Viscous Effects on the Acoustic Levitation of Single Gas Bubbles

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When a gas bubble is subjected to an oscillating acoustic pressure field, it seeks a position in the field wher the time-averaged buoyancy force is balanced by the time-averaged acoustic radiation pressure force. At this equilibrium location - when one exists - the bubble undergoes periodic, coupled volumetric pulsation and translational motion and is said to be 'acoustically-levitated'. The levitation position is intimately linked with the radial bubble dynamics, accordingly acoustic levitation studies can provide an experimental means of evaluating the theoretical model(s) of bubble dynamics. Experimental investigations have displayed overall good agreement with theory; however significant discrepancies were observed in regimes where the radial oscillations are highly nonlinear. Our hypothesis was that viscous drag forces arising from translational motion could possibly be significant in these so-called nonlinear regimes of oscillation, and that the viscous extension to previous inviscid models of levitation might resolve the discrepancies.

To address this issue, the coupled radial and translational motion of a single gas microbubble driven by an oscillating acoustic pressure field in a viscous fluid is examined analytically. A singular perturbation approach is used to incorporate the effects of viscous forces acting on the bubble. The resulting equation of motion for the bubble center is shown to have an rich integro-differential structure; the viscous forces are shown to appear as a combination of (1) a linear 'Stokes-like' drag, and (2) a memory integral ('Basset effect') arising from the interaction of the oscillating bubble with its own viscous 'wake'. A steady-state analysis and computation has been performed to determine the equilibrium position for the bubble in the acoustic field. Our results show that viscous drag forces can be significant only for bubbles driven at frequencies well below resonance. Elsewhere - including the highly nonlinear regime of oscillation - viscous effects are seen to be essentially negligible and fail to resolve the aforementioned experimental discrepancies.

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