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[Extended Abstract]

The Life of a Cavitation Bubble - being Part of a Bubbly Society from Birth to Death

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Introduction

The picture of the cloud cavitation consists of three parts, which are at the same time the three phases of the bubble: (i) birth, i. e. bubble nucleation, (ii) midlife, i. e. transition from sheet to cloud cavitation, and (iii) death, i. e. cloud collapse. To model cavitating flow, these three phases have to be analyzed separately. This paper gives an overview over this trilogy.

(i) Birth, i.e. bubble nucleation: the sheet cavity is composed of parallel streaks consisting of a huge amount of bubbles all originating from a line of roughness, an edge of a hydrofoil, the point of laminar separation, or an artificial roughness. The experiments of Guennoun et al. [1] as well as our own experiments and the recent findings from a very generic experiment [2], [3], [4] indicate a bubble nucleation rate f of the order 1 to 10 kHz depending on the supersaturation of the fluid, shear rate, and size of the surface bound nuclei. The nucleation process itself is a mass transfer problem which has hardly been investigated even though its importance for the understanding of cavitating flows is apparent.

(ii) Midlife, i. e. transition from sheet to cloud cavitation: as soon as a bubble detaches from its nucleation spot, i. e. its place of birth, it is transported downstream with a velocity which is approximately the velocity of the flow. As our experiments show the sheet cavity is formed by the numerous bubbles that nucleate from the different nucleation spots. There are two situations which occur depending on the cavitation and Reynolds number: in the first situation the sheet cavity appears to be stationary. Only at the cavity closure continuously small bubbly vortices are peeled off. This situation is called sheet cavitation. According to the described mechanism it is clear that the flow is never stationary. In the second situation, the cloud cavitation, the re-entrant jet modeled as a viscous spreading film peels off the complete sheet and a large cavitation cloud with an imposed circulation is formed. The sheet comes to rest when the nucleation rate f exceeds the inverse of the bubble collapse time: $f \geq 1/\tau$. The re-entrant jet is considered to be a spreading film. Due to the viscous friction at the fluid-wall interface the Reynolds number influences the transition from sheet to cloud cavitation. Only if the driving potential is high enough to overcome the frictional resistance the film can completely peel off the sheet forming a large cloud. The magnitude of the circulation is given by the flow velocity multiplied with the length of the sheet [5].

(iii) Death, i. e. cloud collapse: due to Helmholtz vortex theorem a vortex cannot end somewhere in the fluid. Thus it must extend to walls of the flow area or form a closed curve. In most cases the cavitation cloud will form a cylindrical vortex which turns into a horse shoe vortex. The horse shoe vortex is excited by two mechanisms: The first one is a dynamic mechanism which acts by increasing the ambient pressure and the second one which is a kinematic mechanism which acts by stretching the vortex ring. We showed that the cloud collapse is largely intensified by the latter situation and developed a model to describe the dynamics of cloud cavitation [6], [7].

1. Methods

This study analyses the three phases nucleation, transition from sheet to cloud cavitation and cloud collapse by means of numerical, experimental and analytical methods. The main focus of the nucleation experiment is on the measurement of the nucleation rates by means of high-speed visualisation. In addition, the growth of the surface nuclei and the detachment process can be visualised. We performed experiments inside a convergent-divergent nozzle and developed analytical models to investigate the transition from sheet to cloud cavitation [6]. A model based on Lagrangian methods describes the dynamics of cloud cavitation [7]. All models go back to the smallest element inside cavitating flow which is a single bubble.

References

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