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Bubble Rupture in a Vibrated Liquid Under Microgravity

Introduction

The bubbles play an important role in a wide range of geophysical and industrial processes [2–4] and the control of bubble size is of primary importance in many practical applications. An elegant method was proposed by Zoueshtiagh et al. [1] which consists of breaking up a bubble by submitting it to vertical vibrations. The authors carried out experiments under normal gravity conditions and showed that the vertical vibrations of a sealed cell containing a large air bubble (~4 ml) in a liquid of small viscosity could “uniformly” split the bubble to smaller pieces. The break-up threshold was found to occur at a constant acceleration of around \( G \), where \( G \) denotes gravitational acceleration (981 cm/s\(^2\)). It was also found that a Bond number \( Bo \) based on the acceleration of the cell containing the bubble characterized that threshold:

\[
Bo = \frac{D}{2l_c} = \frac{D}{2} \sqrt{\frac{\Delta \rho A (2 \pi f)^2}{\gamma}}
\]

where \( D \) is the volume equivalent diameter of the bubble defined by \( D = (6V/\pi)^{1/3} \) for a bubble of a volume \( V \). \( l_c \) is a capillary length based on the acceleration of the cell and is given by \( l_c = (\gamma/\Delta \rho A (2 \pi f)^2)^{1/2} \). \( \gamma \) is the surface tension, \( \Delta \rho \) the density difference between air and liquid, \( A \) and \( f \) the amplitude and frequency of the cell, respectively. Here, we present the break-up thresholds of a bubble in microgravity obtained by experiments in parabolic flights and compare them with the results on ground.

Experimental

The setup consists of a liquid-filled rectangular cell which contains an air bubble (\( V = 3 \) ml). The cell has an inner dimension 6\( \times \)8\( \times \)6 cm. All experiments were performed at a room temperature \( \sim 25^\circ \)C. The cell is vibrated along a vertical axis in a sinusoidal manner by a computer controlled servomotor. The system enables frequencies 0.1\( \leq f \leq 3.5 \) Hz and amplitudes 0.5\( \leq A \leq 11 \) cm. Bubble behaviour is observed with a high speed camera (120 images per second) in a view along the vibration axis as well as in a lateral view by a mirror equipped on a lateral wall of the cell at an angle of 45°. To determine the bubble break-up threshold, we increase the frequency step-by-
step with a small increment $\Delta f$, keeping the amplitude constant and observing whether any break-up occurs or not.

![Images of bubble behavior under vibrations](image1)

Fig. 1: Bubbles under vibrations (a) with no break-up (silicon oil 47V50, $f=0.8$ Hz, $A=7.0$ cm) and (b) with break-up (silicon oil 47V100, $f=2.5$ Hz, $A=6.0$ cm). $t=0$ corresponds to the start of vibrations. In each picture, the upper half part represents a side view obtained by reflection on the mirror and the lower half corresponds to a view along the vibration axis.

**Results**

Prior to each experiment, the bubble is squeezed on the upper wall of the cell (see the first picture in figure 1 (a)), as a consequence of 2G phase of a parabolic flight. After microgravity condition is established, the bubble becomes spherical and the cell is put under vibrations. The bubble is observed to undergo deformations (2nd and 3rd picture of figure 1 (a)). In figure 1, the vibration is below the break-up threshold. The bubble travels back and forth in the cell along the vibration axis, deforming its shape typically in the form of a spherical cap. When the frequency exceeds a critical value $f_{cr}$, the bubble is rapidly divided into small pieces (see figure 1 (b)). This division process continues until the bubbles size becomes small enough for the capillary pressure to counteract the breaking. Thereafter, the bubbles move back and forth in a shape of spherical caps without any further break-up.

In figure 2, the critical frequency $f_{cr}$ of bubble break-up is shown. The frequency is normalized by the natural frequency $f_N$ of a spherical bubble of the same volume: $f_N = (4\gamma/\pi \rho V)^{1/2}$. It is seen that $f_{cr}$ is inversely proportional to $A^{1/2}$, in other words, that the break-up threshold is given by a constant acceleration. In figure 3, data obtained in micro- and normal gravity for liquids of different viscosities are shown in terms of the Bond number (1). The threshold of bubble break-up in microgravity is found to be substantially smaller than in normal gravity.

**Conclusion**

The break-up of a large bubble by vibrations under micro- and normal gravity conditions was investigated. In comparison to experiments on ground, a substantial drop in the critical acceleration (or critical Bond number) for the break-up was observed in microgravity. This suggests an easier break-up of bubbles in microgravity in spite of the reduction of squeezing (wall) effects on bubbles.

![Graph showing critical frequency](image2)

Fig. 2: Critical frequency of bubble break-up in microgravity. $f_N$ is the natural frequency of a spherical bubble.

![Graph showing break-up thresholds](image3)

Fig. 3: Break-up thresholds in micro- and normal gravity.

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**References**