Acoustic Interaction Between a Coated Microbubble and a Rigid Boundary

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It is of interest to identify the dynamic behavior 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]. We present a numerical investigation of the nonlinear interaction between a microbubble that is coated by a polymeric or phospholipid shell and a nearby rigid boundary. 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 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 taken to be axisymmetric [3]. Benchmark simulations are first conducted in order to recover the dynamic behavior of free bubbles in the vicinity of a rigid boundary [4]. The simulations capture the basic aspect of this flow arrangement, namely jet formation directed towards the boundary (fig. 1a). 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 volume pulsation when a step change disturbance is applied (fig. 1b). However the fluid in its aft region retains its accelerating motion and, for large enough initial disturbance, it penetrates the bubble without forming a jet (fig 1b). Rather, it causes rapid shell bending in the aft region where break-up occurs as a result of stress concentration. When a sinusoidal pressure change is applied the microbubble is attracted to the boundary and performs volume pulsations at the forcing frequency. For moderate amplitudes shape deformation occurs as a result of resonance that is more pronounced along the direction of translation (fig. 1c). When the amplitude further increases shape deformation and break-up occurs in a fashion similar to the case with step change illustrated in fig 1b, where the balance between inertia and bending dominates (fig. 1d) generating a region of very small radius of curvature.

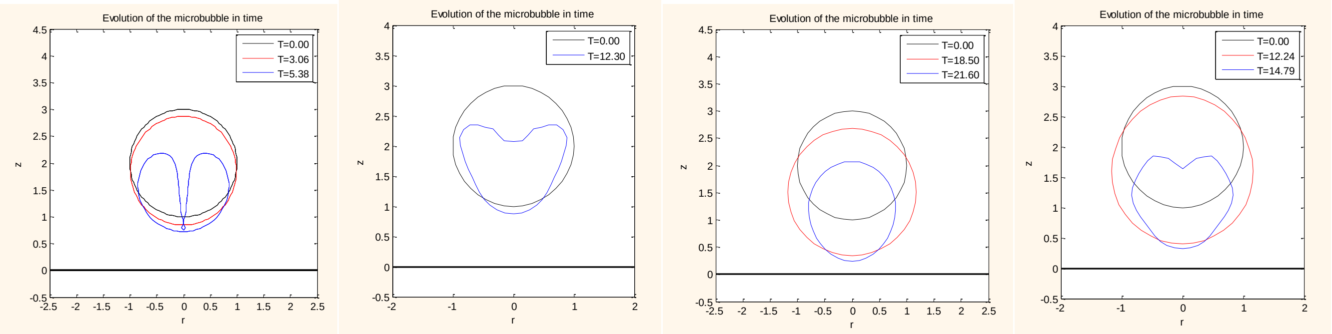

Figure 1: (a) Shape sequence of a free bubble and (b) a coated microbubble approaching a rigid wall, subject to a step pressure change. Shape sequence of a coated microbubble approaching a rigid wall, subject to a sinusoidal pressure change for (c) a relatively small ($\varepsilon=2$) and (d) a large amplitude ($\varepsilon=3$) of the acoustic disturbance; simulation parameters are set to: $R_0=3.6$ μm, $G_s=80{\cdot}10^6$, $\mu_s=20$ Pa·s, $k_B=3{\cdot}10^{-14}$ N·m, $b=0$ (Mooney-Rivlin shell), $\nu_0=1$ MHz, $\nu_f=1.7$ MHz, $\gamma=1.07$, Pst=101325 Pa, $\delta=1$ nm.

References

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