

Acoustic Qualities of Ship Wakes

D. L. Bradley, R. L. Culver, X. Di, L. Bjørnø*

Applied Research Laboratory and Graduate Program in Acoustics, The Pennsylvania State University, P. O. Box 30, State College, PA 16804, USA

Summary

The major influence on sound propagation and attenuation in surface ship wakes arises from the presence of bubbles. The aim of the research behind this paper is to obtain a better understanding of the propagation conditions for sound in surface ship wakes in order to be able to produce realistic sound propagation models for predicting acoustic qualities of wakes. A high resolution, multi-beam sonar, looking upward at a wake produced by a passing surface ship, has provided data characterizing the wake structure in the along-wake, the cross-wake and the depth directions. A simple wake model has been developed from historical data, and this model has been used with a 2D PE code to calculate the loss of acoustic energy in the wake. Understanding the complexity of the wake bubble structure, and its effect on acoustic propagation, remains a challenging research goal.

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1. Introduction

Air bubbles of various sizes are created in copious quantities in wakes of surface ships. The bubbles arise from propeller cavitation (steady and transient), from breaking of the ship's bow and stern waves, from air entrainment in the flow boundary layer near the ship's hull, etc. The fluid dynamics and the acoustics of wakes represent a great challenge to engineers and scientists, and very little has been done in this field until now [1].

The purpose of this paper is two fold: The first is to present a sample of data collected with a high resolution, multi-beam sonar, looking upward at a wake created by a passing surface ship. These data demonstrate that the bubble distribution and dynamics are extremely complex in both space and time. The second is to show a speculative representation of the spatial complexity of a surface ship wake and some preliminary looks at the behavior of a propagating acoustic signal in that bubble field. As the presentation unfolds, the limitations of the data collected, the models used and the results will be discussed, together with plans for improvement.

2. Measurements

Figure 1 is a conceptual view of the measurement process, indicating the goal and the general methodology [2]. It is believed that the speed of the AUV is sufficiently rapid to “freeze” the bubble field in space and coverage would be both over large spatial dimensions and still high enough

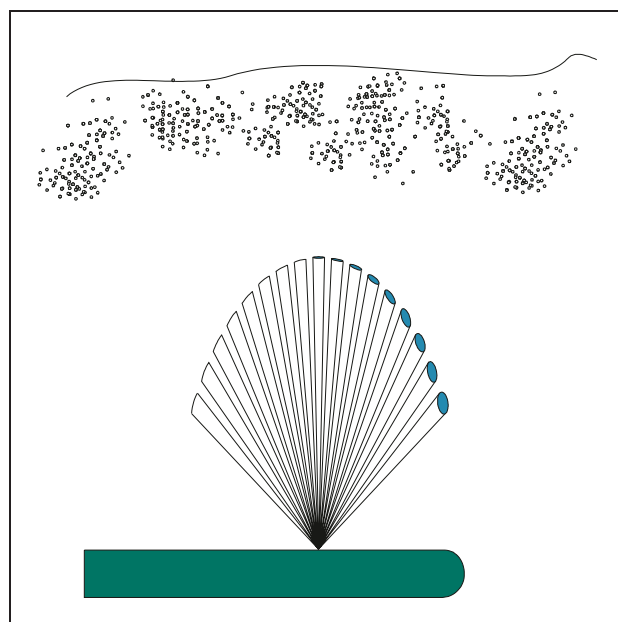


Figure 1. Conceptual view of AUV-mounted multibeam sonar ensonifying a ship wake bubble field. An AUV-mounted sonar was run under the wakes of two large ships. Purpose is to provide: – Along and across-wake data, – Spatial variability of bubbles (and velocity) field.

resolution to characterize the spatial variability of the bubble clouds.

