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Experimental study of the bubble sweep-down phenomenon on three bow designs

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ABSTRACT

The bubble sweep-down phenomenon around the oceanographic research vessels generates acoustic perturbations. A specific experimental protocol has been developed in a wave and circulating tank to study this phenomenon. This protocol is used to carry out trials on three different ship models in order to study the influence of the bow geometry on the bubble generation. For different test configurations, bubble clouds are described and compared in terms of area, maximal depth and vertical velocity to highlight bubble cloud dynamics surrounding the three ship models. The relation between the hydrodynamic flow field and the bubble generation is studied by means of Particle Image Velocimetry (PIV) measurements to study the phenomenon by the use of phase averaged velocity fields. The overall results enable us to characterize the bubble sweep-down phenomenon from the air bubble generation and propagation to the frequency of occurrence and the clouds behaviour.

1. Introduction

The bubble sweep-down phenomenon is a widely well known phenomenon even if it is not well understood. On many specialized vessels, such as oceanographic survey and research vessels, bubble-sweep down can significantly degrade the effectiveness of transducer performance. Even if the use of the acoustic technique has demonstrated its potential for the water column and the sea-bed characterization (Trenkel et al., 2009), it remains challenging for ship designers to select the optimal hull shape and sonar location to avoid the phenomenon. This phenomenon is divided into two important events (Deane and Stockes, 2002). The first one is the generation of air bubbles induced by a perturbation at the free surface. The second one is the entrainment of these bubbles by a path backwards along the ship hull and under the transducers which disrupt the acoustic signals and may result in a considerable reduction of the ships productivity (Delacroix et al., 2016a).

The tools for the study of this phenomenon are therefore limited. The main difficulties come from the scale differences between the bubble generation, governed by the surface tension, and the overall flow around the ship. Experimental studies have been carried out by (Waniewski et al., 2001) and Tavakolinejad (2010) to study the air entrainment by the bow waves, but they do not take into account the sea state which is a significant parameter for the bubble sweep-down phenomenon.

Bonmarin (1989) and (Duncan, 1981, 1983) have described the breaking waves dynamics in order to develop theoretical models. Many other experimental studies (Lamarre and Melville, 1994) and Deane and Stockes (2002) have been carried out to measure the void fraction and bubble size distribution in breaking waves. Noblesse et al. (2008, 2013). and Delhommeau et al. (2009). have studied the behaviour of the breaking waves depending on the bow geometry and the Froude number. Similarly, numerical simulations of two-phases flow are still being developed. Ma et al. (2011), Carrica et al. (1999), (Castro and Carrica, 2013). describe a sub-mesh model coupled with a two phases RANS model to resolve the flow and obtain a quantitative numerical prediction of the distribution of void fraction around the ship hull. However, these simulations relied upon simple entrainment models or arbitrarily set bubble sources. Moraga et al. (2008). developed a model for locating regions of high void fraction using bubble distributions observed by Deane and Stockes (2002) during breaking waves.

These models provide a lot of information: from the forward speed of a ship and the bow geometry, one can obtain the characteristics of the wave generated and estimate the properties of the plunging jet causing the air entrainment. Knowledge of these properties then enables us to calculate the quantity of air entrained, the size of the bubbles generated as well as the penetration in depth. However, the air entrainment by the bow wave described above is valid only in calm water. These models are

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List of symbols

L_{pp}	Length between perpendiculars (m)
C_B	Block coefficient
B	Beam (m)
D	Draft (m)
λ	Wave length (m)
H	Wave height (m)
Fr	Froude number
Re	Reynolds number
We	Webber number
g	Gravitational acceleration ($m.s^{-2}$)
U	Current velocity ($m.s^{-1}$)
ν	Kinematic viscosity ($m^2.s^{-1}$)
σ	Surface tension ($N.m^{-1}$)
ρ	Fluid density ($g.m^{-3}$)
f_0	Wave and ship motions frequency (Hz)
f	Occurrence frequency of bubble clouds (Hz)
A_0	D*0.2*Lpp (m^2)
Z_0	Model draft (mm)
A_{cloud}	Bubble cloud area at model scale (mm^2)
Z_{max}	Bubble cloud depth at model scale (mm)
W_{cloud}	Bubble cloud vertical velocity at model scale ($m.s^{-1}$)
A	Bubble cloud area at full scale (m^2)
Z	Bubble cloud depth at full scale (m)
W	Bubble cloud vertical velocity at full scale ($m.s^{-1}$)
T	Wave and ship motions period (s)
N_t	Number of PIV snapshots
W_{pod}	Vertical velocity component of the flow after the POD application ($m.s^{-1}$)
X_1	A point near the bow
X_2	A point far away from the bow
w_1	Vertical velocity component of the flow at the point X_1($m.s^{-1}$)
w_2	Vertical velocity component of the flow at the point X_2($m.s^{-1}$)
$d\omega$	Velocity difference $w_1 - w_2$ ($m.s^{-1}$)

