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Experimental study of bubble sweep-down in wave and current circulating tank: Part II—Bubble clouds characterization

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ABSTRACT

In this second part, images acquired from the specific trials developed in order to study the phenomenon of bubble sweep-down are analysed. A post-processing method has been developed to analyse the two air entrainment mechanisms described in the first part, for several test configurations. Bubble clouds are described in terms of depth, area and velocity for both vortex shedding and breaking wave bubble clouds. A parametric study is also performed to calculate the influence of each test parameter on the frequency of bubble generation. It is demonstrated that the occurrence of bubble clouds is proportional to the wave height, with a considerable influence of the phase shift between waves and motions. The overall results provide new elements for the understanding and the study of the phenomenon, with the final objective of obtaining a reliable tool that facilitates the design of research vessels.

1. Introduction

Bubble generation by wave breaking and body-wave interaction is a source of diverse interest. For naval ships, this kind of bubbles generates underwater sound and a wake visible far behind the ship. In the particular case of research vessels, bubble generation must be avoided to reduce the degradation of acoustic equipment performances. Indeed, in bad weather conditions, the ship bow wave generates a significant aeration carried out by the flow under sonar locations. This phenomenon of bubble sweep-down must be prevented as much as possible in order to ensure high quality acoustic surveys (Delacroix et al., 2016), even if today there are no experimental and numerical tools allowing the exact reproduction of bubble generation by a ship's bow under waves and motions.

As shown in the first part of this study (Delacroix et al., 2014), bubble clouds are caused by the body-wave interaction in the bow vicinity of the ship. In the past, two kinds of wave breaking processes have been widely studied and described: spilling and plunging. In spilling breakers, turbulent fluid from the crest spills down the front face, where bubbles and droplets are formed. The plunging breaking wave is more energetic. The forward face of the crest turns into a jet that impacts the front face and the air cavity formed is entrained downward almost instantaneously into a turbulent two-phase flow. In both cases, bubble generation appears in the regions of high vorticity and turbulent breakdown. Experimental works of Duncan (1981, 1983) and Bonmarin (1989) described the spilling breaking waves dynamics used to develop theoretical models (Cointe and Tulin, 1994). Particle Image Velocimetry (PIV) systems enabled a better investigation of velocity and vorticity fields in quasi steady breaking waves (Lin and Rockwell, 1995; Dabiri and Gharib, 1997). Many studies (Lamarre and Melville, 1994; Loewen et al., 1996; Deane and Stokes, 2002; Blenkinsopp and Chaplin, 2007) have been dedicated to the measurement of void fraction and bubble size distribution in plunging breaking waves. Chanson and Summings (1994), Cummings and Chanson (1997) studied the air entrainment mechanism by a plunging jet and developed a model to predict the sizes of the entrapped bubbles, the maximum penetration depth and the air–water gas transfer, and applied this model to plunging breaking waves. Kiger and Duncan (2012) also reviewed the mechanisms of air entrainment by a plunging jet, and the application to plunging breakers, pointing out the insufficiencies of the model to obtain a global air-entrainment model for plunging breaking waves. These works brought a lot of knowledge on the bubble generation mechanisms and are used as references in the development of numerical models of air entrainment around surface ships in stationary flows (Carrica et al., 1999; Moraga et al., 2008; Ma et al., 2011).

Despite all these studies and measurements of air-entrainment, the experimental characterization of bubble generation by the breaking bow waves of a ship is limited. The behaviour of these waves, depending on the bow geometry and the Froude number,

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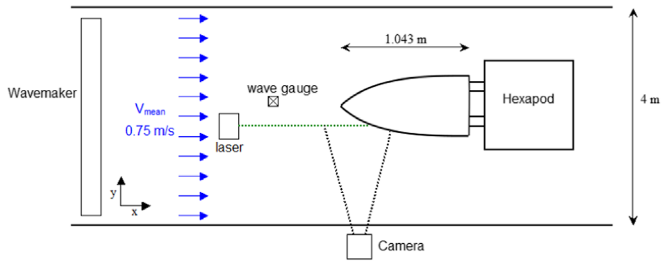

Fig. 1. Drawing of the experimental set-up showing the wavemaker and the light sheet generation system location.

have been well studied by Noblesse et al. (2008, 2013) and Delhommeau et al. (2009). However, studies of bubble generation in this configuration are scarce. Waniewski et al. (2001) used IVFM (Impedance Void Fraction Meter) to measure the void fraction in a breaking bow wave simulated by a deflecting plate. Shakeri et al. (2009) and Tavakolinejad (2010) have developed a 2D+t technique allowing the simulation of a 21.03 m model at 27.5 knots during which bubble sizes and void fraction have been acquired by a shadowgraph measurement system. Both studies focused on thin and fast ship's steady bow wave in calm seas. The influence of sea states and motions, which are significant on the acoustic survey efficiency, is not considered.