The measurement geometry, shown in Figure 2, shows the AUV run positions relative to the ship track. A cable problem terminated data acquisition after only three wake crossings. Figure 3 describes the “coordinate transformation” process used to shift vehicle-based measurements to the axis of the ship wake. Figure 4 shows bubble den-

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* RESON A/S, Fabriksvangen 13, DK-3550 Slangerup, Denmark

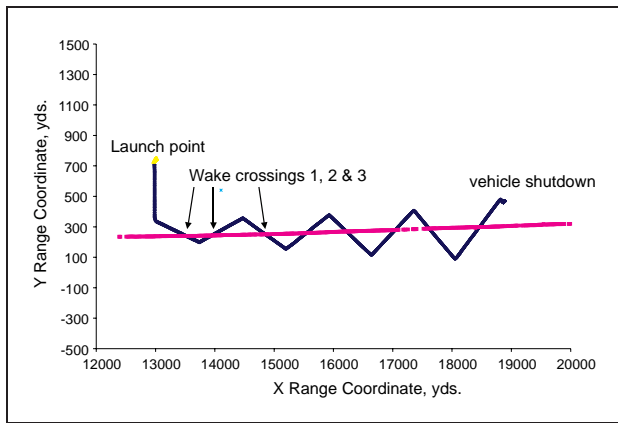


Figure 2. Geometry of ship wake measurement. Lavender line indicates the ship track; blue zig-zag line shows the AUV track.

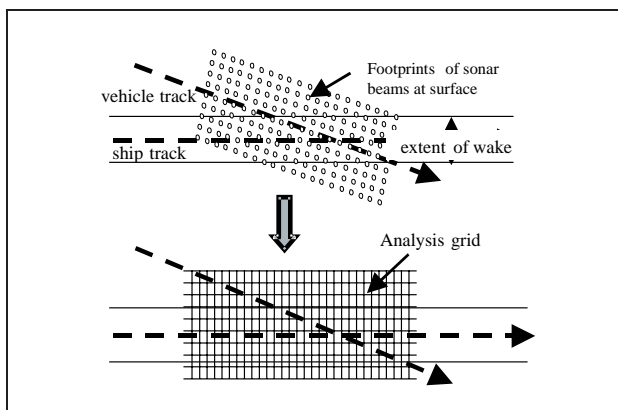


Figure 3. Transformation of multibeam sonar data to an analysis grid aligned with the axis of the ship's wake.

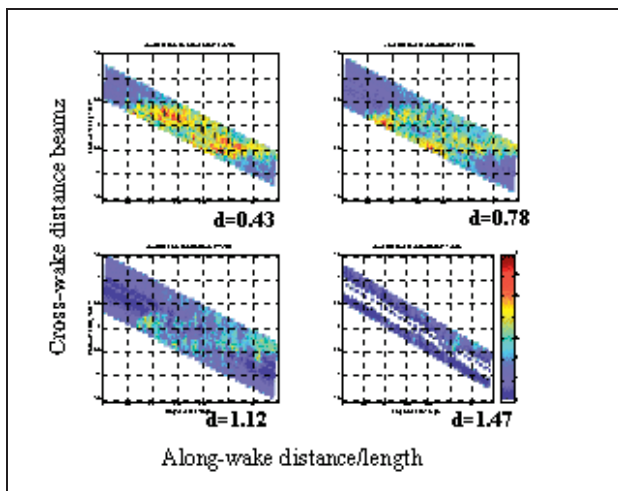


Figure 4. Log of N_0 , the scaling coefficient of the bubble density, as a function of normalized cross-wake distance and along-wake distance for a number of depths d , normalized by ship draft. The center of each panel is located 2.3 ship lengths astern.

sity estimated for one wake crossing. The sonar measures backscatter at 250 kHz. The limitations of the measurements must also be appreciated. To obtain the estimation of N_0 , it is assumed the total bubble distribution is a log-

