Applications of two frequency insonification techniques to oceanic bubble sizing

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Abstract This work presents the results from using a combination frequency acoustic technique to measure the near surface bubble population in the open sea. The technique monitors the appearance of sum-and-difference signals generated by the nonlinear interaction of two sound fields: one high frequency signal scattering geometrically from the bubble surface and the other used to excite the bubble into resonant pulsation. The results from the most recent sea trial are presented, and the adaptation of the rig for the next set of trials detailed.

INTRODUCTION

The use of acoustical techniques are especially potent in bubble measurement [1], as there is a large backscattering of incident sound from the bubble wall. Additionally, when driven by a sound wave whose wavelength is much larger than the bubble radius, the bubble can pulsate as a single degree of freedom oscillator. The resonant frequency of these pulsations can be readily used to calculate the bubble radius. The technique used in the oceanic measurements described here uses a combination frequency excitation method, where the bubble population is simultaneously insonified with two sound fields. The first is a fixed high frequency beam, called the *imaging* signal ω_i, which in these tests was set at 1 MHz and scatters approximately geometrically from the bubble wall. The second is a much lower frequency signal, the *pump* signal ω_p which is varied between 17 and 200 kHz at ten discrete frequency values, and is intended to drive the bubbles into resonant pulsation. These frequencies correspond to bubble radii between 192 and 16 μm. When the pump signal coincides with or is close to a bubble resonance, the scattered imaging signal will be amplitude modulated as it is scattering from a target whose area is varying in time. This generates signals at $\omega_i \pm \omega_p$. Thus the technique monitors the linear resonant pulsation characteristics of a bubble through the generation of a nonlinear component in the scattered signal. The benefits of using this combination frequency technique are that the collected data is taken from a very spatially localised volume of liquid, the method is more accurate and less prone to ambiguities than linear backscatter measurements, and it affords a significant increase in the signal-to-noise ratio over other single frequency insonification techniques [2,3].

EQUIPMENT CALIBRATION AND OCEANIC MEASUREMENTS

The schematic of the apparatus and the layout of the deployment buoy are given elsewhere [3,4]. The equipment set up was designed such that the focus of the transducer was 0.5 m below the surface of the sea. The calibration procedure, required to relate the height of the scattered sum-and-difference signals to the number of resonant bubbles, involved: (a) using the apparatus set up in the laboratory, measuring the strength of the sum-and-difference scattering from a free rising bubble steam whose members are of equal size: (b) modelling the amplitude of the sum-and-difference scattering for identical insonification conditions as the measured bubbles: (c) using a comparison of the model and the experimental heights to calculate a transfer function relating measured signal heights to number of resonant bubbles: (d) measuring the frequency response of the equipment in the returned signal path: (e) modelling the sum-and-difference signal strengths for the bubbles resonant at the ten pump frequencies employed in the oceanic tests. Using this information, and theoretically derived estimates of the insonification volume and the strength of the contribution to the measured signal from off-resonant bubbles, allows the measured height of the scattered signal to be converted to numbers of resonant bubbles per cubic metre of fluid per micrometre radius increment. More details on the calibration procedure can be found in other publications [2-4].

The model chosen for predicting the response of the bubbles to two frequency insonification was the Herring Keller model. This was solved analytically by assuming that the bubble pulsations could be described in terms of a small amplitude radial perturbation x, and then truncating the expanded Herring Keller formulation after terms in x^2.

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This methodology has been shown to yield very accurate estimates for the sum-and-difference signal heights (when compared with the strength of the geometric imaging signal backscatter) and for the *Q* factors of the pulsations [3].

The buoy was last deployed on the 27th June 1997 in water whose depth ranged from 17 to 22 m and in (unseasonally high) wind speeds between 10 - 12 m/s, gusting up to 16 m/s. From consideration of the dominant wave period and water depth, it was determined that the data was collected in water that can be considered to be deep (using an oceanographic definition). The equipment was deployed off the Southampton coast, and 6 runs consisting of ten 'snap-shots' of the bubble population at each of the ten frequencies were taken. The time averaged population corresponding to one of the runs is shown in figure 1, and is compared with four historical measurements of deep water bubble populations.

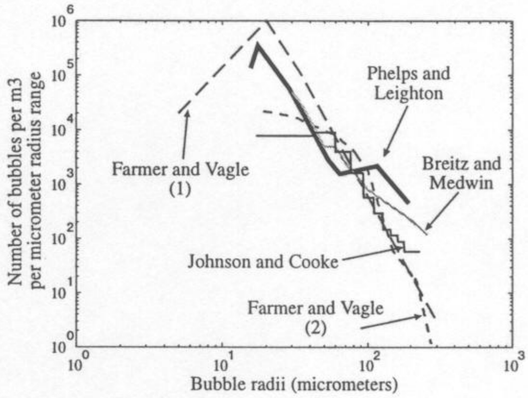

FIGURE 1. Comparison of time-averaged data measured in deep water using the sum-and-difference technique (thick unbroken line), with historical estimates taken from references [5] (large dashes), [6] (grey unbroken), [7] (black unbroken) and [8] (small dashes).

The next series of tests are planned for spring 1998, and for these the set up of the apparatus and experimental procedure have been slightly altered. The buoy has been redesigned such that the body of the canister sits vertically in the water and is fully submerged. This alignment is held through attaching weights to the bottom of the canister and attaching floats to scaffolding above the cable attachment end of the canister. This will ensure that the measured bubble population is not increased through the action of waves breaking against the buoy itself. The transducer arrangement is still held such that the focus is 0.5 m below the level of the water. Additionally, two extra hydrophones have been placed at known distances from the pump signal transducer. These will collect data on the local bubble mediated attenuation and variations in the speed of sound at the ten pump frequencies for a comparison with theoretical predictions which can be obtained using the measured population [9]. It is also envisaged that in principle this attenuation data can be inverted using linear finite element techniques [10], potentially giving two simultaneous estimates of the population.

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