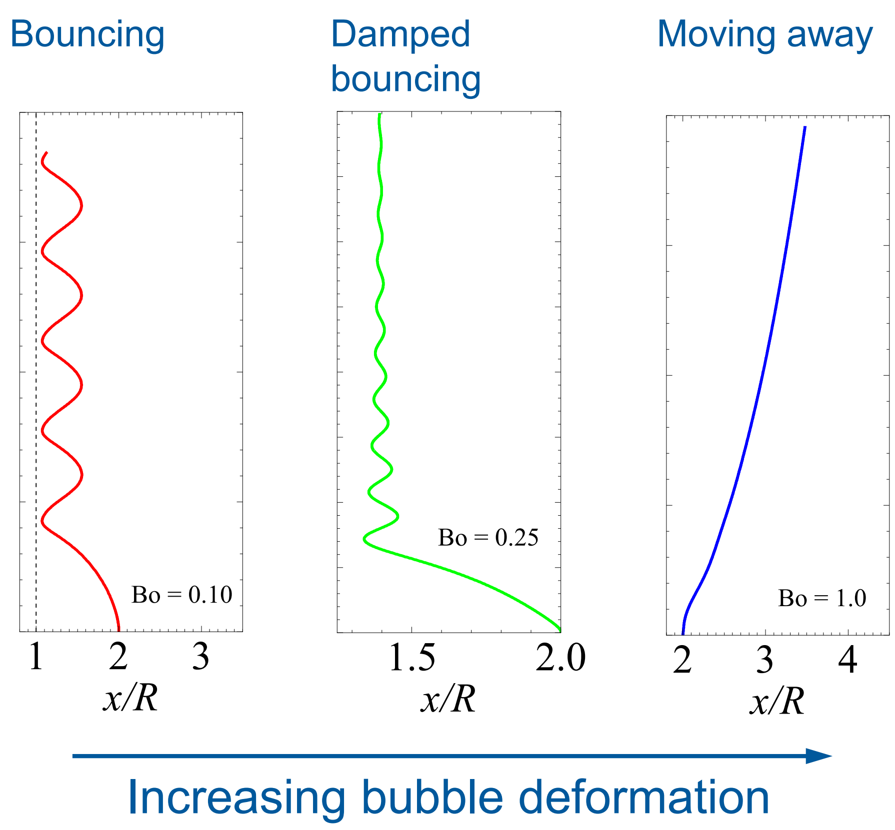
    $1/136R$ if $\delta \leq 0.1R$

Bubble trajectories

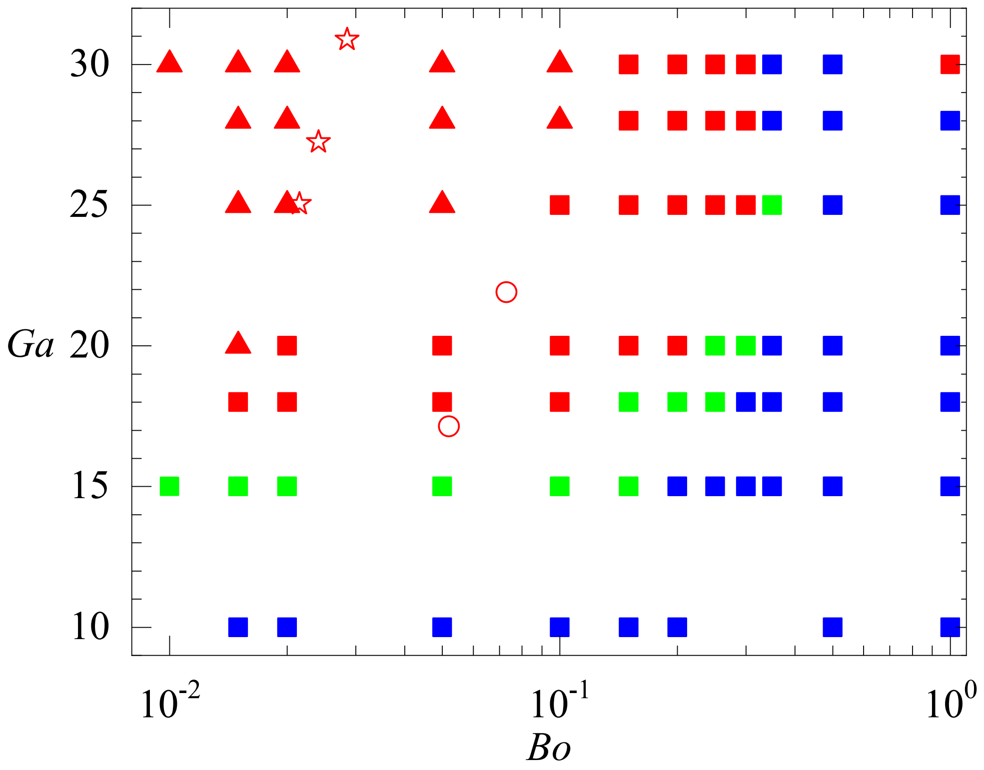


Solid symbols: data from present work
○ : Takemura & Magnaudet (2003)
☆ : de Vries (2001, phd dissertation)

Some trajectories at Ga = 20



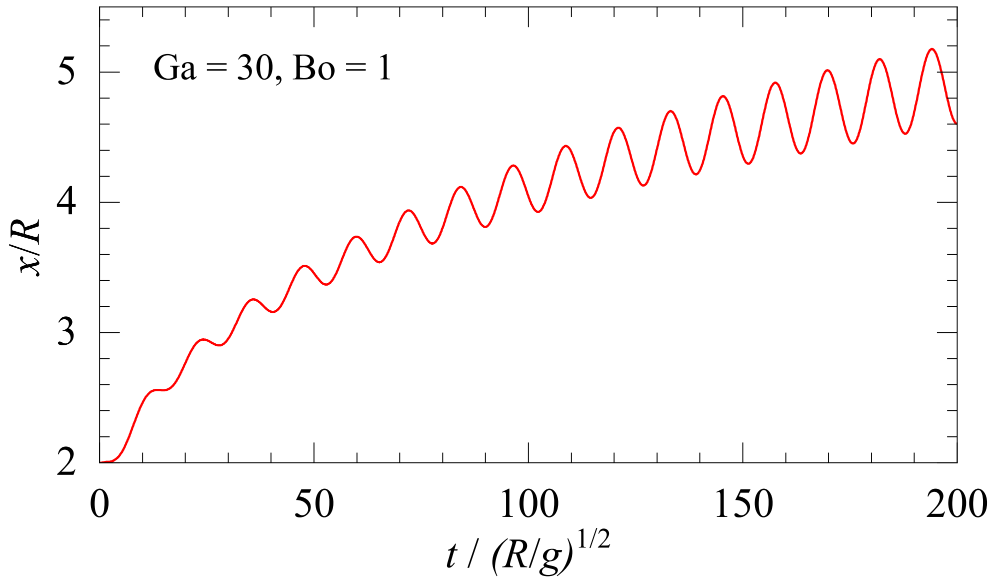
