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ACOUSTIC DOPPLER CURRENT PROFILER (ADCP) MEASUREMENTS OF BREAKING WAVES

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ABSTRACT

Detailed flow measurements of the turbulent multiphase flow associated with wave breaking present a unique instrumentation challenge. Measurement systems must be capable of high sampling rates, large dynamic ranges, and be capable of making measurements in water, air and optically opaque regions. An experiment was performed at the Naval Surface Warfare Center, Carderock Division, in October 2007 to measure various characteristics of the breaking wave generated from a submerged ship transom. The primary objective of this work was to obtain full-scale qualitative and quantitative flow field data of a large breaking transom wave over a range of conditions, specifically transom drafts and Froude numbers.

Several types of measurements were made on the transom stern wave during this experiment, however, this paper will focus on the Nortek Acoustic Wave and Current (AWAC) profiler measurements of the stern wake. The AWAC has a center acoustic beam in addition to the three angled beams typically found on an acoustic Doppler current profiler. The trends of the acoustic return from the AWAC and the trends of the bubble density and location on the water surface compare well, and it is anticipated that this return can be related to void fraction and bubble measurements in the future. This type of non-intrusive measurement could be very useful in the evaluation of breaking waves.

INTRODUCTION

The physics of the transom stern wave continues to be of great importance to understanding both ship breaking waves and bubble wakes. The full-scale breaking transom stern wave is a complex non-linear turbulent flow field, and while Computational Fluid Dynamics (CFD) codes have demonstrated improved capability in predicting the large-scale Kelvin wave structure for a variety of naval craft, the ability of CFD codes to predict the short-scale surface evolution and the energy dissipation involved in breaking regions, spray sheets, and turbulence has not yet been validated and remains a challenge. The primary objective of this work is to obtain full-scale qualitative and quantitative flow field data of a large breaking transom wave over a range of Froude numbers. The necessary detailed flow measurements of the turbulent multiphase flow associated with wave breaking in the transom region present a unique instrumentation challenge.

EXPERIMENTAL DESCRIPTION

The experiment was performed in the Deep Water Towing Basin on Carriage 2. The basin is approximately 22 ft (6.7 m) deep, 1886 ft (575 m) long and 50.96 ft (889 ft) wide, with a maximum Carriage Speed of 33.8 ft/s (20 knots, 10.3 m/s) . The transom model (shown in Fig. 1 and Fig. 2) was designed to minimize the bow wave generated so that the transom wake could be more easily investigated. The model is about 30 ft long, with a maximum beam of 5 feet.

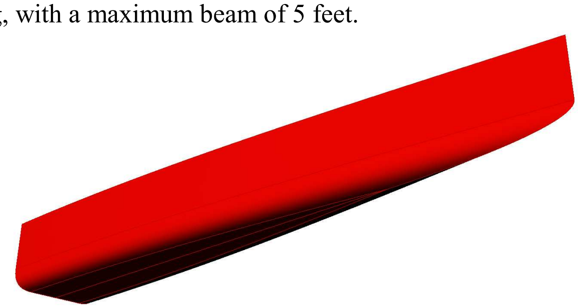

Fig. 1 Transom model

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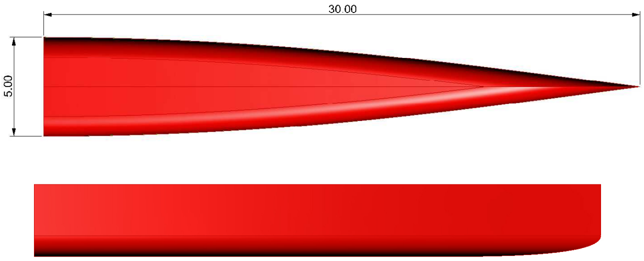

Fig. 2 Plan and profile views of the transom model

Several types of measurements were made during the experiment. Senix Ultrasonic acoustic sensors, a scanning LiDAR system and a laser sheet flow visualization technique (Quantitative visualization (QViz)) (Furey & Fu, 2002) were all used to quantify the free surface elevation. An underwater camera was mounted to a scissor-lift to quantify bubble size distributions under the hull. Additional measurements were made using the Nortek Acoustic Wave and Current (AWAC) profiler, as well as an array of void fraction probes, which were used to measure the entrained air at various locations behind the stern and various water depths.

