124b Weak Viscous Oscillations and Collapse of Elongated Bubbles

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The fashion by which a bubble oscillates and collapses plays an important role in ultrasound based applications and in phenomena like sono-luminescence. In the present study, a hybrid boundary-finite element method is used in order to follow the shape deformation and collapse of axisymmetric bubbles in the presence of weak viscous effects, in response to an initial elongation and possible internal overpressure. The description of the bubble's interface is based on a Lagrangian representation. B-cubic splines are used for the discretization of the unknown functions along with the 4th order Runge-Kutta method for the time integration. The mesh and time step are updated during the simulation in order to capture curvature variations. The effect of small viscosity is included in the computations by retaining first-order viscous terms in the normal stress boundary condition and by satisfying the tangential stress balance. Construction of the system matrix is parallelized for optimal code efficiency.

An extensive set of simulations was carried out until the bubble either returned to its initial spherical shape, or broke-up. For a relatively small initial elongation, S=(b/R)~1, the bubble returned to its initial spherical state regardless of the size of Reynolds number, Re=(rRs)**(1/2)/m; r and m denote the density and viscosity of the surrounding liquid, s interfacial tension, R the radius of a spherical bubble occupying the same volume as the elongated one and b the length of the smaller semi-axis of the prolate spheroid representing the initial shape of the elongated bubble. For larger initial elongations, S<1, there is a threshold value in Re above which the bubble eventually breaks up giving rise to a “donut” shaped larger bubble and a tiny satellite bubble occupying the region near the center of the original bubble. The latter is formed as the round ends of two liquid jets that approach each other from opposite sides along the axis of symmetry, coalesce. During the last stages of collapse the two rounded ends form dimples where the two jets first meet. The minimum distance between opposite facing dimples residing on the approaching jets scales with the 3/2 power of the time from collapse in a fashion similar to capillary pinch-off of drops. This pattern persists for a range of large initial deformations with a decreasing threshold value of Re as the initial deformation increased. As its equilibrium radius increases the bubble becomes more susceptible to the above collapse mode.

The effect of initial bubble overpressure (the initial pressure inside the bubble in excess to the amount needed to balance the static pressure in the surrounding liquid when the bubble is spherical) was also examined and it was seen that small initial overpressures, for moderate to large initial bubble deformations, have a stabilizing effect and translate the threshold of Re to larger values while at the same time increase the size of the satellite bubble. The case of very large internal overpressures and elongations was also examined in order to simulate the internal energy and initial shape of the LASER beam that is often applied as a means to generate bubbles. Simulations show that a threshold value exists in internal overpressure, below which the two approaching jets interact with and collapse on the bubble wall, i.e. off the axis of symmetry and away from the equator. Above this critical value the collapse mode via the two colliding jets is recovered, leading to the formation of a tiny bubble at the center of the original bubble. Prolate bubble shapes obtained by the numerical simulations compare well against experimental observations of LASER induced bubbles. Micro-bubble formation has not yet been observed experimentally, but has been conjectured as a mechanism that provides the degree of sphericity that is necessary for luminescence to take place during the final stages of aspherically collapsing bubbles.