Why do bubbles bounce at low-to-moderate Bo?



Solid symbols: data from present work
○: Takemura & Magnaudet (2003)
☆: de Vries (2001, phd dissertation)

In unbounded flow, path instability is usually triggered by wake instability

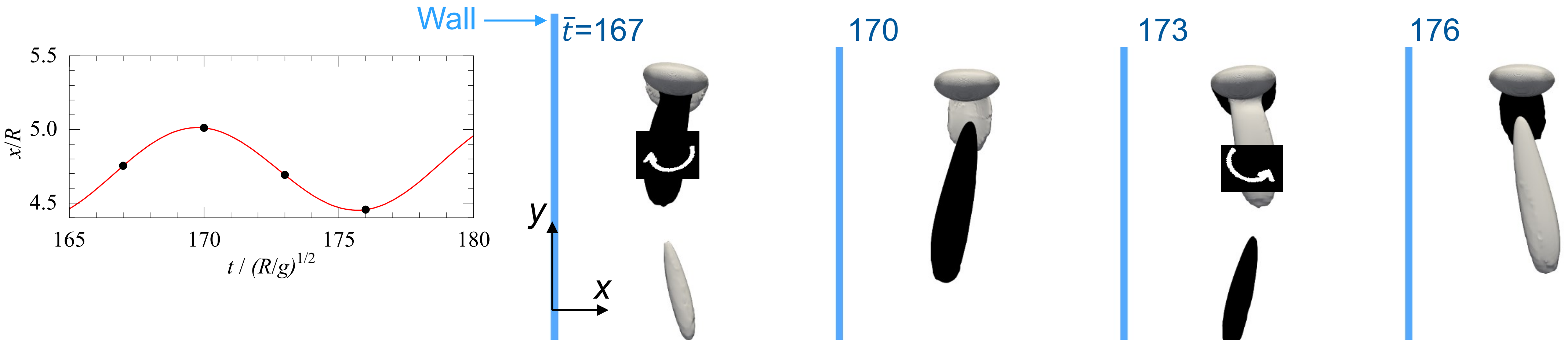
This is the case for, e.g., Ga = 30, Bo = 1



