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DISCUSSION

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The authors are to be congratulated for reporting in this paper results of interest for their bearing on the mechanism of cavitation damage and bubble dynamics in general.

The shock wave which in a real flow situation is irradiated by collapsing bubbles is obtained here by means of a spark discharge and subsequent growth of a vapor bubble. This results in a good simulation of the real process if the parameters of the shock wave (notably its width and strength) are comparable in the two cases. Maybe the authors can comment on this point referring to their collapse shock results shown e.g. in Fig. 10.

I was also interested in the bubble-bubble interaction results shown in Fig. 5 in view of some numerical work based on potential flow which we did on the problem some time ago (L. Guerri, G. Lucca, and A. Prosperetti, "A Numerical Method for the Dynamics of Nonspherical Cavitation Bubbles," in *Proceedings of the Second International Colloquium on Drops and Bubbles*, Monterey, November 19–21, 1981, D. H. Le Croissette Ed., Jet Propulsion Laboratory Publication 82-7, pp. 175–181). The figure reproduced here shows some results for the case of axisymmetric collapse of one spherical and one hemispherical bubble attached to a solid wall (or, by reflection in the horizontal plane, of three equally spaced bubbles). Successive shapes of the bubbles are shown by thick lines, while the thin lines indicate particle paths. The situation is different from that of the paper because the bubbles begin to collapse at the same time. However these results show that the hemispherical bubble is impeded in its collapse by the neighbouring one and takes on an elongated shape qualitatively similar to that of the vapor bubble in the experiments (Fig. 5(*b*), frames 4-6). The numerical results also show that the time to collapse is affected by the presence of other bubbles, a factor which is not taken into account in the calculations of the paper. I would suggest that the discrepancy between calculated and measured collapse times for large R_e which can be seen in Fig. 7 is caused by the flow field of the spark-generated bubble. When the bubbles come close together (which, for the conditions of the experiment, implies large radii and greater collapse times) the interaction is not only due to the pressure wave but also to the actual flow field. Maybe some other effects depending on R_e reported in the paper are due to this factor.

Finally I would like to make a remark, and ask the authors' opinion, on the difficult question of shock waves versus microjets as agents of cavitation damage. The unambiguous identification of a shock wave irradiated by the bubble upon rebound and a failure to identify pressure pulses caused by the microjet does not necessarily demonstrate that cavitation damage is not to be imputed to the latter. If the action of the microjets is to cause very minute fractures of the surface of the solid, they could have such an effect without producing

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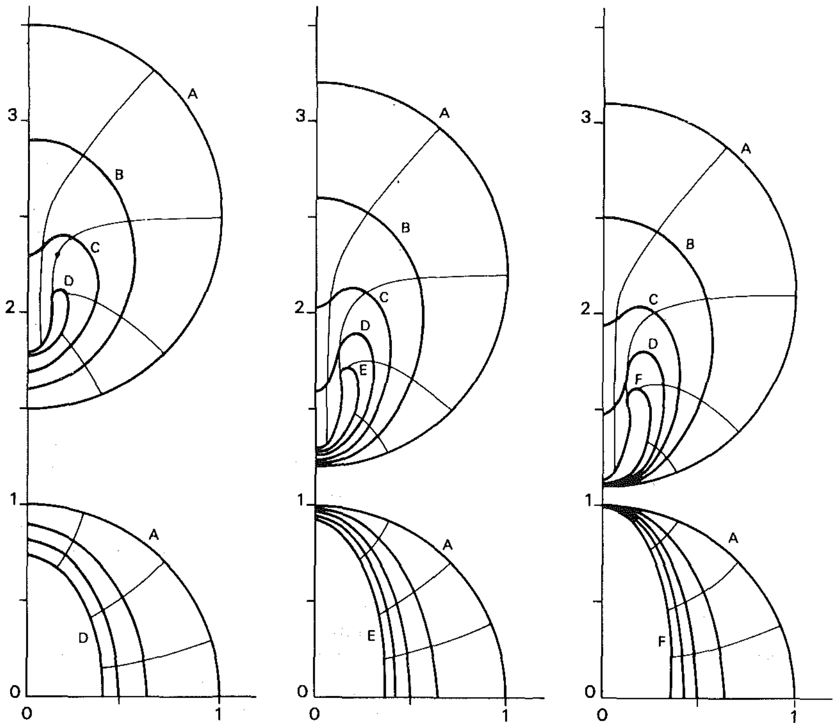

