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CLOUD CAVITATION:
OBSERVATIONS, CALCULATIONS AND SHOCK WAVES

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Abstract

A recent significant advance in our understanding of cavitating flows is the importance of the interactions between bubbles in determining the coherent motions, dynamic and acoustic, of the bubbles in a cavitating flow. This lecture will review recent experimental and computational findings which confirm that, under certain conditions, the collapse of clouds of cavitating bubbles involves the formation of bubbly shock waves and that the focussing of these shock waves is responsible for enhanced noise and potential damage in cloud cavitation. The recent experiments of Reisman *et al.* (1998) complements the work begun by Mørch and Kedrinskii and their co-workers and demonstrates that the very large impulsive pressures generated in bubbly cloud cavitation are caused by shock waves generated by the collapse mechanics of the bubbly cavitatting mixture. Two particular types of shocks were observed: large ubiquitous *global* pressure pulses caused by the separation and collapse of indiviual clouds from the downstream end of the cavitation and much more localized *local* pressure pulses which occur much more randomly within the bubbly cloud.

One of the first efforts to model cloud cavitation was due to van Wijngaarden (1964) who linked basic continuity and momentum equations for the mixture with a Rayleigh-Plesset equation for the bubble size in order to study the behavior of a bubbly fluid layer next to a solid wall. In the 1980s there followed a series of papers on the linearized dynamics of clouds of bubbles (for example, d'Agostino *et al.* 1983, 1988, 1989). But highly non-linear processes such as the formation of shock waves require computational efforts which are capable of resolving these phenomena in both time and space. A valuable first effort to do this was put forward by Kubota *et al.* (1992) but by limiting the collapse of individual bubbles they prevented the formation of the large pressure pulses associated with bubble collapse. Wang *et al.* (1994, 1995) and Reisman *et al.*

(1998) present accurate calculations of a simple spherical cloud subject to a low pressure episode and show that, for a large enough initial void fraction, the collapse occurs as a result of the formation of a shock wave on the surface of the cloud and the strengthening of this shock by geometric focussing as the shock propagates inward.

This review will discuss other efforts to investigate these phenomena computationally. Wang and Brennen (1997, 1998) have extended the one-dimensional methodology used for the spherical cloud to investigate the steady flow of a bubbly, cavitating mixture through a convergent/divergent nozzle. Under certain parametric conditions, the results are seen to model the dynamics of flashing within the nozzle. Moreover, it is clear from these steady flow studies that there are certain conditions in which no steady state solution exists and it is speculated that the flow under those conditions may be inherently unstable. Of course, it has frequently been experimentally observed that cavitating nozzle flows can become unstable and oscillate violently.

Finally, we will also describe recent efforts (Colonius *et al.* 1998) to extend the code to two and three space dimensions. A simple example of such a calculation is the collision of a plane pressure pulse with a cylindrical or spherical cloud of bubbles. When the pressure pulse is negative, the growth and subsequent collapse of the cloud is particularly interesting and is seen to involve the formation and propagation of a shock waves within the cloud. Moreover, the non-linear scatterring of the pressure waves into the far field provides valuable information.

The long term objective is to develop computational techniques and experience which would allow practical calculation of much more complex bubbly flows such as occur on hydrofoils, on propellers and in pumps where there is a real need for CFD methodologies which allow calculation of the noise and damage potential of these flows.

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