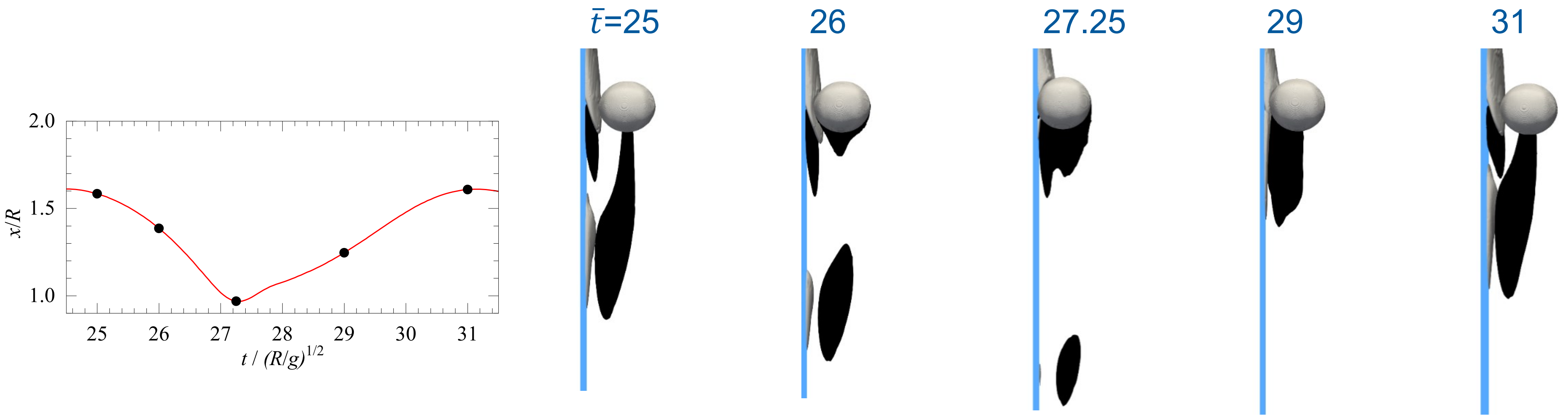
Wall specifies the symmetric plane, but has nothing to do with the bouncing

