Modeling the complex dynamics of nonspherical microbubbles

Michael L. Calvisi, Ph.D.
Associate Professor
Department of Mechanical & Aerospace Engineering
University of Colorado Colorado Springs
mcalvisi@uccs.edu

Abstract

Microbubbles are bubbles on the order of 1-10 microns in diameter that were originally developed to enhance contrast in ultrasound sonography. More recently, microbubbles are being explored for therapeutic uses, e.g., as vehicles for targeted drug and gene delivery within the circulatory system. Microbubbles are injected intravenously and are coated by a shell of lipid, polymer, or protein to slow dissolution in the bloodstream. Under acoustic excitation, microbubbles can deform nonspherically due to asymmetries in the surrounding flow, such as caused by nearby bubbles or boundaries. Nonspherical oscillations are important for enhancing the acoustic echo from microbubbles, promoting rupture, and creating microstreaming that can improve the uptake of therapeutic agents across the blood vessel wall and into the surrounding tissue. However, modeling nonspherical bubble deformation is challenging both analytically and numerically due to the complex, evolving interface between the liquid and gas. In this talk, we discuss the modeling of both small and large amplitude nonspherical microbubble oscillations by different approaches. For small nonspherical oscillations, equations of motion (EOM) represented by coupled ordinary differential equations (ODEs) can be developed through perturbation theory. These EOM can be solved numerically using an ODE solver for a variety of fluid and acoustic parameters to understand the nonspherical dynamics and scattered echo from microbubbles subject to small to moderate acoustic forcing. However, the perturbation approach breaks down for large amplitude nonspherical oscillations, such as occurs during strong acoustic forcing and/or microbubble rupture. To model the deforming gas-liquid interface in such cases requires a fully numerical approach, such as the boundary element, level set, or volume-of-fluid method. We present results of modeling nonspherical bubbles using both ODE models (for small oscillations) and numerical methods (for large oscillations) in an effort to elucidate the dynamical response of microbubbles in applications relevant to biomedicine.