Abbreviations

PP	Pourquoi pas?
IB	Inverted Bow
TB	Thin Bow
CAD	Computer Aided Design
PIV	Particle Image Velocimetry
POD	Proper Orthogonal Decomposition

thus more relevant to study the air-water exchange close to the free surface than the bubble sweep-down phenomenon occurring deeper under more severe conditions. On the other hand, the body-wave interaction in the bow vicinity of the ship is the origin of bubble clouds (Delacroix et al., 2016c). Therefore, it is overriding to take into account the hull geometry characteristics as well as the sea state conditions.

In this work, the bubble sweep-down phenomenon around three ship models with different bow geometries is studied within the same experimental protocol (Delacroix et al., 2016c) in order to reproduce the ships behaviour in terms of generation and propagation of air bubbles. The first part of this paper presents the experimental set-up allowing the reproduction of the phenomenon in a wave and current circulating tank. The PIV system used to measure the flow on a plane around the bow is then described. The second part is devoted to the characterization of bubble cloud dynamics for the three models in term of area, maximal depth and vertical velocity for different configurations. The final part focuses on PIV and POD (Proper Orthogonal Decomposition) data analysis in order to identify the flow behaviour during air entrainment.

2. Experimental set-up

2.1. The wave and current flume tank

Experiments have been carried out at the Ifremer (French Research Institute for Exploration and Exploitation of the Sea) wave and current flume tank (Fig. 1). The tank working section is 18 m long by 4 m wide and 2 m deep. The streamwise flow velocity range is U = 0.1–2.2 m/s. The flow turbulence in the tank is 3% by the use of flow straighteners. A wave generator (Fig. 1 right), composed of eight independent displacement paddles, each 0.5 m wide and 500 mm deep, can be easily moved between an upstream or a downstream surface position to create waves propagating with or against the current. When the wave generator is used to generate waves with the current, it increases the turbulence level to 15% close to the free surface. The system is able to generate regular and irregular waves with a frequency range between 0.5 and 2 Hz and a maximum amplitude of 280 mm with a current speed up to 0.8 m/s. Measurements have revealed that the resulting reflection coefficient was less than 12% for all the usual periods and amplitudes. A side observation window of 8$*$2m^2 placed on one side of the tank allows users to observe

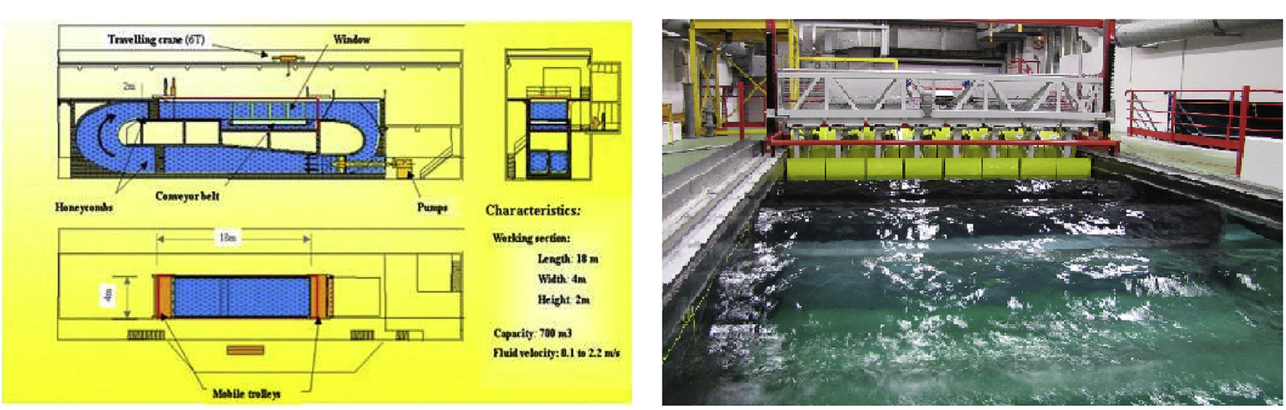

Fig. 1. Schematic view of the wave and current circulating tank (left) and a view of the wave generator with regular waves (right).

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