Acoustic Interaction Between a Coated Microbubble and a Rigid Boundary

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Introduction

It is of interest to identify the dynamic behaviour and acoustic signature of coated microbubbles during insonation in the vicinity of nearby boundaries. Experimental studies identify asymmetric pulsations of microbubbles adherent to tissue [1,2], accompanied by a decrease in their acoustic signal [1,3]. The present study presents a numerical investigation of the nonlinear interaction between a coated microbubble and a nearby rigid or deformable surface in order to assess the possibility for the onset of shape oscillations or jet formation that may affect its acoustic signature or even damage nearby tissue.

Materials and Methods

We present a numerical investigation of the nonlinear interaction between a microbubble that is coated by a polymeric or a phospholipid shell and a nearby rigid or deformable boundary, Figure 1. The response to a step or sinusoidal change in the far field pressure is investigated. Owing to the dominant shell viscosity, to a first approximation, we ignore viscous and acoustic damping, while accounting for nonlinearity in the elastic behaviour of the shell.

The boundary element method is employed [4] for the solution of the velocity potential in the surrounding fluid, coupled with the appropriate dynamic and kinematic conditions at the microbubble/liquid and boundary/liquid interfaces. Thus, and assuming axisymmetry, we need only discretize two lines, namely the microbubble and boundary generating curves, Figure 1.

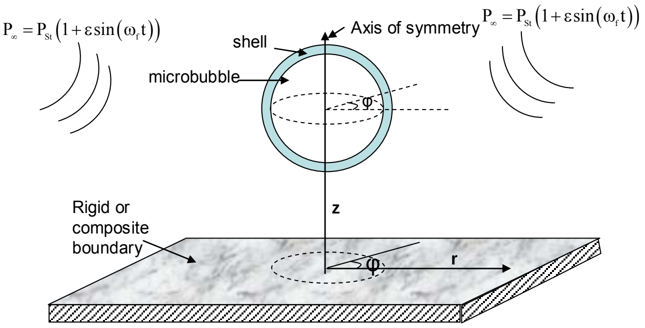


Figure 1: Schematic of the flow arrangement.

Results and Conclusion

Benchmark simulations are first conducted in order to recover the dynamic behaviour of free bubbles in the vicinity of a rigid boundary or a free surface [5,6]. The simulations capture the basic aspect of these two flow arrangements, namely jet formation directed towards/away from the boundary for the case of a rigid/free surface, respectively.

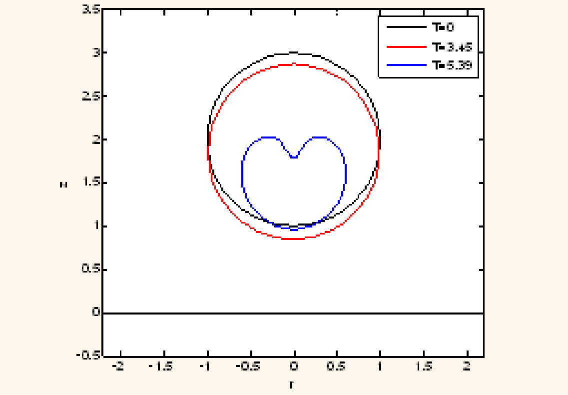


Figure 2: Shape sequence of a free microbbuble approaching a rigid wall; d=d'/R=1 denotes dimensionless initial distance, γ=1.4, P_{st}=101325 Pa, R_o=1 mm, σ=0.075N/m, ν_o=3622.9 Hz, ε=2.

Preliminary simulations of the acoustic response of a coated microbubble, whose shell behaves as a neo-Hookean solid with significant dilatational viscosity, in the vicinity of a rigid boundary reveal the stabilizing effect of the viscoelastic coating with respect to jet formation when a step change, figures 2,4 or a sinusoidal disturbance, figures 3,5, is applied.

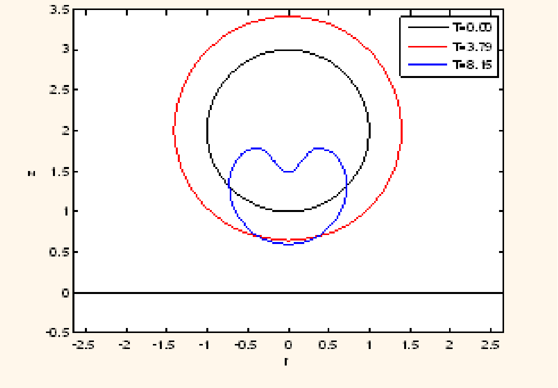


Figure 3: Shape sequence of a free microbbuble approaching a rigid wall; v_f=5553 Hz.

In the case of a step change in pressure the coated microbubble initially pulsates with its natural breathing frequency, while approaching the boundary as a result of the secondary Bjerknes force, until shell viscosity damps the radial motion. However, the microbubble retains its translational motion due to inertia and when it gets close enough to the rigid boundary it deforms in its aft region, figure 4. Nevertheless, it never quite forms a jet. Rather it exhibits shape deformation manifested in the form of bending and stretching of its shell.

Similarly, when a sinusoidal pressure change is applied the microbubble is attracted to the boundary while performing volume pulsations at the forcing frequency. As it approaches the boundary, shape deformations are only exhibited during the compressive phase of the pulsation, figure 5, with the microbubble large axis mainly oriented perpendicularly to the rigid boundary. The latter arrangement has also been observed in experiments with microbubbles in contact with a wall [2].

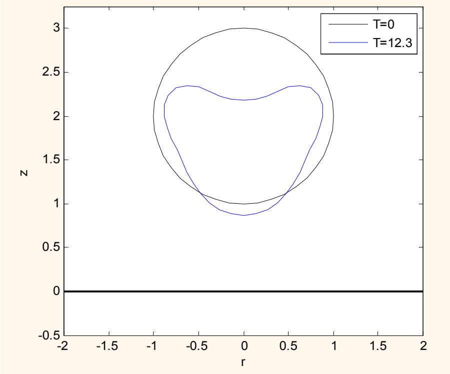
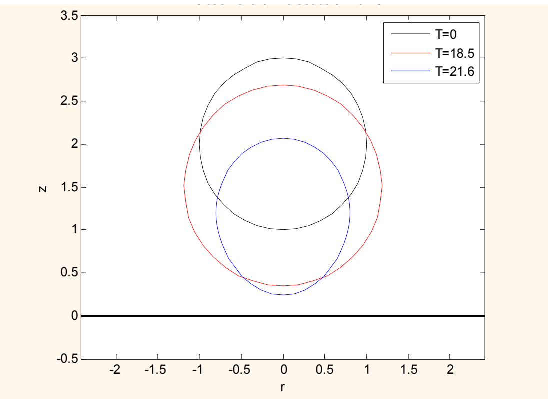


Figure 4: Shape sequence of a coated microbbuble approaching a rigid wall; R_0=3.6 μm, μ_s=20 Pa·s, k_B=3·10^{-14} N·m, b=0 (MR shell), ν_o=1 MHz, γ=1.07, Pst=101325 Pa, δ=1 nm.



Figures 5: Shape sequence of a coated microbbuble approaching a rigid wall; v_f=1.7 MHz.

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