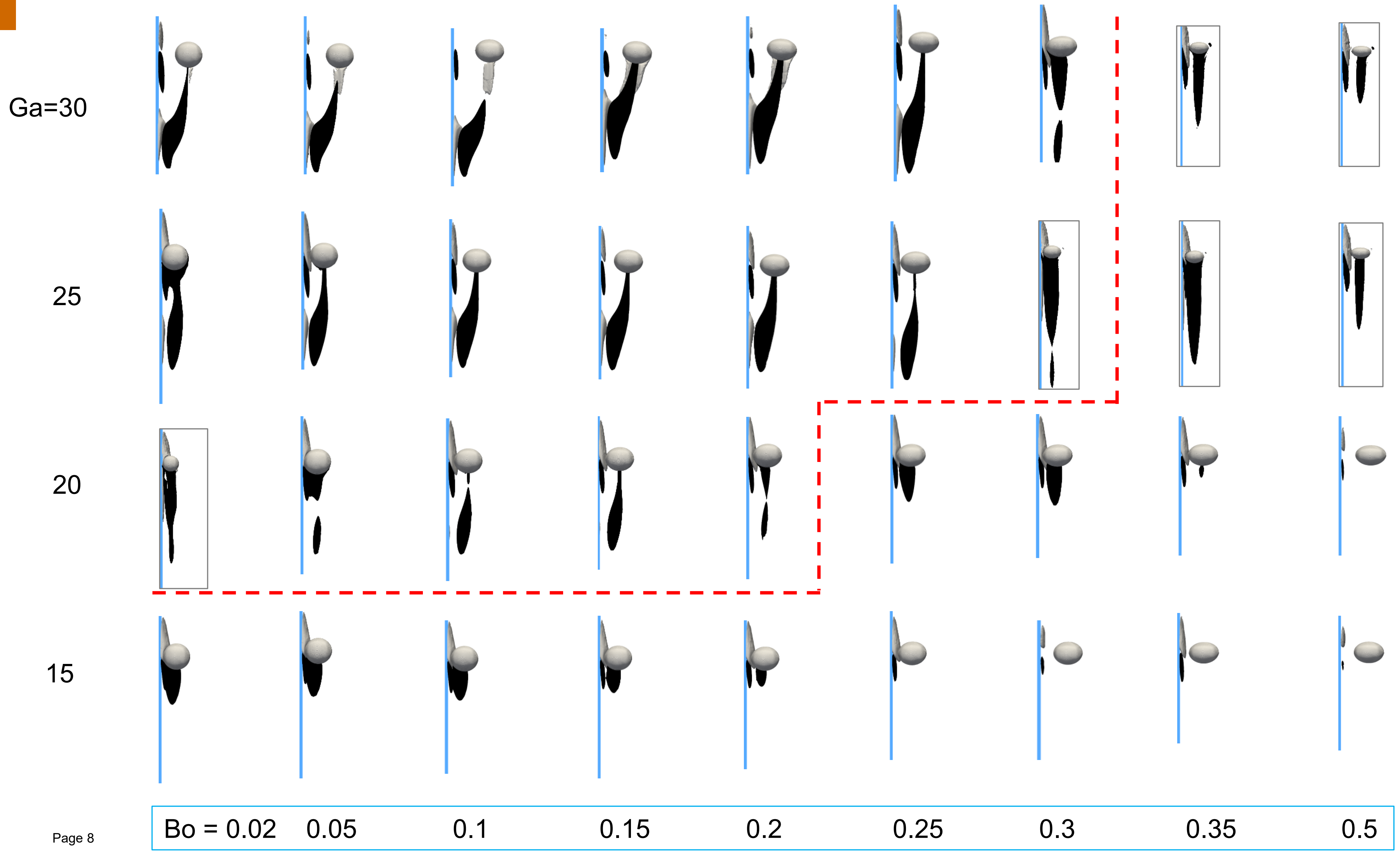
Isosurface of streamwise vorticity in the half space z < 0

Ga = 30,
Bo = 1



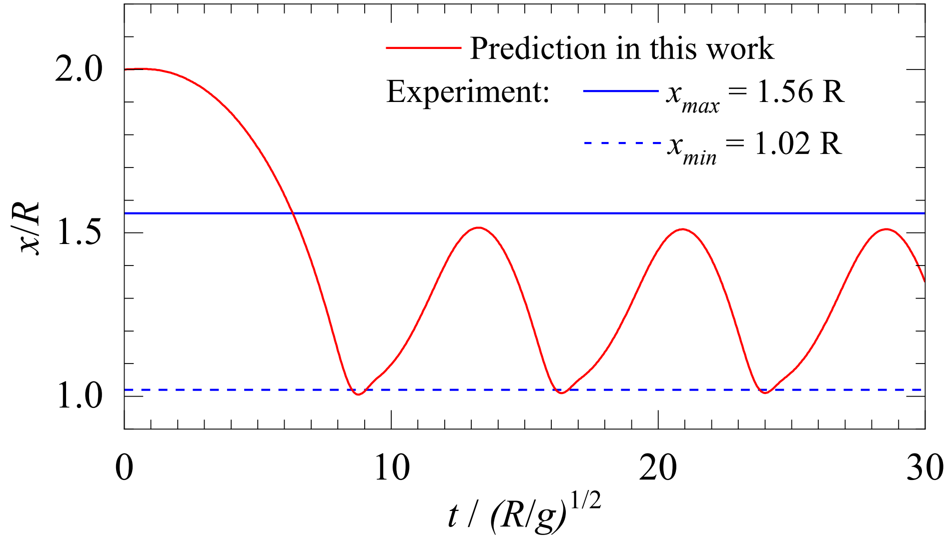
Ga = 25,
Bo = 0.05




Ga=30
25
20
15
Bo = 0.02
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.5

Mismatch with Experiment

Case details: Ga = 21.9, Bo = 0.073 (Takemura and Magnaudet 2003)
Numerical settings: Δ_{min} = 68/R, ξ_u = 0.01, T_ε = 1e-4, *CFL* = 0.5