Fig. 12 Simultaneous axisymmetric collapse of one hemispherical and one spherical bubble in an inviscid incompressible liquid. The figures show successive bubble shapes (thick lines) and particle paths (thin lines). The initial distance between the bubble centers is, from left to right, 2.5, 2.2, and 2.1 initial radii. The shapes shown are for: *A*, $t = 0$; *b*, $t = 0.950$; *C*, $t = 1.063$; *D*, $t = 1.105$ (left and right), $t = 1.103$ (center); *E*, $t = 1.130$; *F*, $t = 1.135$. Distances are made dimensionless with respect to the initial radius R_0 and times with respect to $R_0\{\rho/(p_\infty - p_i)\}^{1/2}$, where ρ is the liquid density and p_∞ and p_i denote the ambient and internal pressure taken as constants.

notable pressures. It is possible that shock waves become effective in causing weight loss only after the surface has been exposed to "working" by the microjets? In this case both mechanisms would be important and, once more, the truth would be in the middle.

Authors' Closure

The authors wish to thank Professor Prosperetti for his useful discussions.

In the present experiment, shock waves with strength $p_s <$ about 5 MPa and pulse width $w_s \approx 5$ μs are used in order to study the sock wave-bubble interaction. These values were determined by referring to the experimental study on the ultrasonic cavitation [34] in which the shock amplitudes of about 5 MPa were measured at the position of 1 mm apart from the center of collapse by means of optical methods. By the way, parameters of the shock wave produced in Fig. 10 are measured as $p_{G,\max} = 10.4$ MPa and $w = 2.6$ μs. The peak pressure $p_{g,\max}$ will reduce to the value of about 3 MPa at $L = 5$ mm along a $1/L$ decrease curve.

The authors are also thankful to Professor Prosperetti for his suggestion concerning the bubble-bubble interaction, and believe that the numerical results obtained by him and co-worker provide valuable addition to this paper. As a gas bubble increases in size, the interaction of it with a spark bubble becomes remarkable. This relation is shown in Fig. 13, where $\bar{R}_{v,0}$ indicates an averaged curve of five trials. It is clearly seen that when R_e increases, the discrepancy of H_v from $\bar{R}_{v,0}$ becomes larger. This means that a gas bubble will be affected by a spark bubble with increasing R_e. In general, there exists Bjerknes force between pulsating bubbles at a distance $2d$ apart. Two bubbles pulsating in phase attract each other, and bubbles pulsating 180 deg out of phase repel each other. These are mathematically equivalent to the motion of a bubble at a distance d from a solid wall for the former and from a free surface for the latter, respectively. The periods of collapse will be lengthened near a solid wall and shortened near a free surface. In our experiment the motions of two bubbles are 180 deg out of phase in the initial stage of their motions. As a result, the calculated collapse times would be overestimated than measured collapse times because the interaction of a gas bubble with a spark bubble is not taken

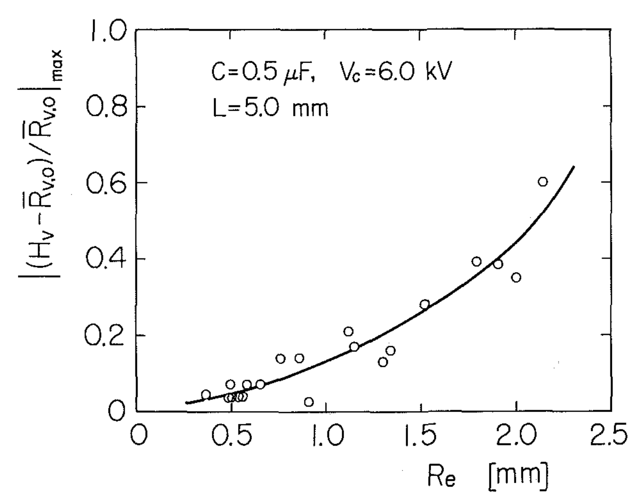

Fig. 13 Interaction between a gas bubble and a spark bubble

into account in our calculations, and thus the discrepancy between them becomes larger with increasing R_e.

Now the authors would make a remark on the mechanism of impact pressure generation. We do believe that three types of damage forces are possible, and basically agree with the discussor's opinion. They are resulted from a shock wave, from a liquid jet and from both a shock wave and a liquid jet. The induced impact wall pressure modes are fairly corresponding to the bubble collapse modes depending on L/R_{max}, where L is the distance between the electrodes and the solid wall and R_{max} a maximum bubble radius (see reference [35] for details).

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