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Secondary Bjerknes forces between ultrasound contrast agent microbubbles

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Acoustic radiation forces arise on UCA microbubbles from pressure gradients in the ultrasound pressure field. The ultrasound wave emitted by an oscillating UCA microbubble and experienced by a neighboring bubble results in the so-called secondary Bjerknes force. Typically, only the (time) averaged value of the secondary Bjerknes force is estimated from experiments. Here, the ability to resolve in time the radial dynamics of UCAs and the evolution of their relative distances, allows us to obtain a quantification of the instantaneous secondary Bjerknes force. Two bubbles were selected and confined within two separate optical traps and positioned away from the sample chamber wall prior to insonation. The radius-time curves and distance-time curves were then extracted from high-speed optical recordings. The camera fully resolved the alternating attractive-repulsive features of the secondary Bjerknes force in time. The effect of the time averaged secondary Bjerknes force results in a net attraction of the two bubbles, with a typical observed displacement of 1-2 μm, with an instantaneous peak value of the secondary Bjerknes force of up to 10^{-6} N. We predict the mutual interaction of the two coated bubbles in their translation with an accuracy better than 10%.