Deconvolution of Acoustically Detected Bubble Collapse Shockwave

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1 Introduction

When detecting a broadband acoustic signal with a hydrophone, artefacts arising from the convolution the will manifest. This is of particular importance for bubble collapse shock waves as both an apparent negative phase and the peak positive pressure amplitude or incorrectly measured if the signal is not deconvolved. Using high-speed imaging, the collapse of a laser induced bubble is observed, with the subsequent emission of a shock wave. The shock wave is detected by a needle hydrophone at three distances, in which experimental results are compared to theoretical predictions of the shock wave properties. To achieve this the capability of performing unprecedented shadowgraphic imaging of the bubble collapse was paramount, both for controlling the bubble size and a spherical rebound after the collapse. The high speed observation was also used to guide the simulation of the theoretical prediction.

2 Experimental configuration

When a laser pulse of energy sufficient to cause optical break down, is focused into a liquid, a single laser-induced bubble (LIB) forms. A LIB initially undergoes an expansion phase in response to the energy deposition, which the inertia of the host medium decelerates eventually causing the bubble to contract and collapse, often followed by several rebound oscillations. Acoustic detection of the LIB process is characterised by the emission of a series of shock waves. The first is generated by the plasma formed on absorption of the laser pulse, with a second emitted during the collapse of the primary bubble after a duration equal to the oscillation period of the LIB. Successive rebounds may also emit shocks of diminishing pressure amplitudes.

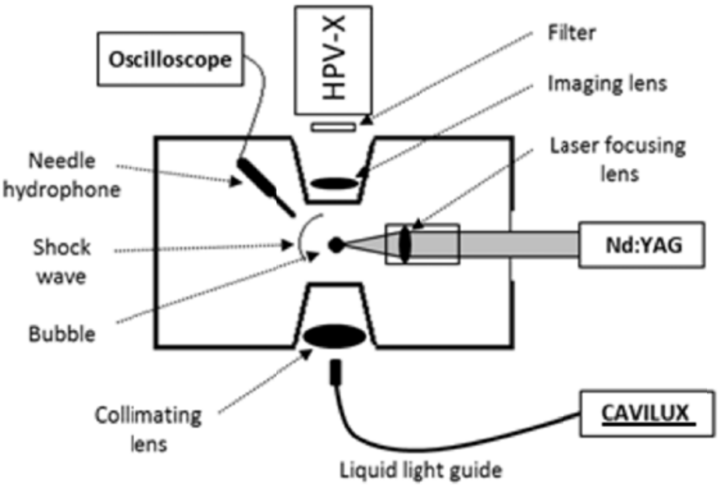

Figure 1: Schematic of experimental setup.

To study the BCSWs reliably, LIBs are generated within a custom built chamber, represented schematically by Fig. 1 measuring 420 x 438 x 220 mm^3 and filled with degassed, deionised water. Two of the walls are recessed, allowing imaging optics to be placed in proximity to the intended location of the LIB, facilitating spatial resolution at 7.6 ± 0.1 µm per pixel. A single 4.0 ± 0.2 mJ (instrument error according to manufacturer), 6–8 ns laser pulse (Nano S 130-10 frequency doubled Q-switched Nd:YAG, Litron Lasers, UK), is brought to a focus through a long working distance microscope objective lens (50 x 0.42 NA Mitutoyo, Japan), submerged in a sealed unit, and mounted on an xyz manipulator (Velmex Motor, Bloomfield, NY, USA). High-speed shadowgraphic imaging of the resulting cavitation activity is undertaken at 5 x 10^6 frames per second (HPV-X2, Shimadzu, Japan), with synchronous 10 ns laser pulses (CAVILUX Smart, Cavitar, Finland) providing the illumination and effective temporal resolution. A delay generator (DG535, Stanford Research Systems, USA) provides electronic triggering to synchronise each of the instruments. The HPV-X2 camera offers 256 frames per image sequence, such that the dynamics of the collapse of a single bubble is sampled sufficiently for modelling purposes. Much of the literature on this type of experiment relies on the selection of frames from a number of different high-speed sequences of a number of different bubbles, under the assumption that each bubble reaches an equivalent maximum radius and undergoes an equivalent collapse.