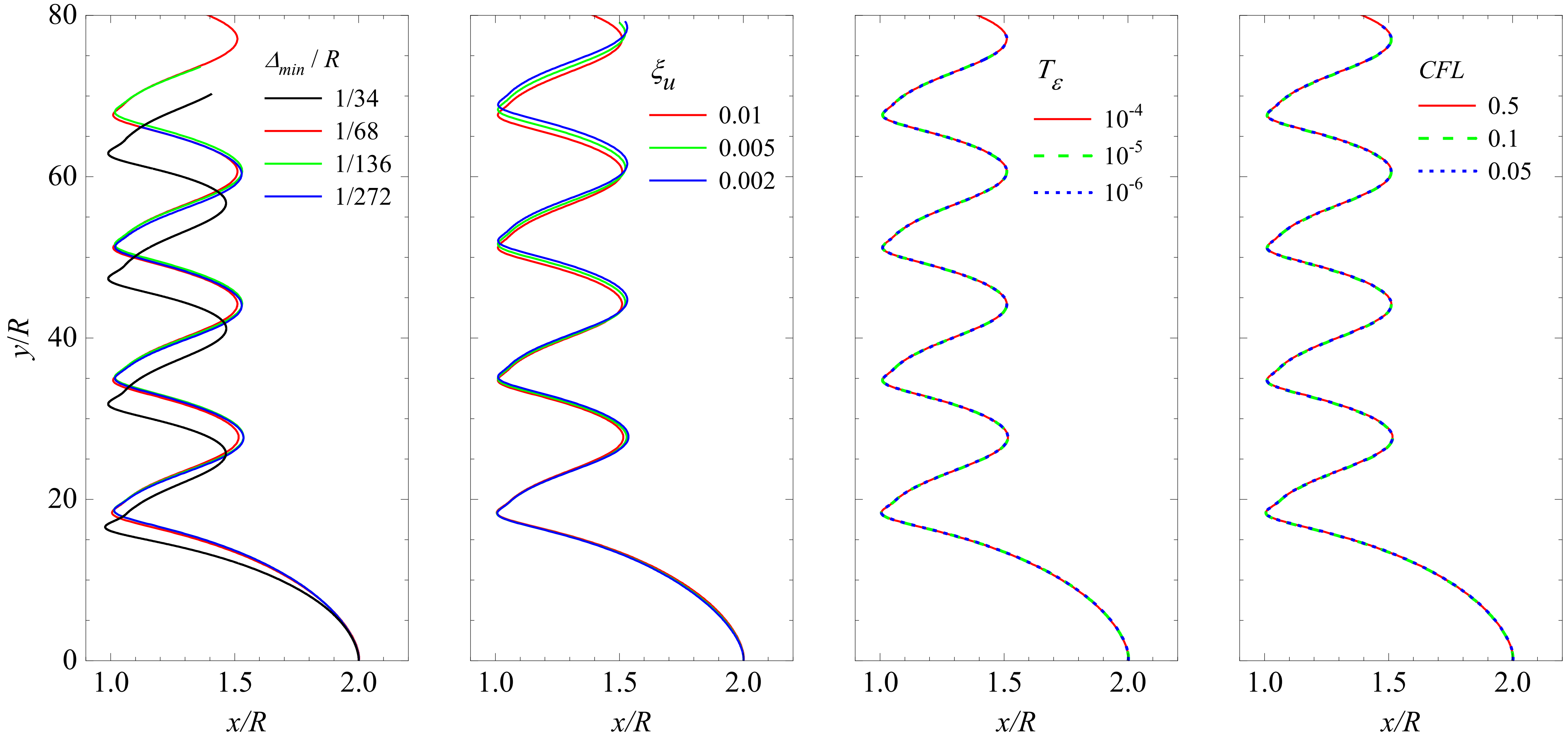


Bouncing motion: $x(t) = R[\varepsilon_0 + \varepsilon \sin(\omega t)]$

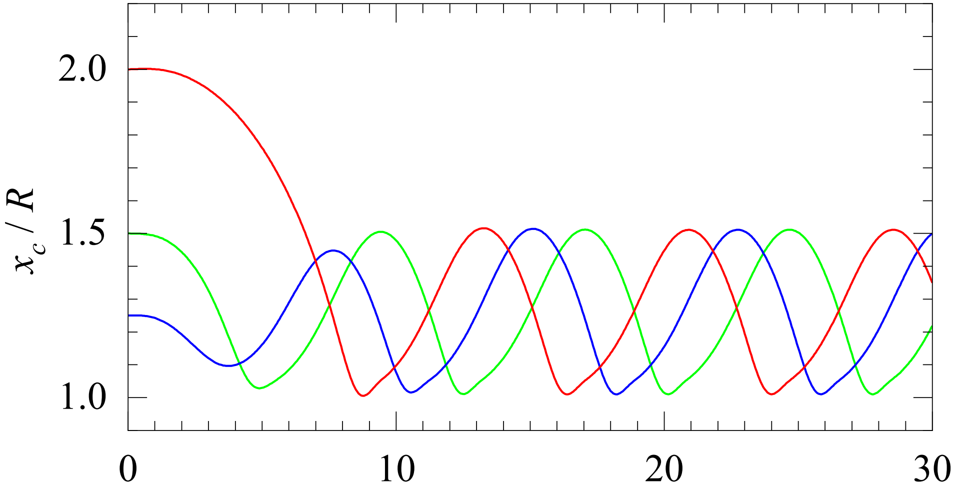