The AWAC and its bottom mount are shown in Fig. 3, which were deployed on the basin floor and cabled up to a computer alongside the tank for real-time data collection and viewing. The AWAC is an acoustic Doppler current profiler with some added features. In addition to the three acoustic beams angled at 25 degrees from vertical, which are typically found on an ADCP, the AWAC system has a dedicated vertical center beam which is used to measure the water surface through Acoustic Surface Tracking (AST). This center beam transmits a short acoustic pulse that can be finely resolved, allowing for free surface waves of short periods to be accurately measured. This information also provides the acoustic return at a fine vertical resolution, which may be correlated to the entrained air in the water. The AWAC is capable of sampling at 4 Hz to capture the surface level; if all bins are recorded to acquire acoustic return through the water column, the sampling frequency is limited to 2 Hz. Measurements were made using the AWAC positioned to measure under the centerline of the model, as well as 21.75 and 51.75 inches port of centerline.

The model was tested as free to sink and trim, with the draft and trim recorded. Four different speeds were tested, including 5, 7, 8 and 9 knots.

Fig. 3 AWAC on bottom mount

DATA ANALYSIS

Fig. 4 shows the water level data collected by the AWAC at the centerline position, with time converted to distance from the bow. Each panel shows two separate repeated runs for each speed, with the 5 knot case in the top panel through the 9 knot case in the bottom panel. The passage of the model can be seen in the plot at 30 feet. The wake behind the ship is difficult to resolve from the plots, likely due to the sampling rate of 4 Hz. The transverse wave is apparent in the 7, 8, and 9 knot plots, and the length of this wave increases with vessel speed, as expected.

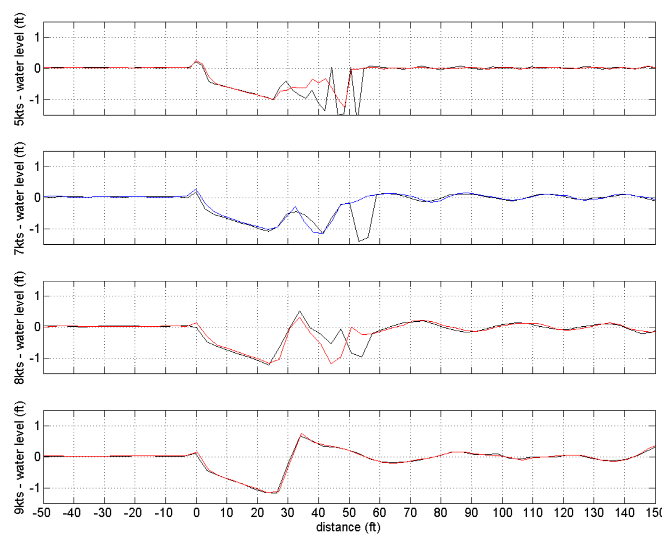

Fig. 4 Water level time series

Fig. 5 and Fig. 6 show the acoustic return for the center beam of the AWAC in counts while the instrument was in the centerline position. Each figure shows an independent run, with the time converted to distance past the bow. Each panel shows a different speed, with 5 knots in the top panel and 7 knots in the bottom panel. The black line shows the level of maximum acoustic return, which is the water surface or the outline of the model. From these plots, it can be seen that the model sinks lower at greater speeds, which was verified through the draft measurements taken during testing. Assuming acoustic return is related to bubble density, it appears that more bubbles are present lower in the water column at lower speeds than at greater speeds.