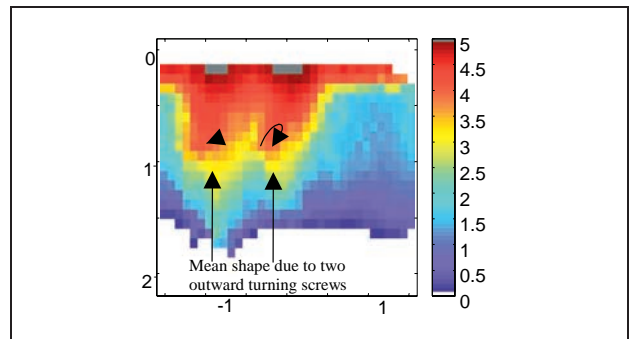


Figure 5. Cross-wake view of N_0 data shown in Figure 4 averaged for approximately one ship length and centered at a distance of 2.3 ship lengths astern. Vertical axis is depth/draft; horizontal axis is cross-wake distance divided by ship beam dimension. Arrows show approximate location and direction of rotation of ship's propellers.

arithmic function. Also assumed is the bubble distribution "reaction" to the sonar confined to a single bubble radius and the bubble field is sparse enough to avoid the complication of multiple scattering. Measured backscatter data are then used to estimate bubble density based upon a procedure developed by Commander [3] and documented by Vagle and Farmer [4]. We have modeled the bubble density as $n = N_0 \exp(-\alpha a)$, where a is bubble diameter, α is a coefficient which depends upon location in the wake, and N_0 is a scaling function. Figure 4 shows $\log_{10}(N_0)$ for one crossing under the ship wake. The parameter d for each plot is depth normalized by the ship's draft to illustrate the third dimension of the wake.

If one then "collapses" the data shown in Figure 4 along the axis of the wake into a single plane showing depth and width, the result is Figure 5.

3. Model of the Wake Bubble Field

A few moments study of Figure 4 will convince one that an analytic description of the spatial variation is not going to be an easy task. A model has been developed to provide inputs to a Parabolic Equation (PE) acoustic propagation model. Although the model has not been verified through comparison with the field data, but it does represent a first order estimate of spatial variation of the bubble field. Its basis, WWII data and more recent measurements of both wake and naturally occurring bubble fields [5, 6, 7, 8]. The model assumes that the spatial variability is separable, that each dimension can be described by exponential reduction of the mean bubble density with spatial coordinate away from the wake axis, and that a Gaussian variability can be ascribed to the mean density at any physical location [9]. Also assumed is that the form and slope of the bubble size distribution are constant over the entire wake. Figure 6 is an illustration of mean attenuation at 30 kHz for a notional wake. The geometry for this case is noted on the figure. The next figure (Figure 7) is an example of the effect of Gaussian-based spatial variation with the parameters of along- and cross-wake structure dimension, as well as two