Experiment: ε_0 = 1.29, ε = 0.256, $\omega R^2/\nu$ = 8.3
Simulation: ε_0 = 1.26, ε = 0.253, $\omega R^2/\nu = 2\pi/T$ Ga = **18.0!**

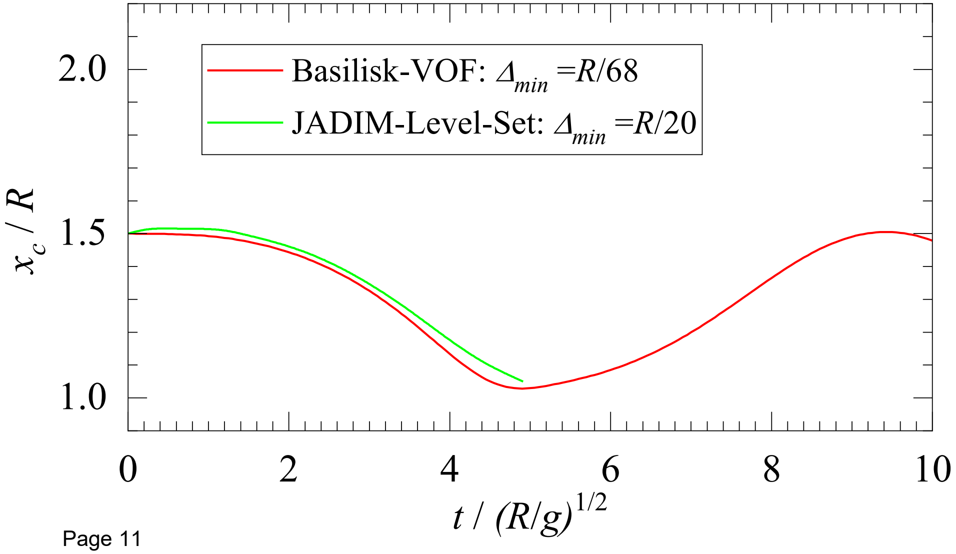
Numerical parameters?