Figure 7 through Fig. 10 are still photographs of the flow aft of the transom for 5 knots through 7 knots. These figures show that at 5 knots, the transom flow is relatively flat with many bubbles behind the hull. As the speed increases, the density of bubbles observed decreases, resulting in a cleaner flow with bubbles only at the surface, which agrees with what is seen in the acoustic return plots.

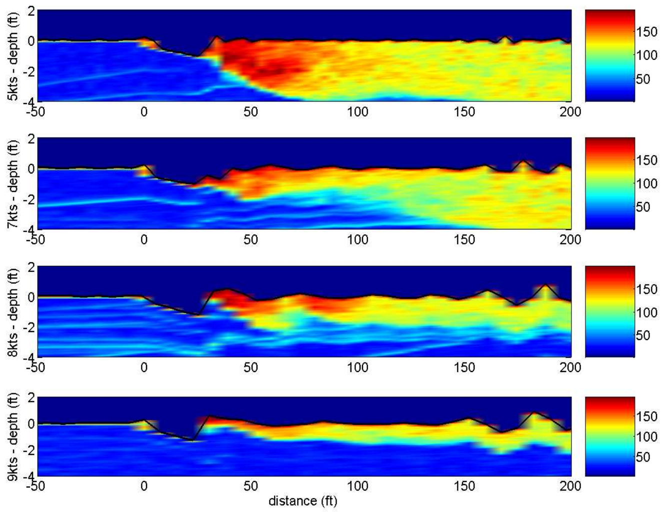

Fig. 5 AWAC return from centerline for 5, 7, 8, and 9 knots (first set of runs)

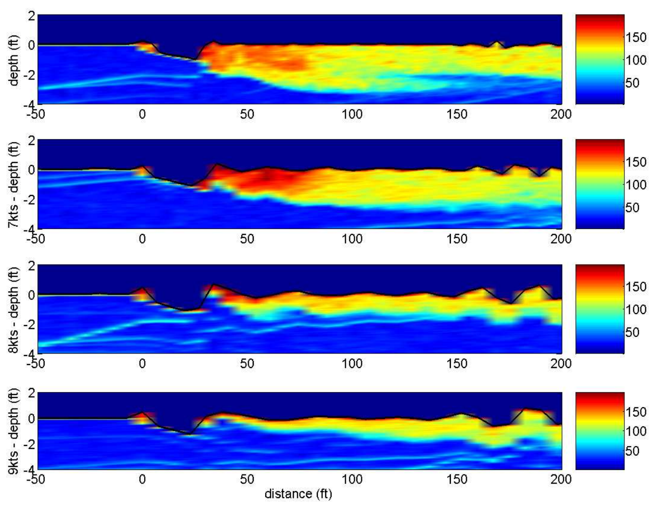

Fig. 6 AWAC return from centerline for 5, 7, 8, and 9 knots (second set of runs)

