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RECENT THEORIES OF CAVITATION DAMAGE INCLUDING NON-SYMMETRICAL BUBBLE COLLAPSE EFFECTS

by

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Recent theories of cavitation damage mechanisms will be discussed in the present paper as opposed to the classical theories on that subject, originated primarily by Rayleigh in 1917 (1), who considered the collapse of an empty spherical bubble initially at rest in a static, incompressible, inviscid, infinite liquid. It was assumed in the various studies based on this initial work that at least the mechanical portion of cavitation damage (as opposed to chemical effects) resulted from shock waves propagated through the liquid by the collapse of cavitation bubbles under the ideal fluid and spherical symmetry assumed by Rayleigh.

A more realistic approach to the problem requires primarily a consideration of the non-symmetries inherent in most actual cavitation collapse situations. Photographic evidence, dating primarily from the work of Naude and Ellis (2), shows that the actual collapse of bubbles near a symmetry-destroying feature such as a nearby wall results in a toroidal-like collapse, with final generation of a liquid microjet oriented toward the wall. However, this has since been substantiated by numerous photographic studies, and also theoretical studies of varying and increasing complexity (3, and 4, e.g.). Present photographic and numerically-computed evidence indicates that the microjet velocity is only marginally sufficient to be the sole cause of the observed cavitation pitting in strong materials.

Relatively recent numerical calculations including numerous real fluid effects (5, and 6, e.g.) indicate that the shock wave intensity emitted during collapse is not likely to be strong enough to be damaging to most materials, even if spherical symmetry were maintained through a very large volume ratio, and if the bubble were touching the wall at the start of collapse. Of course, spherical symmetry is impossible for the collapse of a bubble in such a position, but the shock wave intensity is in general of maximum intensity for a given volume ratio of collapse, if spherical symmetry is maintained. However, the numerical calculations go on to show that if a "rebound" occurs such that the bubble grows again after collapsing, the event is similar to a micro-explosion (rather than implosion as for collapse), and in this case the radiated shock-waves are much stronger, so that damage through their impingement on a neighboring wall is much more likely. Photographs by various investigators, including Kling of our own laboratory (7, 8, e.g.), show that non-symmetrical collapses with rebound occur almost exclusively in a real flowing system. Hence it appears to this writer that actual damage is usually a result of a combination of the impact effect of the microjet and the shock-wave pressures generated by bubble rebounds. There is much more confirmatory evidence than that which can be covered in this relatively brief paper. However, much of the general applicable material is covered in the book Cavitations (9), as well as an extensive pertinent bibliography.

A final pertinent point is the photographically demonstrated and theoretically justified fact that the bubble centroid during collapse is strongly attracted toward a solid wall, and that the microjet is then directed toward the wall, provided other influences such as velocity or pressure gradients are not sufficient to overcome the wall-attraction effect. For these reasons, a relatively strong sorting mechanism exists preventing the great majority of bubble collapses in the vicinity of a wall from reaching damaging intensity. This is confirmed experimentally. On the other hand, a collapse near a free (or very flexible) surface, affects the bubble behavior in a precisely opposite manner. The bubble is repelled from the flexible surface and the jet is directed away. This also is observed photographically (10, e.g.) and is also expected on theoretical grounds. It may explain the surprisingly good cavitation resistance of various elastomeric materials.

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