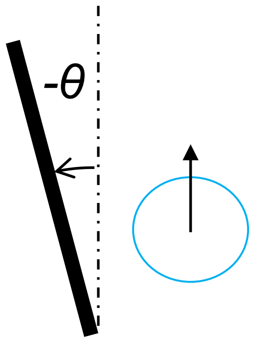
Reference case: Δ_{min} = 68/R, ξ_u = 0.01, T_ε = 1e-4, *CFL* = 0.5

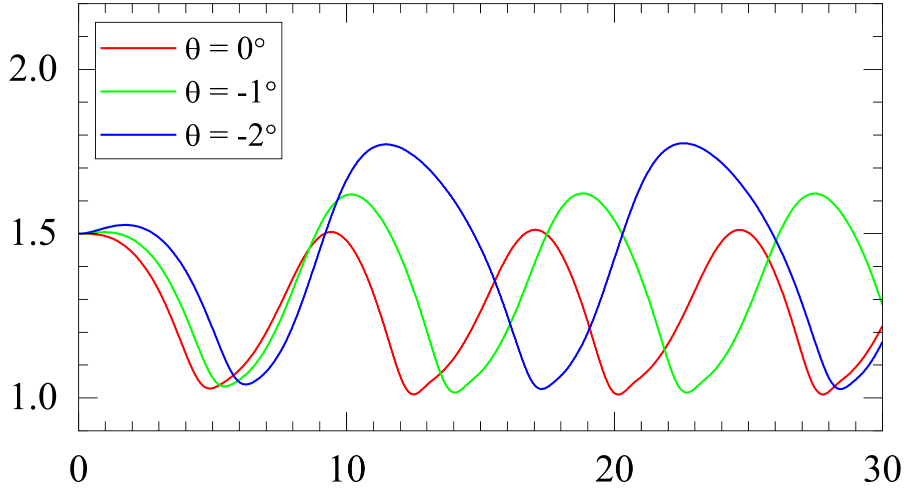


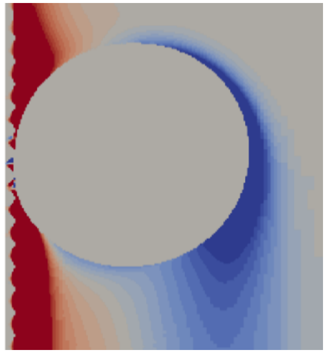
Other parameters?