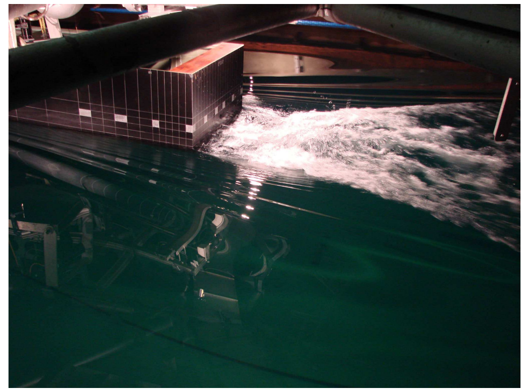

Figure 7. Transom wake flow at 5 knots

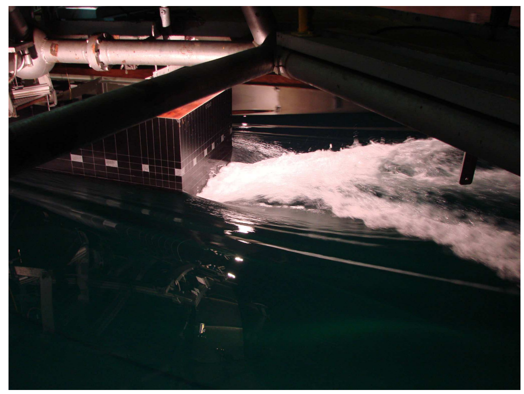

Fig. 8 Transom wake flow at 7 knots

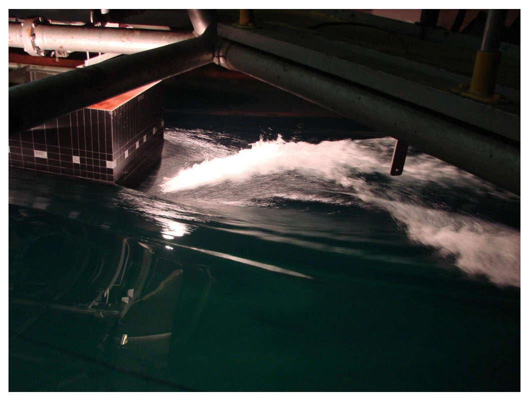

Fig. 9 Transom wake flow at 8 knots

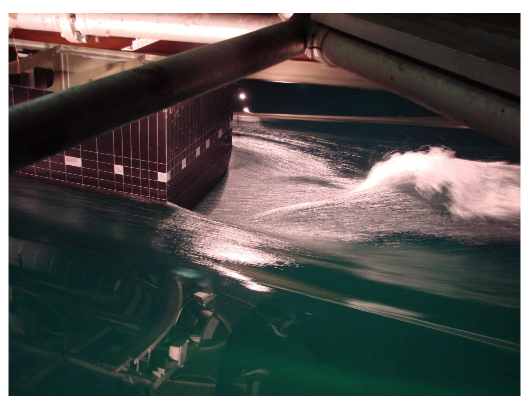

Fig. 10 Transom wake flow at 9 knots

Fig. 11 through Fig. 14 show the acoustic return for two other locations, 21.75” port of centerline and 51.75” port of centerline. There are two plots for each position representing two different runs for the same speed. The AWAC return at the 21.75” port of centerline position looks similar to the return at the centerline position, with a higher intensity return penetrating deeper at the lower speeds than at the greater speeds, where the higher intensity return is confined more closely to the surface. The AWAC return is much lower at the 51.75” port of centerline position than at the centerline or 21.75” port of centerline position, with very little return other than the water surface, particularly for the higher speeds. This trend makes sense when examining the still photos of the flow (Figure 7 through Fig. 10), where the bubbles on the surface spread less across the beam of the wake with greater speeds.

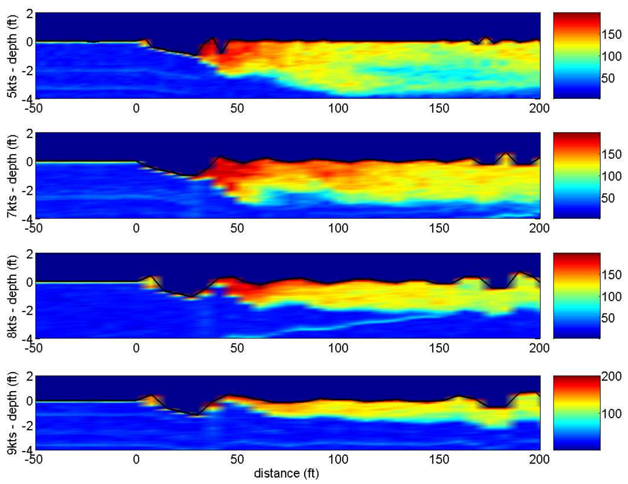

Fig. 11 AWAC return from 21.75" port of centerline for 5,7,8, and 9 knots (first set of runs)