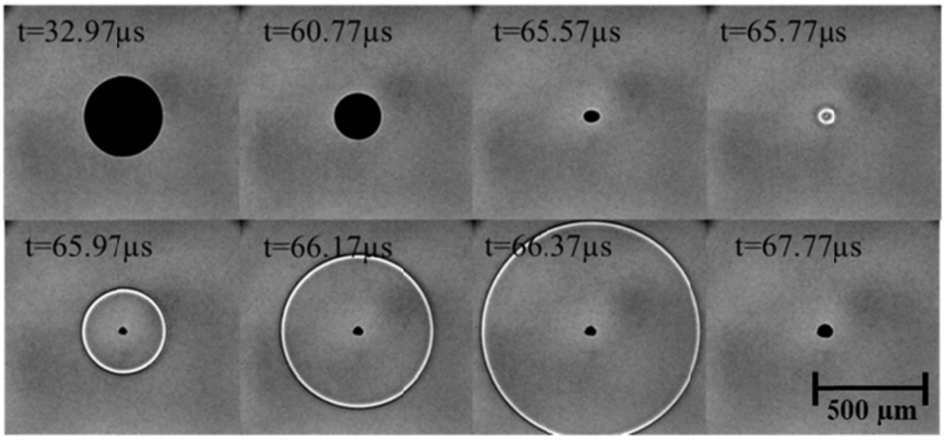

Figure 2: High-speed images of a collapsing laser induced bubble with the emission of a shock wave, and a spherical rebound. Imaging is undertaken at 5 million frames-per-second with synchronous 10 ns laser pulses CAVILUX Smart providing the illumination and effective temporal resolution.

3 Results after deconvolution of needle hydrophone

When removing the impulse response from the needle hydrophone via deconvolution, the theoretical competition is in reasonable agreement with the experimental measurement. This is particularly noticeable as the apparent negative phase in the convoluted experimental measurement is gone. Thus, for broadband signals it is important that the measurement is deconvolved with information of both the magnitude and phase, such that the temporal shape the measurement remains a physical.

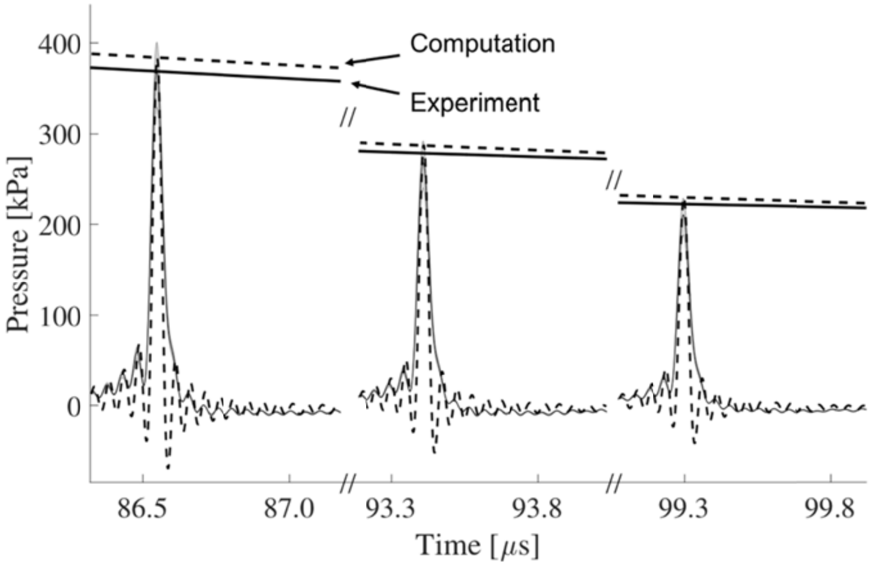

Figure 3: Theoretical computation (stapled black) and deconvolved experimental measurement (solid black) of bubble collapse shock wave at distances 30,40 and 50mm from the nucleation site.

4 Further studies by Glasgow University using CAVILUX

Characterising focused ultrasound via high speed shadowgraphic imaging at 10 million frames per second, Kristoffer Johansen, Jae Hee Song and Paul Prentice, Ultrasonics Symposium (IUS), 2016 IEEE International, Date of Conference: 18-21 Sept. 2016

An analysis of the acoustic cavitation noise spectrum: The role of periodic shock waves, Jae Hee Song, Kristoffer Johansen, Paul Prentice (CavLab, Cluster of Ultrasound Science, Technology and Engineering Research, University of Glasgow, UK); JASA, Volume 140, Pages 2494 – 2505, 2016

About the author

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