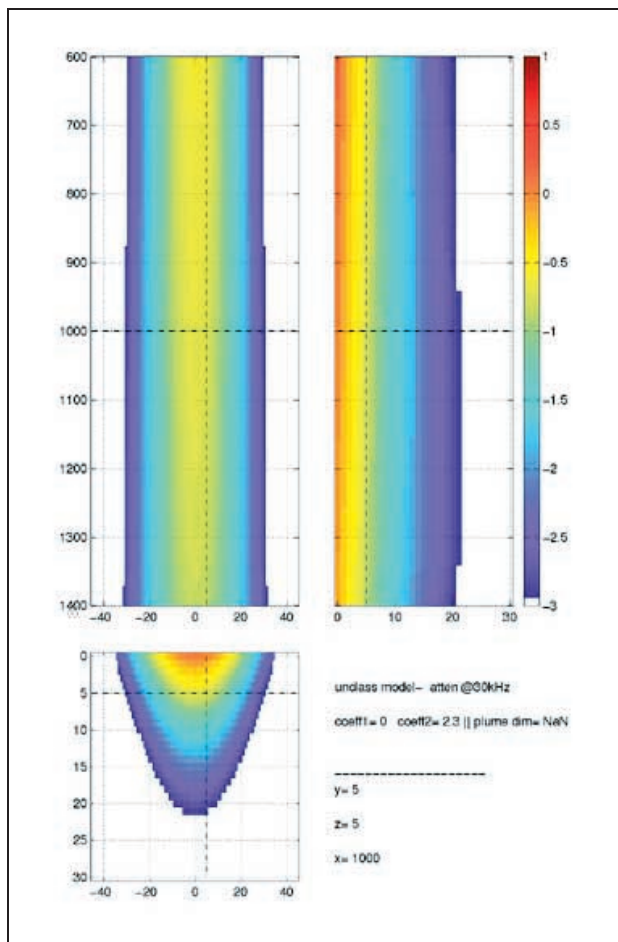


Figure 6. The mean wake bubble field. Upper left panel is an 'overhead' view, upper right a vertical cut along the wake and lower left a vertical cut across the wake.

coefficients that control the depth and strength of the variations. It must be emphasized that the choice of spatial variability parameters used in Figures 6 and 7 has not been driven by comparison with/use of the field data shown in Figure 4 and 5. Equipment failure and uncertainty as to the resolution capability of the multibeam sonar used have limited the usefulness of the data.

4. Propagation Calculations in a Bubble Field

Nevertheless, some preliminary calculations using a 2-D Parabolic Equation and the notional model just discussed were made [10, 11, 12], with the intent of gaining some understanding of the behavior of the acoustic field. Figure 8 displays transmission loss from the PE model in a vertical plane parallel to the wake axis. Each panel shows TL for a particular source depth and for either the mean or randomized wakes shown in Figures 6 and 7, respectively. Figure 9 shows PE-predicted in horizontal planes.

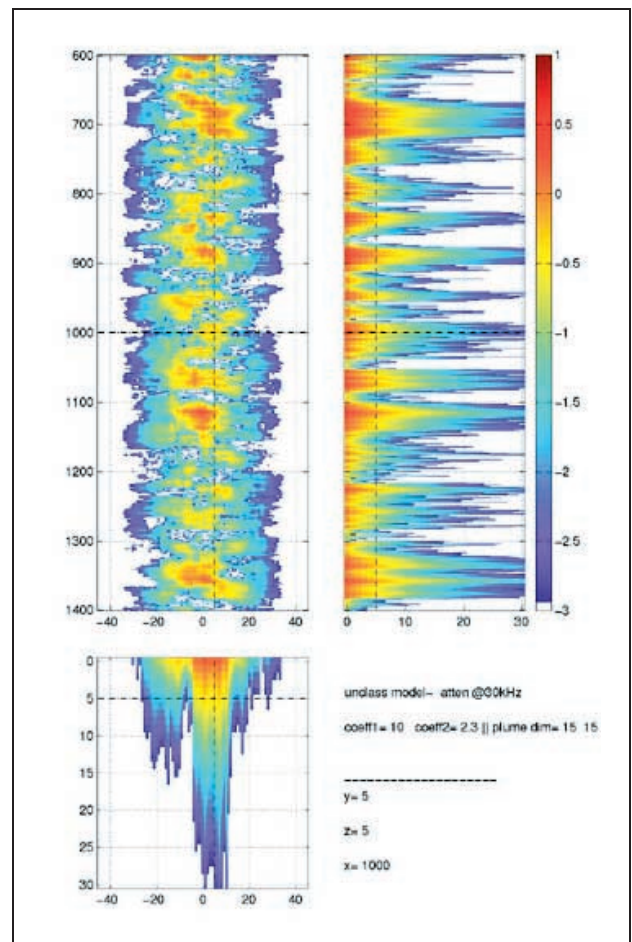


Figure 7. The wake bubble field with added structures. Upper left panel is an 'overhead' view, upper right a vertical cut along the wake and lower left a vertical cut across the wake.