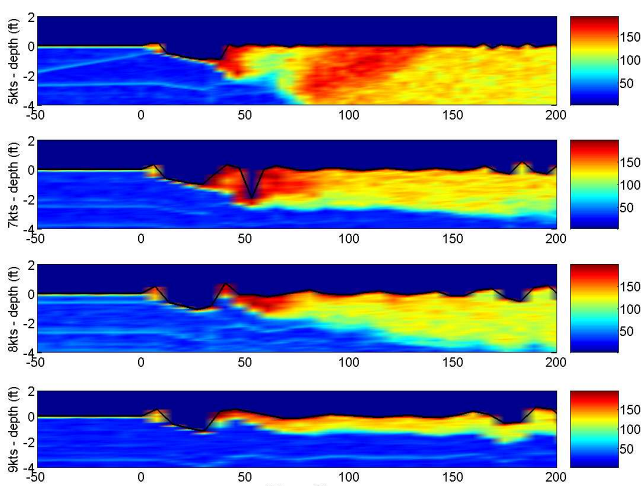

Fig. 12 AWAC return from 21.75" port of centerline for 5,7,8, and 9 knots (second set of runs)

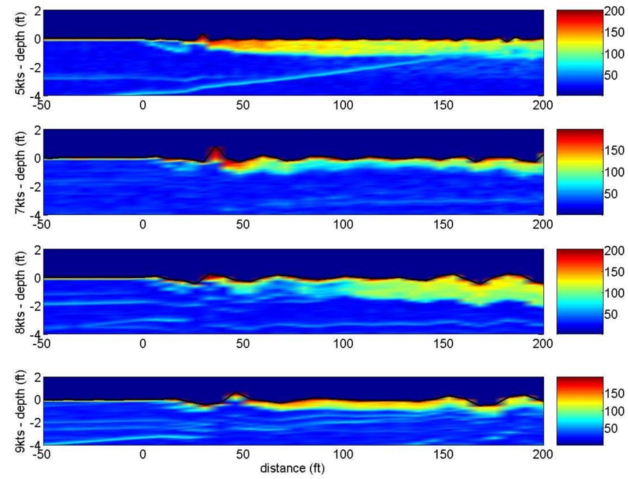

Fig. 13 AWAC return from 51.75" port of centerline for 5,7,8, and 9 knots (first set of runs)

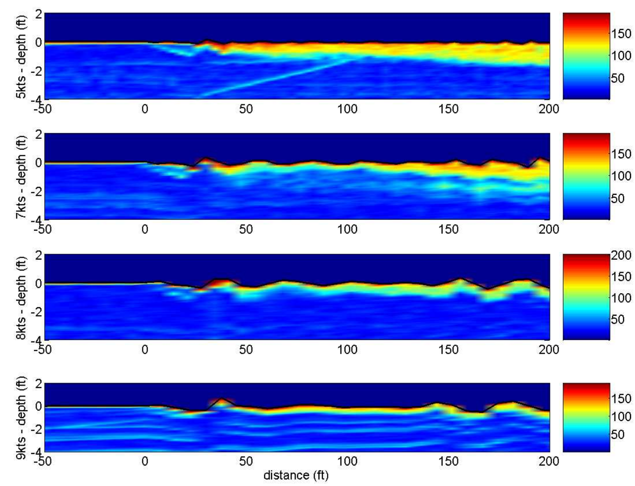

Fig. 14 AWAC return from 51.75" port of centerline for 5,7,8, and 9 knots (second set of runs)

CONCLUSIONS

The trends of the acoustic return from the AWAC and the trends of the bubble density and location on the water surface as shown by the still photos seem to be correlated. It is hoped that the acoustic return can be related to the void fraction measurement and a transfer function to determine bubble concentration. The AWAC is able to make these measurements non-intrusively, as well as recording multiple levels through the water column simultaneously. This type of measurement could prove to be very useful in the measurement of breaking waves.

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