In this paper, we study bubble generation around a ship model submitted to waves and motions in order to understand the mechanisms of air entrainment at real scale despite the similarity issues discussed in the first part of this study. A quantification of these mechanisms is performed on a 1/30 model of the *Pourquoi pas?*, corresponding to a ship model of 3.13 m length between perpendiculars (Lpp), 0.67 m beam and 0.18 m draft, in a wave and current tank. Delacroix et al. (2014) describe the experimental setup developed to reproduce the real conditions of bubble sweep-down in a circulating tank (presented in Fig. 1). Acquisition systems and first observations of bubble generation are also detailed. This study was facilitated by the use of a hexapod allowing to consider the four base configurations: (1) with current only, (2) with current and waves, (3) with current and motions and (4) with current, waves and motions. Two phenomena of air entrainment have been observed: air entrainment by vortex shedding or by the breaking bow waves, for which a schematic description is given in Fig. 2. The distinct bubble clouds (as opposed to single bubbles) frequency are recalled in Fig. 3.

The interaction between the turbulent incoming flow and the bow generates low frequent vortex shedding clouds (configuration 1). This phenomenon is present in the four configurations with similar frequencies and the hull motions may amplify the amount of air entrapped. Configuration 2 shows that the impact of waves on the bow generates breaking waves and a higher frequency of

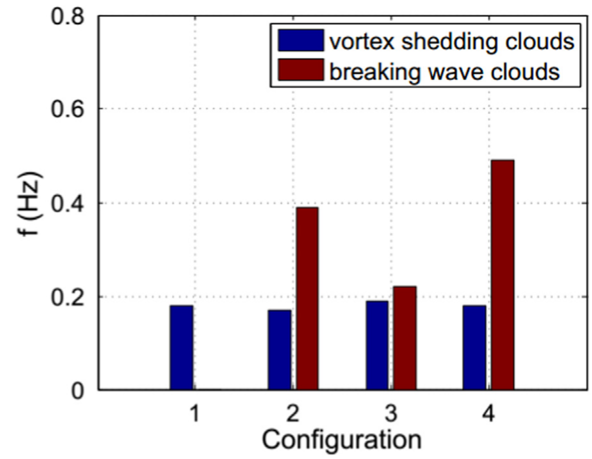

Fig. 3. Frequency of occurrence of the vortex shedding and breaking wave clouds for the 4 base configurations.

bubble generation. Configuration 3 with motion also generates some breaking waves. The fourth configuration with waves and motions corresponds to the highest frequency of bubble clouds.

In this second part, the methodology of image post-processing is presented in Section 2, while the results in terms of bubble clouds characterization in Section 3. Section 4 is devoted to study the influence of several parameters on bubble generation, and finally a discussion about the results and their generalization are discussed in Section 5.

2. Configurations and analysis method

The experimental setup was developed to simulate real conditions of bubble sweep-down in a wave and current circulating tank. Many parameters are involved in the bubble generation (current speed, waves and motion characteristics, etc.). Several configurations have been carried out to characterize the phenomenon in the tank and are detailed in this section. Typical bubble clouds are studied to describe the mechanisms of air entrainment. The image analysis method to obtain the bubble clouds characteristics and the clouds occurrence in each configuration is described below.

2.1. Test configurations

Numerous tests were conducted to characterize the influence of each parameter of the experiment on the phenomenon. The parameters of these tests are given in Table 1.

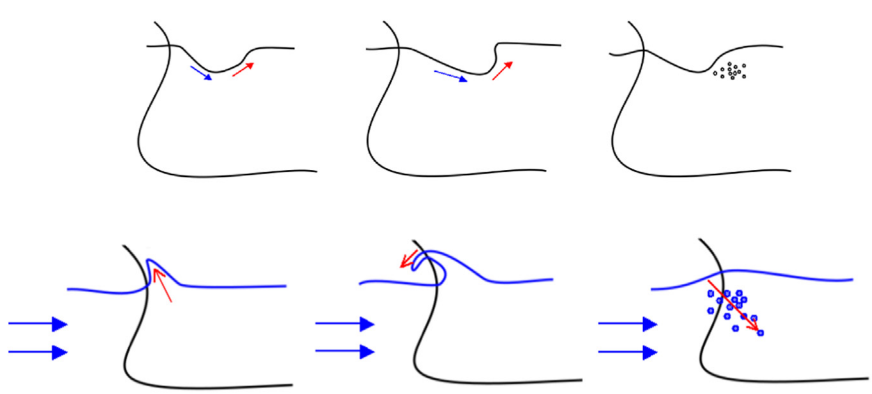

Fig. 2. Schematic description of the vortex shedding and breaking wave clouds.