5. Summary and Conclusions

Data from a reasonably high resolution multibeam sonar is presented that demonstrates the spatial and temporal complexity of surface ship wakes from the perspective of their bubble field content. Also presented is a notional model of the spatial variability of a surface ship wake bubble field, together with 2-Dimensional calculations of the acoustic field, based on the Parabolic Equation. Taken together, the information indicates that a strong requirement exists for a hydrodynamic model that would provide the basis for bubble distributions and dynamics. Equally strong is the requirement for more acoustic backscatter data from surface ship wakes using high resolution, multibeam sonars. The time and space variability of the bubble field imply that a 3-D propagation model is necessary, but it is less certain that a true 3-D model would be significantly better than a "modified" 2-D model to account for some degree of out-of-plane scattering.

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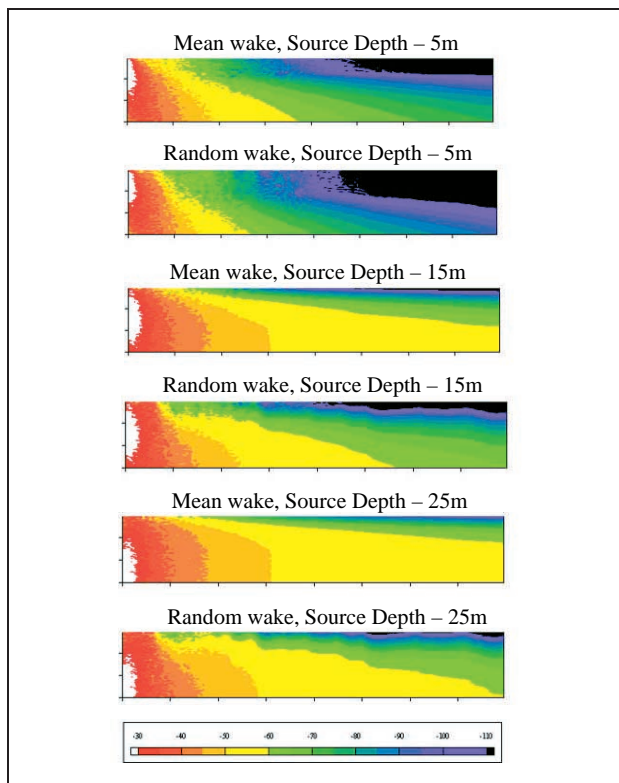


Figure 8. Transmission loss predicted by the PE acoustic model in vertical planes for the wakes shown in Figure 6 and Figure 7. Each panel shows depth to 30m in the vertical direction and range to 800 m in the horizontal (along wake) direction.

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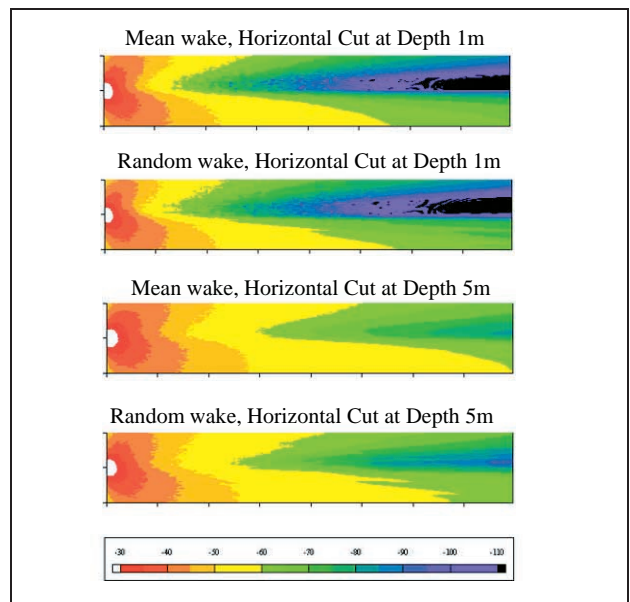


Figure 9. Transmission loss predicted by PE in horizontal planes for the wakes shown in Figure 6 and Figure 7. Each panel shows ± 45 m in the cross-wake direction and range to 800 m in the along wake direction.

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