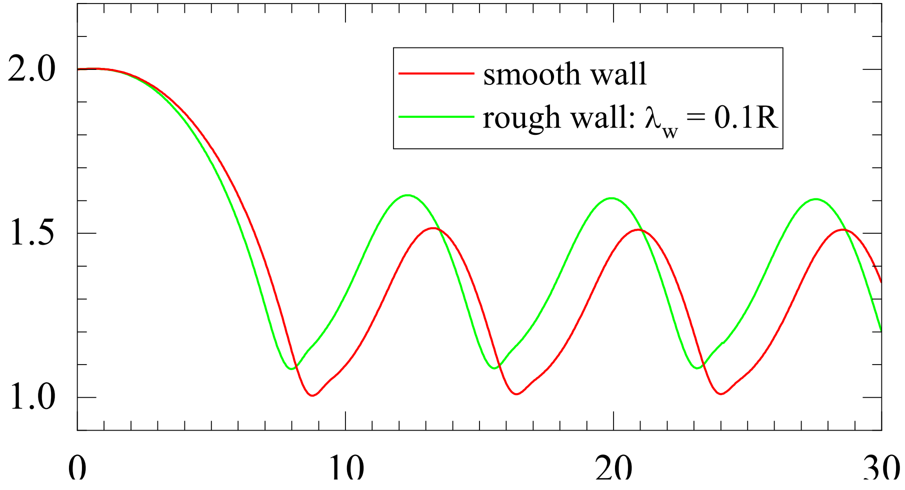










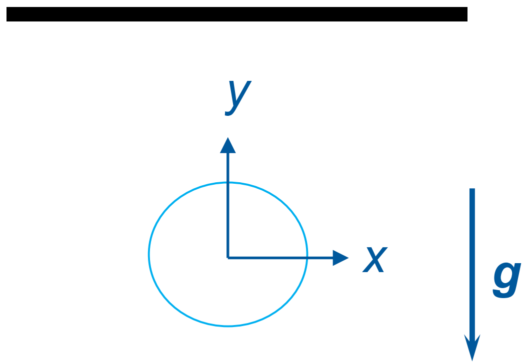


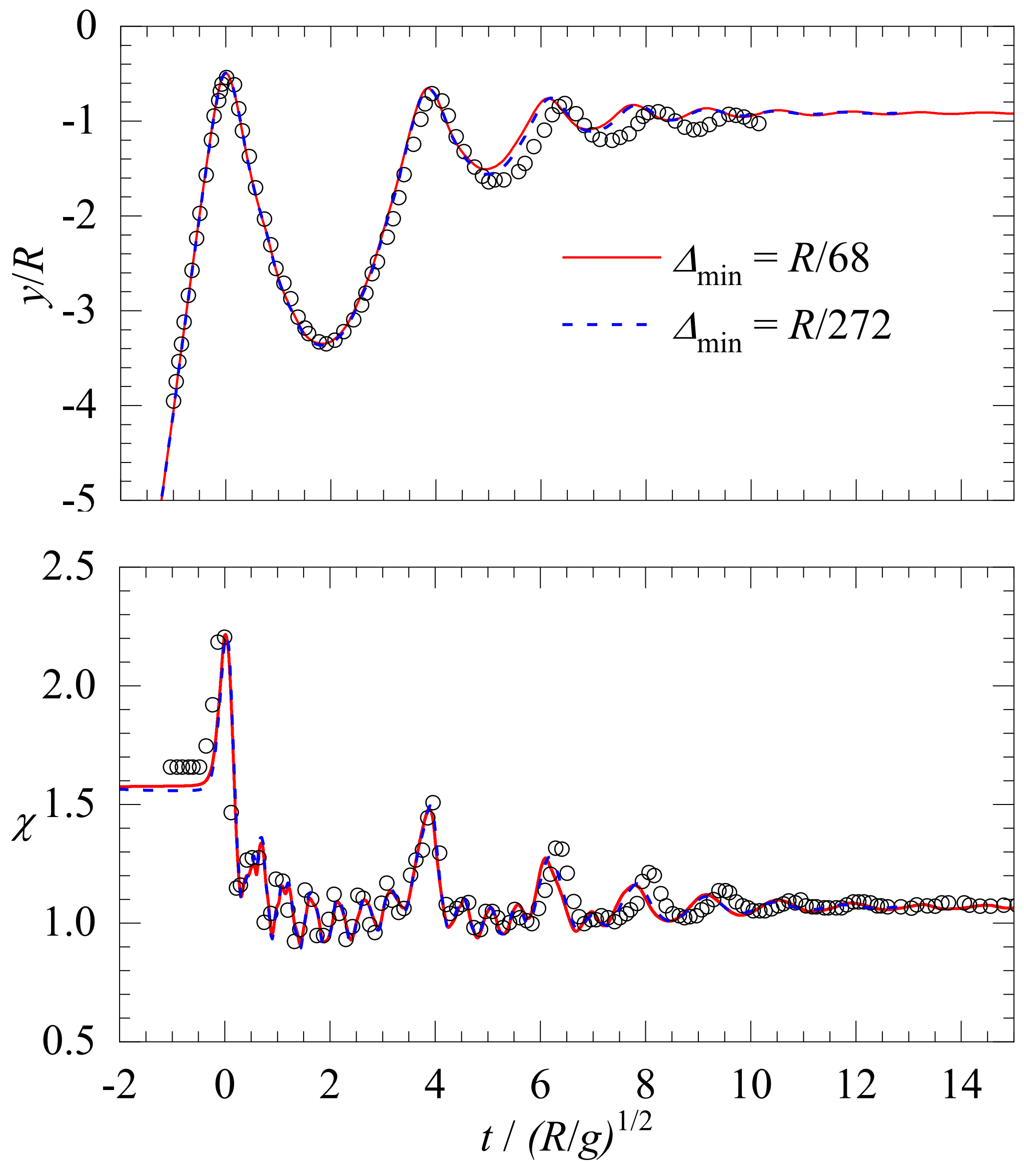
Summary and concluding remarks

- At a given Ga (hence Re), bubbles bounce close to wall at low-to-moderate Bo
- Their is a point-to-point connection between near-wall bouncing and vortex shedding
- Finally, there is likely a big mismatch with the experiment in the bouncing frequency, for which the cause is still unclear

Some extra but indirect validations

Case A: Ga = 63, Bo = 0.074, clean bubble bouncing close to horizontal wall (Kosior et al. 2014)





Case B: Ga = 27, Bo = 0.14, clean bubble rising along inclined wall (Barbosa et al. 2016)